Frequency and relevance of acute peritraumatic pulmonary thrombus diagnosed by computed tomographic imaging in combat casualties

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BACKGROUND: Posttraumatic pulmonary embolism is historically diagnosed after clinical deterioration within the first week after injury. An increasing prevalence of immediate and asymptomatic pulmonary embolism have been reported in civilian and military trauma, termed hereafter as acute peritraumatic pulmonary thrombus (APPT). The objective of this study was to define the frequency of APPT diagnosed by computed tomographic (CT) imaging in wartime casualties. An additional objective was to identify factors, which may be associated with this radiographic finding

METHODS: A 1-year retrospective cohort analysis conducted using the US and UK Joint Theater Trauma Registries performed to determine the prevalence of and risk factors for the diagnosis of APPT in casualties admitted to Bastion Hospital, Afghanistan. APPT imaging characteristics were collected, and demographics, injury severity and mechanism, and risk factors were included in the analysis. Logistic regression was used to identify factors independently associated with APPT.

RESULTS: APPT was found in 66 (9.3%) of 708 consecutive trauma admissions, which received a CT chest with intravenous contrast as part of their initial evaluation. Diagnosis of APPT at the time of injury was made in 23 patients (3.2%), while thrombus was detected in 43 additional patients (6.1%) at the time of reexamination of CT images. Of the APPTs, 47% (n = 31) were central, 38% (n = 25) were segmental, and 15% (n = 10) were subsegmental. Forty-seven percent (n = 31) had bilateral APPT. Logistic regression found presence of deep venous thrombosis on admission (odds ratio, 5.75; 95% confidence interval, 2.44–13.58; $p < 0.0001$) and traumatic amputation (odds ratio, 2.53; 95% confidence interval, 1.10–5.85; $p = 0.030$) to be independently associated with APPT. All APPTs were felt to be incidental and likely would not have required interventions such as anticoagulation or vena caval interruption.

CONCLUSION: This report is the first to characterize acute, peritraumatic pulmonary thrombus in combat injured. Nearly 1 in 10 patients with severe wartime injury has findings of pulmonary thrombus on CT imaging, although many instances require repeat examination of initial images to identify the clot. APPT is a phenomenon of severe injury and associated with deep venous thrombosis and lower-extremity traumatic amputation. Additional study is needed to characterize the natural history of peritraumatic pulmonary thrombus and the indications for anticoagulation or vena cava filter devices. (*J Trauma Acute Care Surg*. 2013;75: S215–S220.

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KEY WORDS: Pulmonary embolism; combat casualties; computed tomography.

Pulmonary embolism (PE) following trauma is typically diagnosed after a cardiopulmonary deterioration and may result in hypoxia, myocardial strain, and potentially death. Current best evidence warrants that the diagnosis of PE initiates a complex and sometimes disruptive management algorithm including the use of anticoagulation. Systemic anticoagulation in the severely injured carries associated complications and is particularly risky in patients with solid-organ, traumatic brain, spinal cord, or severe pelvic injury. Certain situations result in the placement of a vena cava filter adding to the risk of complications. Especially challenging is the diagnosis of PE in the combat casualty care setting. Patients injured in wartime often have a constellation of injuries and require long-distance medical evacuation. This vexing set of circumstances makes imperative the accurate and relevant diagnosis of PE.

Traditionally, PE is diagnosed after clinical symptoms prompt an imaging study. In these cases, a relevant change in the clinical course has occurred owing to venous thromboembolism. This event typically occurs within the first week with as many as 6% diagnosed within 24 hours after injury.[1–3] Recent civilian reports show that routine use of contrast-enhanced computed tomographic (CT) imaging has resulted in an increase in the diagnosis of asymptomatic or incidentally discovered PE.[4] These same studies propose a new imaging phenomenon referred to as de novo pulmonary artery thrombus. In such instances, it has

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been hypothesized that thrombus observed on CT may originate from the pulmonary arterial system, not via embolism from pelvic or extremity veins.[5,6]

Although described in civilian populations, acute peritraumatic pulmonary thrombus (APPT) has yet to be characterized in wartime casualties. The objective of this study was to define the frequency of APPT diagnosed by CT imaging in wartime casualties. An additional objective is to identify factors, which may be associated with this radiographic finding.

PATIENTS AND METHODS

Study Approval, Cohort, and End Points

Approval for this retrospective cohort analysis was provided by the US Medical Research and Materials Command Institutional Review Board and the UK Role III Multinational Hospital, Camp Bastion, Helmand Province, Afghanistan. The cohort originated from the US and UK Joint Theater Trauma Registries, which were queried for consecutive trauma admissions to Bastion between July 1, 2011, and June 30, 2012. Patients were included in the study if they sustained traumatic injury and had CT imaging of the chest with intravenous contrast as part of their first or initial trauma evaluation. Patients were excluded if they were classified as captured persons, killed in action, were moribund, sustained isolated thermal injury, classified as drowning, or did not receive a chest CT imaging with intravenous contrast as part of their first or initial trauma evaluation.

Demographic data were collected including sex, age, injury mechanism, and severity. Injuries recognized as risk factors for PE were recorded including spinal cord injury and spine, pelvis, and major extremity fracture; severe head and chest injury; and traumatic amputation. As the trauma CT imaging technique did allow for diagnosis of remote (pelvic or extremity) deep venous thrombosis (DVT) in some patients at the time of initial imaging, this was also included as a variable. Tourniquet and tranexamic acid (TXA) use before CT imaging were also recorded. Admission temperature and systolic blood pressure (SBP) were included.

The primary end point was presence of APPT identified on CT imaging performed at the time of initial trauma evaluation. Secondary end points included association of clinical variables with the diagnosis.

Radiographic Analysis of CT Imaging

Two radiologists (J.L.R. and I.G.) blinded to the clinical course of patients examined all CT images to evaluate for presence of APPT. If the diagnosis was made, the radiographic characteristics of APPT were recorded. The quality of each CT was scored as good, fair, or poor based on certain criteria. A good evaluation included intense, homogeneous contrast opacification (>200 Hounsfield units) of the pulmonary arteries (PAs) through or beyond the subsegmental level and minimal-to-no respiratory motion or beam hardening artifact. Fair pulmonary artery evaluation consisted of homogeneous contrast opacification (150–200 Hounsfield units) through the segmental to subsegmental level with mild respiratory motion or beam hardening artifact limiting evaluation of some peripheral PA. A poor evaluation consisted of less dense contrast opacification (<150 Hounsfield units) through the segmental level with mild mixing of contrast with or without respiratory motion or beam hardening artifacts, which limited evaluation of peripheral PA up to the segmental or subsegmental levels.

Imaging Technique

The contrast-enhanced CT imaging of the chest evaluated in this study was part of a trauma imaging study obtained in acutely injured patients. Images were acquired on a 64-detector General Electric (GE, Fairfield, CT) Lightspeed scanner at 5-mm thickness and 5-mm interval. A dual-phase injection of contrast was administered before examination using a Nemoto (Nemoto Kyorindo Co., Ltd, Tokyo, Japan) power injector system. A dedicated CT PE study acquired images at 0.625-mm thickness and 0.625-mm interval using a single phase of contrast injection.

Statistical Analysis

Clinical factors to be evaluated for their association with APPT were identified based on literature concerning the subject and included age; sex; mechanism of injury; admission SBP; admission temperature; presence of traumatic amputation; presence of a long-bone fracture; pelvic fracture; spinal cord injury; or spine fracture; severe (Abbreviated Injury Scale [AIS] score > 2) head, chest, or extremity injury; the use of TXA; and the use of an extremity tourniquet.[5–9] Continuous data are presented as medians with 25th and 75th interquartile range except where annotated with comparisons between groups performed using Student's t test. Categorical data are reported as proportions and, where appropriate, tested for significance using the χ^2 test. Risk factors for APPT found to be significant on univariate analysis were entered into a backward, stepwise logistic regression model, and odds ratios and confidence intervals were reported.

RESULTS

Diagnosis of APPT

Of 1,632 patients, 708 met inclusion criteria (Fig. 1). Mean age was 24 years, with 97% being male. The mean Injury Severity Score (ISS) and New Injury Severity Score (NISS) of the cohort were 14 and 19, respectively. The remainder of the demographics and injury characteristics of the overall cohort are shown in Table 1. Median time from injury to CT imaging was 1 hour 41 minutes and did not differ between cohorts (1 hour 24 minutes in APPT group vs. 1 hour 42 minutes, $p = 0.13$). The majority of imaging studies were performed within 2 hours of admission unless patients received resuscitative surgery (14.3%; n = 101) before imaging. Although some patients received treatment at a Role II facility before transfer and imaging, these data were not available. The majority of studies in those with and without APPT were classified as good (76% vs. 69%, $p = 0.26$). There was no difference between those with and those without APPT in the frequency of studies classified as fair (21% vs. 24%, $p = 0.59$) or poor (3% APPT group vs. 7%, $p = 0.23$).

A total of 66 patients (9.3%) were found to have APPT on initial CT. Among these, 47% (n = 31) were central, 38% (n = 25) were segmental, and 15% (n = 10) were subsegmental. Of the

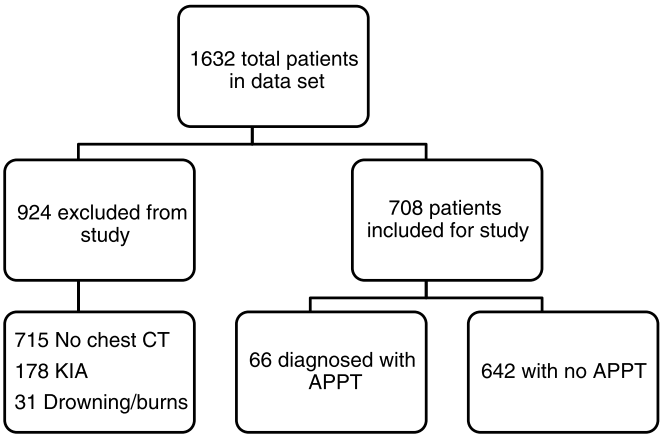

Figure 1. Breakdown of patients included from initial query of US and UK Joint Theater Trauma Registries. KIA, killed in action.

31 patients with central pulmonary findings, 19 had thrombus in lobar and 12 in main pulmonary arteries. Nearly half of patients (n = 31, 47%) had findings that were bilateral. The mean Hounsfield unit density taken along the length of the main pulmonary artery filling defects (n = 12) was 43.4 Hounsfield unit (range, 17–66 Hounsfield unit), consistent with thrombus.[7] Interestingly, only 23 (35%) of APPTs were diagnosed at the time of hospitalization, with the remaining 65% found retrospectively as a result of the performance of this study.

TABLE 1. Demographics and Characteristics of Cohort Studied

Demographic/Characteristic	Frequency/Proportion
Age, y	23 (20–27)
Male	97%
ISS	14 (5–25)
NISS	19 (9–36)
SBP, mm Hg	129 (110–146)
Temperature, °C	36.9 (36–37.4)
Time from injury to CT, h:min	1:41 (1:15–3:14)
Emergency surgery before CT	14.3% (101/708)
Mechanism of injury	
Explosive mechanism	62.7% (443/706)
Admission physiology	
Shock	12.8% (90/705)
Associated injury	
Pelvic fracture	11.2% (79/708)
Spinal injury	11.9% (84/708)
Long-bone fracture	30.2% (214/708)
Traumatic amputation	22% (156/708)
Hemostatic adjuncts	
Use of TXA before CT	30.9% (219/708)
Use of tourniquet	31.6% (224/708)
DVT on CT imaging	4.5% (30/669)
Severe chest injury	18% (127/705)
Severe head injury	11.3% (80/705)
Severe lower-extremity injury	38.4% (271/705)

Shock defined as SBP of 90 mm Hg or lower; severe injury defined as AIS score of 2 or greater. Numbers in parentheses include number of patients meeting criteria for definition in relation to number with data available for specific variable.

Injury Characteristics and Risk of APPT

Explosive mechanism made up the majority of patients diagnosed with APPT (n = 59 of 66, 89%), followed by gunshot wound (n = 6, 9%) and motor vehicle collision (n = 2, 1%). When looking at injury mechanism, 13% of patients injured as a result of explosion, 3% as a result of gunshot wound, and 2% as a result of motor vehicle collision were found to have an APPT. When considering the diagnosis of APPT in the context of a constellation of injuries, 26% (n = 40 of 153) of patients sustaining a combination of explosive mechanism injury who also sustained a traumatic amputation were found to have an APPT.

Comparison of Cohorts

Table 2 demonstrates a comparison of demographic and injury characteristics between the groups. Patients with APPT had a higher ISS (20 [16–29] vs. 13 [5–24.75], $p = 0.005$) and NISS (36 [21.25–47.25] vs. 17 [9–34], $p < 0.001$) as well

TABLE 2. Clinical Variables in Patients With APPT Versus No Pulmonary Thrombus

Clinical Factor	Pulmonary Thrombus	No Pulmonary Thrombus	*p*
Age, y	23.5 (20–26.75)	23 (20–28)	0.24
Male	100%	97%	0.17
ISS	20 (16–29)	13 (5–24.75)	0.005
NISS	36 (21.25–47.25)	17(9–34)	<0.0001
SBP, mm Hg	128 (108.5–142)	129 (110–146)	0.87
Temperature, °C	37 (35.65–37.3)	37 (36–37.4)	0.13
Time from injury to CT, h:min	1:24 (1:14–2:31)	1:42 (1:15–3:15)	0.13
Emergency surgery before CT	23% (n = 15)	13% (n = 86)	0.04
Mechanism of injury			
Explosive mechanism	89% (n = 59/66)	60% (n = 384/640)	<0.0001
Admission physiology			
Shock	11% (n = 7/66)	13% (n=83/639)	0.60
Associated injury			
Pelvic fracture	15% (n = 10)	11% (n = 69)	0.23
Spinal injury	8% (n = 5)	13% (n = 79)	0.26
Long-bone fracture	50% (n = 33)	28% (n = 181)	0.0003
Traumatic amputation	61% (n = 40)	18% (n = 116)	<0.0001
Hemostatic adjuncts			
Use of TXA before CT	61% (n = 40)	28% (n = 179)	<0.0001
Use of tourniquet	70% (n = 46)	28% (n = 178)	<0.0001
DVT on CT imaging	23% (n = 13/57)	3% (n = 17/612)	<0.0001
Severe chest injury	11% (n = 7/66)	19% (n = 120/639)	0.67
Severe head injury	8% (n = 5/66)	12% (n = 75/639)	0.31
Severe lower-extremity injury	76% (n = 50/66)	35% (n = 221/639)	<0.0001

Shock defined as SBP of 90 mm Hg or lower; severe injury defined as AIS score of 2 or greater. Numbers in parentheses include number of patients meeting criteria for definition in relation to number with data available for specific variable.

as requiring resuscitative surgery before CT imaging more frequently (23% vs. 13%, $p = 0.04$). In addition, patients with APPT had long-bone fracture (50% vs. 28%, $p = 0.003$) and traumatic amputation (61% vs. 18%, $p < 0.001$) diagnosed more frequently than those without APPT.

Patients with APPT received TXA (61% vs. 28%, $p < 0.001$) and had tourniquet use (70% vs. 28%, $p < 0.001$) more frequently than those without APPT. Patients with APPT were also found to have lower-extremity DVT on trauma CT scan more frequently (23% vs. 3%, $p < 0.001$). In the logistic regression model, presence of lower-extremity DVT and traumatic lower-extremity amputation were independently associated with APPT (Fig. 2). Hospital mortality for the entire study cohort was 6% (39 deaths in 708 patients), and there was no difference in mortality between those with (3%, n = 2) and without (6%, n = 37) APPT ($p = 0.35$). Owing to the nature of rapid evacuation from a deployed military medical facility and the retrospective diagnosis of APPT in the majority of patients, no APPT-attributed mortality was able to be determined.

DISCUSSION

This report is the first to characterize the prevalence of APPT from a large number of consecutive CT scans performed during the immediate postinjury phase in wartime casualties. Findings show that almost 10% of patients with severe combat injury have APPT. Nearly half of APPT were bilateral and in the central pulmonary vasculature. In addition, more than 50% of APPTs were found during the performance of this study, not at the time of injury/image acquisition. Findings from this study are hypothesis generating with regard to the possibility that they may be incidental in nature and may not mandate the use of anticoagulation or vena cava filter devices.

PE Versus De Novo Pulmonary Thrombus

Other studies to date have been registry-based and have used diagnostic codes to define the incidence of PE.[1–9] Even when such studies have included radiographic imaging, it has been only in patients assigned the diagnosis of PE based on their clinical course. Menaker et al.,[2] Owings et al.,[3] and Spencer Netto et al.[4] have reported that this phenomenon typically occurs in the days and weeks following injury.

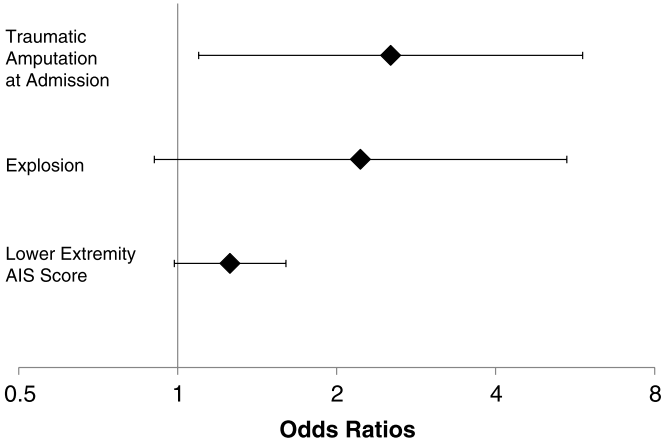

Figure 2. Forest plot illustrating markers of severe injury and specifically severe lower-extremity injury that were used in the final logistic regression model.

As such, the pathophysiology of this recently described entity, that is, immediate PE or APPT, may lend support to recent literature hypothesizing a possible de novo mechanism for pulmonary thrombus development. In recognizing that extremity DVT was present in only 15% of patients with PE, Velmahos et al.[6] suggested that thrombus may not always originate from the veins of the pelvis and proximal lower extremities. In the largest study to date, Knudson et al.[5] also reported that DVT was present in only 20% of patients with the diagnosis of PE. Both groups suggest a possible uncoupling of DVT from PE and suggest that clot may originate de novo in the pulmonary vasculature.

Rates of Pulmonary Thrombus

Importantly, significant differences in study design make it impractical to compare the rate of APPT in this study (9.3%) to the rate of PE defined in previous reports. APPT may also have a pathophysiology different from later PE, making comparison of these rates less useful. Other investigators have quantified the rate of PE between less than 1% and nearly 25% from different at-risk trauma populations.[5,6,8–10] These variations in rates reported support Virchow's premise that there exists a spectrum of venous thrombotic pathology following severe trauma.

Phenomenon of Severe Injury

While the absolute rate of pulmonary thromboembolism or thrombus among these different studies may not be comparable, common themes are important to emphasize. One such theme is the association of pulmonary thrombus with injury severity and specifically the mangled extremity. Gillern et al.[9] demonstrated in a combat-injured population that PE was associated with severe lower-extremity injury including traumatic amputation. Similarly, Spencer Netto et al.[4] found that severe injury, including increased AIS score of the pelvis and limbs, was more common in patients with the diagnosis of PE. The study by Knudson et al.[5] found both severe lower-extremity (AIS score ≥ 3) and chest (AIS score ≥ 3) injuries to be independently associated with PE. With the use of imaging-based methodology, the current study adds to these previous reports, specifically that patients with severe, explosive mechanism injury sustaining massive lower-extremity trauma and traumatic amputation, treated with adjuncts such as tourniquets and TXA, are found to have APPT. While only traumatic amputation at admission and presence of DVT on CT traumagram were independently predictive of APPT, the other markers were significantly more common in the APPT group. Especially in light of recent data describing higher rates of venous thromboembolism in combat casualties requiring massive transfusion and receiving TXA, one could speculate that TXA is associated with venous thromboembolism.[11] This speculation, in our opinion, is possible but not answered by the findings of the current study. What is supported by our study is that the most severely injured patients received TXA and were found to have APPT.

Our imaging-based methodology provides the best clinical evidence to date supporting the possibility of de novo pulmonary thrombus. This is supported by studies that show that explosive mechanism causes a significant amount of tissue and endothelial trauma. Kirkman EL (personal communication, August 15, 2012)

used thromboelastography in a model of explosive injury demonstrating an early period of increased clotting. In a separate study, Knudson et al.[5] outlined the pathophysiologic rationale behind primary pulmonary thrombosis and added the process of inflammation to Virchow's triad. Others have reported that severely injured patients are at high risk for developing venous thromboembolism possibly owing to the acute depletion of protein C.[12,13] In our study, 89% of patients with APPT were injured via explosive mechanism, and 61% presented with a traumatic amputation. Assuming that explosive injury leads to tissue and endothelial damage, this effect would be especially severe in casualties in close enough proximity to sustain traumatic amputation. These observations lend support to the premise that APPT in our study may represent a de novo pulmonary thrombotic process.

If the pulmonary thrombus imaged in this study did not arise de novo, one would have to presume migration from remote locations. This mechanism is possible, although only 23% of patients with APPT had DVT present on CT. This number is slightly higher than that reported in previous studies demonstrating disparity between PE and DVT. Our higher percentage may support this CT imaging method for diagnosis of DVT; however, this needs to be validated. As more than three fourth of patients with APPT did not have a DVT on trauma CT, this could mean that the entirety of any pelvic or extremity thrombus migrated acutely to the pulmonary circulation. This seems unlikely without some trace of thrombus present in the source veins on trauma CT; a statement corroborated by cadaveric studies demonstrating that only the free-floating portion of thrombus embolizes.[14,15]

Clinical Implications

If an APPT develops acutely after injury as a result of an acute, intense hypercoagulable state with minimal-to-no residual thrombus, what outcome will be affected by intervention? The study of Spencer et al.[4] described six patients with immediate PE with no adverse sequelae reported in the four patients receiving no systemic anticoagulation or vena caval interruption. Investigators are questioning the efficacy of anticoagulation for isolated subsegmental PE found with increasing frequency, thanks to multiple detector row CT PA imaging.[16] A recent meta-analysis reported no increase in recurrent venous thromboembolic complications when no intervention was made for isolated subsegmental PE.[17] The use of inferior vena cava filters has also been challenged with regard to its efficacy as a method to decrease the PE rate after injury.[8] The use of inferior vena cava filters in patients with APPT likely remains equally or more controversial given the complex pathophysiology that is not yet well understood. Not only were more than half of APPT not diagnosed at the time of imaging, but also a total of 15% (n = 10) of the APPT were subsegmental and may have met criteria for no intervention if the patients were young, had no issues with cardiopulmonary reserve, had no evidence of right heart dilation, and had no significant residual thrombus burden.[18,19] Although mortality was similar between cohorts, this study was retrospective, was not powered to determine a difference, and was not able to determine the true APPT-associated mortality. At a minimum, patients with APPT require close monitoring; some may benefit from anticoagulation or vena cava filter placement. Further study is needed and may be increasingly possible given the common use of high-fidelity CT and heightened awareness of this clinical entity to determine the natural history and necessity of treatment of APPT

Limitations

This study has several limitations including its retrospective nature and lack of inclusion of all wartime casualties preventing true incidence determination. Physiologic markers such as pH, base deficit, and lactate as well as transfusion requirements were not included in the database. This limits the ability to relate markers and techniques of resuscitation with APPT. Owing to operational tempo, CT images were reviewed by only one radiologist; therefore, interobserver variability was not quantified. The practical nature of the study required that the workload of imaging be divided between the radiologists. While in-hospital mortality was determined, the impact of interventions on this and other long-term outcomes remains unknown. Despite these limitations, this study provides an important characterization of this radiographic phenomenon and forms a strong foundation for additional investigation.

CONCLUSION

This report is the first to characterize acute, peritraumatic pulmonary thrombus in patients with combat injuries. Nearly 1 in 10 patients with severe wartime injury has findings of pulmonary thrombus on CT imaging, although many instances require repeat examination of initial images to identify the clot. APPT is a phenomenon of severe injury and associated with lower-extremity traumatic amputation. Additional study is needed to characterize the natural history of peritraumatic pulmonary thrombus and the indications for anticoagulation or vena cava filter devices.

AUTHORSHIP

J.B.L., J.S.O., and N.R.M.T. conceived the study. J.B.L., J.S.O., and K.K.C. designed the study. J.B.L., J.L.R., I.G., G.R.N., and B.J.S. collected the data. J.B.L., K.K.C., J.K.A., and T.E.R. analyzed the data. J.B.L., J.S.O., K.K.C., and T.E.R. wrote the manuscript, which all authors reviewed and approved.

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DISCLOSURE

The authors declare no conflicts of interest.

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