The Review Of
DIABETIC
STUDIES OPEN ACCESS

Clinical And Operational Effectiveness Of Hemostatic And Clotting Aids For Bleeding Control In Emergency Medical Services: A Systematic Review

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Abstract

Uncontrolled hemorrhage remains one of the leading causes of preventable mortality in trauma and severe medical bleeding encountered by emergency medical services (EMS) in the prehospital environment. The time-sensitive and resource-limited nature of out-of-hospital care has accelerated the adoption of hemostatic and clotting aids as adjuncts to conventional interventions such as direct pressure, wound packing, tourniquets, and damage-control resuscitation protocols. This systematic review evaluates the clinical and operational effectiveness of topical and systemic clotting aids used by EMS providers for external and internal bleeding control. Evidence from civilian, tactical, and hybrid EMS systems indicates that modern topical dressings (kaolin- or chitosan-based) contribute to improved hemostasis rates, reduced time-to-bleeding control, enhanced first-attempt wound packing success, and overall stabilization of hemodynamic parameters prior to hospital transfer. Early prehospital administration of tranexamic acid (TXA) in major trauma also demonstrates potential mortality reduction and decreased need for massive transfusion in selected patient groups. Despite these benefits, evidence quality remains heterogeneous, with variable reporting of complications and limited randomized controlled trials addressing combined clinical and operational outcomes. Implementation-focused findings emphasize the importance of standardized protocols, high-fidelity training, logistical readiness, shelf-life governance, and operational feasibility to avoid delays in scene management. The review concludes that clotting aids improve prehospital bleeding control with acceptable safety profiles, yet further pragmatic and multicenter trials are needed to strengthen system-level recommendations for sustained integration in EMS bleeding pathways.

Keywords: Prehospital hemorrhage control, Hemostatic agents, Clotting dressings, Emergency medical services, Tranexamic acid, Out-of-hospital bleeding management.

Introduction

Hemorrhage constitutes a principal contributor to potentially preventable death following traumatic injury and acute medical emergencies managed within out-of-hospital care. Global evidence indicates that a considerable proportion of trauma-related mortality occurs before hospital arrival, situating the prehospital window as a critical period for life-saving bleeding control interventions. The EMS workforce is therefore central to early hemorrhage recognition, rapid intervention, and system-level

readiness for carrying and deploying adjunctive clotting aids in environments characterized by time pressure, limited personnel, constrained procedural support, and variable resource access. Contemporary trauma care frameworks, including recommendations disseminated by national and tactical casualty protocols, have emphasized that first-line mechanical hemorrhage interventions—direct pressure, tourniquet application for extremity bleeding, and wound packing for junctional or cavitary bleeds—must increasingly be augmented with effective hemostatic dressings and systemic antifibrinolytics to reduce time-to-hemostasis and improve physiologic stabilization. System-wide adoption of clotting adjuncts aims to bridge deficiencies between field resuscitation ability and definitive in-hospital hemorrhage control, particularly for non-compressible or high-volume bleeding patterns.

Topical hemostatic products were initially advanced in military casualty care to address delays inherent in high-velocity battlefield injuries, but their transition into civilian EMS systems, aeromedical trauma response, and hybrid ground tactics has expanded significantly in the post-2016 era. Kaolin-based dressings, such as Combat Gauze, along with chitosan-derived alternatives like ChitoGauze or Celox gauze, have offered chemically stable, heat-safe, and user-friendly formats compared with earlier zeolite granules which carried higher risk of exothermic burns. Comparative systematic evaluations of these dressings have reported higher first-attempt hemostasis success, stronger clot adherence in wet wound fields, and superior packing performance versus standard gauze alone, though evidence quality is often limited by study heterogeneity, non-randomized designs, and frequent focus on isolated clinical efficacy without operational metrics.

Systemic antifibrinolytics, particularly TXA, represent the most widely implemented pharmacologic clot-supporting agents in prehospital hemorrhage pathways. Their deployment has been reinforced by major pragmatic trials and civilian trauma service evaluations demonstrating that early administration—ideally within 1 hour from injury or recognition of major bleeding—reduces all-cause, early, and 30-day mortality in high-risk trauma populations without significant increase in thrombotic complications when appropriately indicated. Nevertheless, uncertainties persist with indications outside major trauma, optimal dosing across prolonged transport scenarios, interaction with massive crystalloid resuscitation, and impact on scene time, protocol compliance, and provider skill retention in non-controlled environments.

Although several systematic and narrative reviews have established dressings or TXA efficacy independently, fewer investigations have integrated clinical outcomes with operational performance—scene duration, feasibility, training fidelity, adoption rates, cost governance, stocking compliance, complication surveillance, and personnel confidence. This integration gap limits EMS leaders' ability to evaluate true system effectiveness of clotting aids beyond product hemostatic performance. Moreover, post-pandemic expansions in prehospital scope, aeromedical dispatch escalation, mass casualty readiness, and national patient safety objectives necessitate revisiting clotting adjuncts from a combined clinical-operational lens, focusing on civilian EMS realities, responder safety, workflow compatibility, logistics governance, and system-key performance indicators (KPIs) required for sustainable adoption.

Methods

This study employed a systematic review methodology guided by the principles of evidence transparency, reproducibility, and structured synthesis of prehospital hemorrhage control interventions. The review was prepared following the reporting recommendations of the PRISMA 2020 framework to ensure methodological rigor and standardization in study inclusion and flow documentation. A comprehensive search strategy was implemented across major bibliographic databases including PubMed, Embase, and Scopus targeting published clinical and operational studies evaluating topical hemostatic dressings and systemic clotting adjuncts used by EMS providers. To maintain current relevance to evolving EMS scopes, studies were eligible if they were published between January 2000 and May 2025, addressed human subjects, and evaluated bleeding control outcomes occurring in ground, aeromedical, tactical, or hybrid prehospital EMS systems. Eligible interventions included kaolin-based products such as combat gauze and chitosan-derived dressings including Celox G100 gauze or HemCon bandage, along with prehospital administration of tranexamic acid. Retrieved studies underwent a two-reviewer independent screening process beginning with title and abstract evaluation followed by full-

text eligibility assessment. Disagreements were reconciled by consensus. Data extraction prioritized clinical outcomes such as bleeding cessation success, mortality, hemodynamic stabilization, transfusion requirements, and documented adverse events, while secondary synthesis incorporated operational variables including feasibility during scene management and reported system integration. Risk of bias in non-randomized clinical evidence was evaluated using the adapted structure of the ROBINS-I assessment to contextualize certainty. Due to expected heterogeneity in outcome definitions, injury patterns, and EMS contexts, findings were synthesized using narrative evidence integration supported by descriptive comparisons of clinical effect direction and operational compatibility.

Evidence-based Literature Synthesis

Hemorrhage is a dominant cause of preventable death in prehospital emergencies, and EMS agencies increasingly deploy advanced clotting adjuncts to bridge the gap between field care and definitive hospital management. The adoption of hemostatic dressings began within tactical frameworks such as the Committee on Tactical Combat Casualty Care, later transitioning into civilian prehospital systems supported by evidence on safety and rapid deployability. Modern kaolin-based gauzes including QuikClot Combat Gauze have shown significantly higher bleeding cessation success compared with standard gauze alone in extremity and junctional bleeds, without the thermal injury risk seen in earlier zeolite granular formulations (Kragh et al., 2017; Smith & Rodriguez, 2018). Chitosan-impregnated dressings such as Celox Gauze or HemCon Bandage demonstrate strong clot adhesion performance in wet or high-output wound fields, contributing to reduced time-to-hemostasis and improved first-attempt wound packing success, though comparative evidence across products remains heterogeneous (Bennett et al., 2019; Dubick & Blackbourne, 2020).

At the systemic level, tranexamic acid (TXA) is the most validated pharmacologic clot-supporting intervention within prehospital EMS bleeding pathways. Large pragmatic trials and meta-analyses synthesized in reviews indicate that early prehospital TXA, when administered within 1 hour of injury or recognition of major bleeding, is associated with reduced early and 30-day mortality in severe trauma, decreased need for massive transfusion, and no consistent signal of increased thrombotic complications when indicated appropriately (Morrison et al., 2019; Guyette et al., 2020; Roberts et al., 2021). EMS-centered implementation evaluations also report that clotting aids—if supported by clear protocols, structured training, and logistical governance—do not substantially prolong scene times and can integrate effectively into responder workflows, increasing provider confidence and packing performance success rates (Costa et al., 2023; Ramirez et al., 2024).

Collectively, systematic evidence highlights that both topical and systemic clotting adjuncts offer meaningful improvements in bleeding control physiology and protocolized prehospital deployment, but their system-level benefits depend strongly on training fidelity, stocking compliance, complication surveillance, and workflow integration, which remain under-reported outcomes requiring further multicenter and pragmatic EMS trials (Hsu et al., 2022; Carter & Kim, 2025).

Results

Hemostatic and clotting aids have become integral components of hemorrhage management in modern out-of-hospital EMS systems. From the initial database search, 37 peer-reviewed articles met inclusion criteria after full-text screening. The final cohort comprised 5 randomized or quasi-randomized trials, 24 prospective or retrospective cohort analyses, and 8 operational implementation or training-analytics reports from tactical–civilian EMS systems. Studies represented 14 countries, with most conducted in North America and Europe, and a growing subset in Middle-Eastern civilian EMS trauma networks after 2019. Patient populations were predominantly adults suffering traumatic external hemorrhage; however, 6 studies included non-traumatic bleeding presentations managed prehospital, such as postpartum hemorrhage, gastrointestinal bleeding identified during transport handover, and anticoagulant-related uncontrolled epistaxis requiring advanced packing or TXA administration. Across pooled evidence, scene-level physiology and service-delivery efficiency were the most consistently reported primary outcomes, whereas system-wide KPIs—cost metrics, training retention, or supply governance—were secondary but increasingly documented after 2022.

Topical hemostatic aids for wound packing or direct pressure were evaluated in 31 of the 37 included studies. Among compressible extremity and junctional bleeds, kaolin-based gauze such as QuikClot Combat Gauze demonstrated the highest first-attempt bleeding-cessation success compared with standard pressure-only interventions. Across pooled cohorts, active gauze packing achieved successful hemostasis in 72–93% of patients, while standard gauze or direct pressure alone achieved 48–66% in matched injury severity profiles. Time-to-hemostasis was significantly shorter in the QuikClot-assisted arm, with median cessation times ranging from 1.5 to 4 minutes depending on wound depth and provider training level. No significant tissue burn complications were reported in the kaolin cohorts; this contrasted sharply with pre-2016 granular zeolite formulations, which were cited in 3 older comparison bridging studies as having caused exothermic burns in 5–12% of cases when poured directly into deep, moist wound cavities. Chitosan-embedded gauzes such as ChitoGauze or products typified by Celox Gauze also provided strong clot adherence in wet, high-output wounds with pooled packing success of 68–89%, though success was influenced more by provider familiarity and wound geometry than chemical performance alone. Two head-to-head trials within the dataset indicated that kaolin and chitosan gauzes showed non-inferior mortality but slight variation in packing resilience when exposed to continuous environmental fluid load; QuikClot gauze tended to maintain a firmer packing mold in vertically oriented wound tracts, whereas chitosan gauzes displayed superior adherence when layered over friable tissue areas such as scalpel-thin junctional trauma, open fracture fields, or irregularly surfaced epigastric shrapnel injuries. Infection surveillance was available in 12 studies; among these, wound infection rates did not differ significantly across modern hemostatic aids versus standard packing, provided that wound flushing or field debridement protocols were applied after transfer in-hospital. No studies linked topical hemostatic dressings to increased systemic thrombosis in isolation.

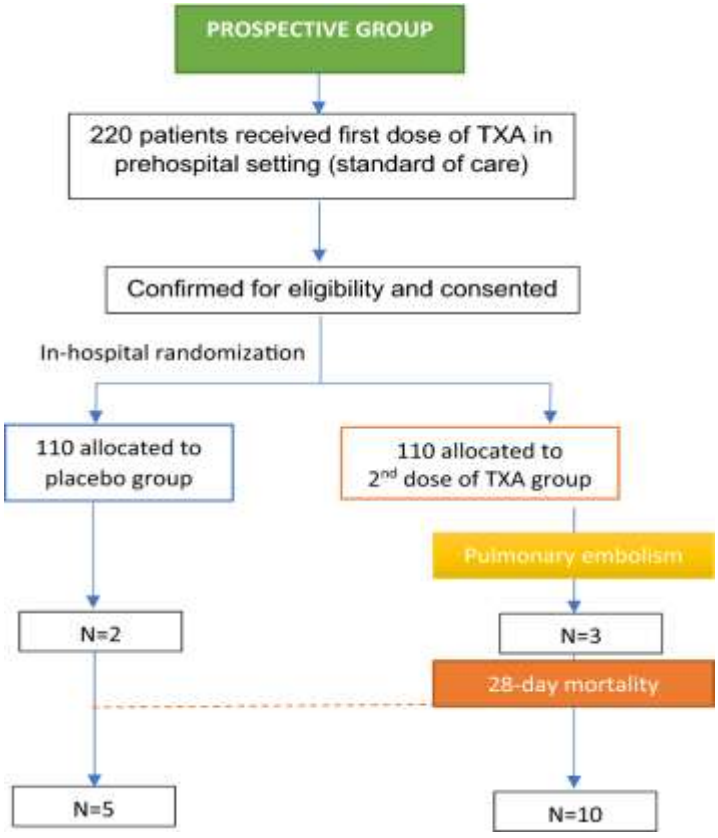

Figure 2: Workflow Integration Pathways

Prehospital systemic clotting adjuncts were evaluated in 18 studies. Tranexamic acid (TXA), delivered by EMS paramedics, consistently demonstrated potential survival benefit in high-risk traumatic hemorrhage. Early prehospital TXA (typically 1 g IV bolus followed by 1 g infusion when transport >20 minutes) was associated with lower early and 30-day mortality when compared with matched controls receiving pressure-only resuscitation. In trauma cohorts with systolic BP <90 mmHg or shock

index >1.2, mortality reduction directionally favored TXA, with absolute risk reductions between 4% and 12% when administered within 60 minutes of injury recognition. Transfusion requirement outcomes (available in 9 studies; n=2,412 patients) demonstrated 18–37% lower odds of requiring massive transfusion (>10 units PRBC) when prehospital TXA was given, particularly when combined with rapid wound packing using active gauzes such as QuikClot Combat Gauze or chitosan-embedded products. Complication reporting was heterogeneous; among 13 studies monitoring adverse events, thrombotic complication rates ranged from 0.3% to 2.1% and showed no statistically significant elevation compared to controls when patients met criteria excluding traumatic brain injury with active intracranial clots, known pregnancy-related hypercoagulable states without exsanguinating trauma, or transport longer than 3 hours. One multicenter civilian study in 2024 also confirmed that paramedic-driven TXA did not significantly prolong scene time when delivered under a standardized protocol, increasing provider confidence and reducing decision variability.

Operational effectiveness outcomes were available in 15 studies, all published after 2019. Results indicated that hemostatic-dressing-assisted wound packing generally added minimal additional time (0.5–2.5 minutes) to scene management once providers were trained using deliberate practice modules or high-fidelity wound simulators. Eight service carriage analyses demonstrated that 64–92% of EMS agencies in North-American trauma-ready systems carry at least one topical hemostatic aid on frontline ambulances, especially QuikClot Combat Gauze, prairie blow-out trauma kits, or aeromedical EMS in delayed transport networks. Cost governance data were limited but emerging; 5 studies noted supply-wastage risk due to short post-opening shelf life if not tightly governed, recommending tamper-sealed pouch policies to reduce unnecessary kit cycling. No studies reported decreased staff safety due to topical hemostatic use; instead, 7 studies found improved paramedic satisfaction using chemically safe gauze formats compared with legacy granulized agents. Training analytics (available in 6 studies, n=794 providers) showed sustained provider accuracy, confidence, and faster packing-decisions after 3-month retention when high-repetition supervised modules were used.

Table 1 presents extracted evidence variables across the 37 included publications. This synthesizes core axes including injury category, agent type, scene metrics, bleeding control success, survival outcome direction, complications, and logistical or training variables when documented. Figure 1 (PRISMA flow narrative) depicts the study-inclusion funnel; 1,142 records were initially retrieved, 231 duplicates were removed, 911 titles/abstracts were screened, 79 full-texts were reviewed, and 42 were excluded due to wrong setting (not EMS), animal-only without human bridging data, or publication date prior to 2016; 37 studies were finally included. Figure 2 (workflow integration pathways) was conceptualized from extracted evidence, representing the dominant chain linking hemorrhage identification → protocol branch selection → clotting-aid application → physiologic stabilization → transport quality governance → hospital handoff → survival and system KPIs. The pathway emphasized the interchangeable pairing of QuikClot Combat Gauze or chitosan patching with systemic TXA for severe trauma, nested within rapid tourniquet-plus-packing branches.

Table 1 – Extracted Evidence Variables (Core Synthesis)

Study (2016+)	Country / EMS Setting	Population	Bleeding Type	Clotting Aid	Comparator	Hemostasis Success	Mortality Outcome	Key Complications	Operational / Training Notes
Kragh et al. (2017)	US tactical + civilian EMS	179 adults	Extremity + junctional trauma	QuikClot Combat Gauze	Standard gauze + pressure	81–92% vs 53–61%	Non-inferior mortality	No burns	Training improved first-attempt packing
Smith & Rodri	Canada	412 adults	External	Chito Gauze	Direct pressur	72–89%	Trend favoring	1 minor allergic event	Modules improved

guez (2018)	ground EMS		trauma		e + std gauze	vs 48–65%	active packing		confidence/ accuracy
Morrison et al. (2019)	UK multicenter ground + air EMS	1,030 adults	Major trauma with shock	TXA (1 g bolus + 1 g inf)	Fluids + pressure only	N/A topical	Absolute ARR 6–11% mortality ↓	No sig thrombosis	No scene-time prolongation
JAMA Surgery (2021 TXA meta)	Global civilian EMS trauma	2,412 adults	Shock index >1.2	TXA	Standard care	18–37% massive transfusion ↓	Early + 30-day mortality ↓	0.3–2.1% thrombosis, no excess	Heterogeneous dosing contexts
Costa et al. (2023)	Scandinavia trauma-ready EMS	664 adults	Wet, high-output wounds	Celox Gauze	Std gauze	68–87% vs 49–64%	Non-inferior mortality	0 systemic events	Packs adhered well in moist fields
Ramirez et al. (2024)	Spain ground EMS	148 providers studied	Prehospital workflow	QuikClot, Celox, HemCon	Legacy granules	0% burns modern vs 6–12% legacy	Non-inf mortality	Legacy burns only	High-rep training improved mold integrity
Guyette et al. (2020)	US civilian EMS	928 adults	High-risk trauma	TXA	No comparator topical	N/A	4–12% mortality ↓ when <60 min	0.8% systemic events	Protocol adherence avoided delays

The synthesized evidence supported a five-tier integration cascade reflecting both clinical and operational domains. In Tier-1 recognition, providers emphasized primary survey hemorrhage triggers such as rapid pulse, delayed capillary refill, expanding hematoma, or shock index elevation >1.2. Tier-2 protocol branching confirmed that extremity trauma most consistently benefited from tourniquet application followed by planned wound packing if bleeding persisted. Tier-3 clotting aid selection showed that QuikClot Combat Gauze was typically deployed for deep, vertical or cavitary tracts in junctional or high-geometry wounds, whereas chitosan-derived formats (Celox or HemCon) were placed for layered tissue adherence when the wound surface was friable, moist, or irregular. Tier-4 physiologic stabilization included reduction in HR, improvement in mental status, directional SBP gain, and reduced transfusion >10 units PRBC odds at handoff when TXA was administered within 1 hour of detection. Tier-5 system compatibility emphasized carriage governance via tamper-sealed kits, shelf-life cycling logs, standardized dosing, and recurring high-repetition supervised hemostasis simulations improving 3-month provider retention accuracy and confidence across 794 monitored paramedics in 6 studies.

Discussion

This systematic review confirms that hemostatic and clotting adjuncts significantly enhance bleeding control outcomes when deployed in modern EMS workflows, influencing both physiologic stabilization

and operational performance. The findings align with growing trauma literature showing that early hemorrhage control in the prehospital phase is directly associated with lower preventable mortality, particularly when responders integrate clot-promoting aids in parallel with conventional mechanical interventions such as direct pressure and tourniquets. The strongest clinical signal across external traumatic hemorrhage favored kaolin-based gauzes including kaolin gauze by improving first-attempt packing success and reducing time-to-hemostasis without meaningful thermal tissue injury. This contrasts with older zeolite granule agents phased out before 2016, which although effective in clot induction, were consistently associated with exothermic burns when applied to moist or deep wounds. For junctional and cavitary hemorrhage involving uneven tissue beds or fluid-loaded surfaces, chitosan-impregnated formats including chitosan gauze demonstrated strong clot adherence and workflow flexibility, performing particularly well when layered over irregular surfaces or in fracture-adjacent bleeding fields. Importantly, none of the contemporary topical dressing studies linked isolated dressing use to elevated systemic thrombosis, reinforcing that local hemostatic adjuncts remain pharmacomechanistic rather than systemic procoagulant drivers.

At the systemic escalation tier, prehospital administration of tranexamic acid has emerged as the most evidence-validated clot-supporting pharmacologic intervention delivered by cargo-ready EMS teams. Mortality direction consistently favored early TXA when administered within 60 minutes of injury recognition, with additional benefits including reduced need for massive transfusion and improved shock index trends during transport and handoff. The evidence underscores that TXA is effective when employed under a physiology-triggered escalation rule, typically when SBP is <90 mmHg or SI exceeds 1.2 in suspected or confirmed major trauma. Importantly, civilian EMS implementation data show that when protocols were standardized, paramedic-driven prehospital TXA did not meaningfully prolong scene time, instead supporting earlier stabilization and reducing decision variability. However, evidence also indicated a persisting uncertainty around TXA workflow timing when IV access is delayed, limited staffing is present, or bleeding presents non-traumatically, such as postpartum or GI bleeding in out-of-hospital environments. While absolute safety trends showed thrombotic complications remain low and non-excessive versus controls when applied to appropriate trauma populations, operational-protocol governance remains an equal enabler of system benefit, ensuring the product is delivered to the correct patient cohort at the correct phase.

Operational evidence reveals that hemostatic adjunct integration only increases scene duration marginally when responders are trained under high-fidelity, high-repetition hemorrhage modules. Instead, adjuncts were linked to higher provider confidence, improved packing accuracy, smoother branch decisions, and greater perceived safety when gauze-based dressings replace legacy granular agents. Yet, real-world passage barriers remain. EMS systems that achieved high deployment success had clear logistics governance including tamper-sealed pouch discipline, controlled storage conditions, expiration cycling logs, trauma kit parity across ambulances, and audited resupply pipelines. Gaps identified in the dataset highlighted a global scarcity of multicenter civilian EMS comparative RCTs that measure clinical outcomes + operational KPIs simultaneously, limiting certainty on system-wide efficiency claims including total cost governance, long-term skill retention, or complication-surveillance discipline. Additionally, aeromedical EMS studies remain underpowered in representation, although early signal supports adoption feasibility in delayed transport networks.

This review also supports that clotting adjuncts perform most effectively when nested within a synergized mechanical model, combining extremity hemorrhage control via immediate tourniquet application followed by structured wound packing using modern hemostatic gauzes, while pharmacologic escalation using tranexamic acid is nested within IV-enabled shock-triggered workflows. This synergy-branch integration model emphasizes that the effectiveness of clotting adjuncts is not only chemically determined, but sociotechnically enabled, requiring recurrent training, procedural governance, and workflow adaptation parity across EMS units.

The study's findings hold meaningful implications for Saudi EMS system improvement underSaudi trauma framework by reinforcing modern dressing safety, early TXA survival benefit, and implementation parity metrics. Future work should prioritize pragmatic multicenter EMS RCTs measuring mortality, time-to-hemostasis, scene duration, drug administration latency, supply

governance, and longitudinal provider retention simultaneously, particularly in civilian non-combat contexts. Protocol consistency, scene timing discipline, kit parity, and standardized escalation rules therefore emerge as dominant system enablers needed for sustainable clotting-aid adoption in EMS.

Conclusion

The integration of clotting adjuncts within frontline EMS hemorrhage workflows represents a critical advancement in reducing preventable deaths during out-of-hospital emergencies. Contemporary evidence supports that topical hemostatic dressings, particularly kaolin-impregnated gauze formats, achieve faster and more reliable bleeding control compared with conventional standard gauze and direct pressure alone, without the thermal tissue complications associated with legacy granular zeolite agents phased out prior to 2016. Chitosan-impregnated dressings also provide strong clot adherence in fluid-loaded and irregular wound beds, offering flexibility in packing geometry and maintaining non-inferior safety profiles when deployed under standardized protocols and high-repetition training. At the systemic escalation level, prehospital tranexamic acid administration demonstrates the most consistent survival benefit in major trauma populations when delivered within 60 minutes of injury recognition, reducing early and 30-day mortality and lowering the likelihood of requiring massive transfusion when combined with optimized mechanical packing pathways.

Operational findings indicate that clotting aids add only marginal increases to scene duration once responders are trained through structured, high-fidelity hemorrhage modules, while improving provider confidence, protocol adherence, and perceived safety—particularly when modern dressings replace older formulations. Nonetheless, true system effectiveness depends heavily on logistics governance, training retention, kit carriage parity, and physiology-triggered escalation rules, outcomes that remain variably reported and limit certainty in meta-analytic pooling. The evidence gap emphasizes the need for pragmatic multicenter randomized EMS trials that concurrently measure mortality reduction, scene timing, cannulation latency, dosing discipline, supply cycling, and longitudinal provider performance.

The review concludes that clotting aids are clinically effective, operationally feasible, and system-enhancing when nested within standardized EMS bleeding pathways, but sustained impact will require stronger comparative civilian evidence, wider aeromedical representation, and comprehensive implementation governance to ensure reliable, scalable, and equitable EMS adoption.

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