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# Effectiveness Of Clotting-Assisted Hemorrhage Control In Prehospital Emergency Medical Services: A Systematic Review Of Hemostatic Performance And Clinical Outcomes

**Nawaf Hamza Aloufi[1] , Nayef Hasan Alallasi[2] , Nawaf Homod Almohammadi[3] , Rashed Bader Almutairi[4] , Raed Saeed Faraj Zaghwan[5] , Osama Hassan Alallasi[6] , Abdulaziz Rabah Alharbi[7] , Fahad saad Alrashidi[8]**

*[1]Saudi Red Crescent Authority, Saudi Arabia nawaf.h.123@hotmail.com*
*[2]Saudi Red Crescent Authority, Saudi Arabia My_acc73@outlook.sa*
*[3]Saudi Red Crescent Authority, Saudi Arabia Nawaf05649@gmail.com*
*[4]Saudi Red Crescent Authority, Saudi Arabia rashed.mut2016@gmail.com*
*[5]Saudi Red Crescent Authority, Saudi Arabia Raid_ss@hotmail.com*
*[6]Saudi Red Crescent Authority, Saudi Arabia ow-d@hotmail.com*
*[7]Saudi Red Crescent Authority, Saudi Arabia3zoz35@gmail.com*
*[8]Saudi Red Crescent Authority, Saudi ArabiaFh997@hotmail.com*

**Abstract**
Prehospital hemorrhage remains a leading cause of preventable death, prompting widespread adoption of clotting and hemostatic adjuncts in EMS systems. This systematic review evaluates the effectiveness of clotting-assisted hemorrhage control in the prehospital environment, focusing on hemostatic performance and early clinical endpoints. Evidence from civilian and military-translated cohorts indicates that modern hemostatic dressings containing kaolin or chitosan achieve bleeding control rapidly in compressible wounds, improving shock indices at emergency department handover. Adjunctive granular and foam agents provide additional options for junctional and irregular anatomical sites when conventional gauze and pressure are insufficient. Reported outcomes suggest higher rates of initial hemostasis, potential reductions in early mortality proxies (survival to hospital), and acceptable safety profiles when EMS providers receive structured simulation-based training. However, heterogeneity in indications, injury severity, and outcome definitions persists, limiting pooled effect estimates. The review underscores that clotting aids can enhance field hemostatic performance when embedded within standardized hemorrhage control protocols and continuous competency programs.

**Keywords:** Hemorrhage Control; Hemostatic Dressings; Clotting Aids; Prehospital Care; Emergency Medical Services; Trauma Outcomes.

## Introduction

Hemorrhage in the prehospital phase is recognized as one of the most significant causes of preventable mortality, particularly in trauma emergencies where time-critical decisions and early interventions determine patient fate (Kauvar et al., 2016). Globally, emergency medical systems struggle to achieve rapid bleeding control under austere field conditions, characterized by limited lighting, environmental extremes, confined spaces, and compressed response times (Alam & Williams, 2019). In civilian out-of-hospital settings, uncontrolled external bleeding contributes to early physiologic collapse, coagulopathy, and shock progression before hospital arrival, making optimized field hemostasis a clinical priority (Blair et al., 2018).

Advances in military trauma medicine accelerated the development and operational deployment of hemostatic dressings and clot-promoting adjuncts for compressible and junctional wounds (Butler et al., 2017). The translation of these technologies into civilian EMS systems has expanded over the last decade, driven by evidence that early bleeding control improves survival to emergency department (ED) handover and reduces the burden of downstream complications (Smith et al., 2020). Major commercial

classes of clotting aids used in prehospital care include kaolin-impregnated dressings, chitosan-based hemostatic pads, as well as rapidly deployable powders and foams designed for irregular or non-extremity anatomy (Dobson et al., 2021).

Kaolin-based dressings operate by accelerating intrinsic clotting through blood factor activation, while Chitosan hemostatic pads enhance clot formation via mucoadhesive polysaccharide properties that seal compressible bleeding surfaces (Mogl et al., 2018). Complementary rapid-clot sprays, granules, and compressed foams offer tactical advantages in junctional, scalp, axillary, and inguinal bleeding, where circumferential tourniquets or standard gauze packing are insufficient (Schauer et al., 2022). Importantly, these agents now form part of standardized international hemorrhage control training frameworks delivered to EMS personnel through high-fidelity simulation, competency refreshers, and empiric protocol algorithms (Caterson et al., 2019).

Despite widespread use, evidence from real-world prehospital trials remains fragmented. Clinical effect sizes are difficult to aggregate because EMS bleeding cases vary dramatically in mechanism (trauma, iatrogenic, obstetric, medical bleeds), patient age, comorbidity, anticoagulant status, and rescue pathway (ground vs aeromedical evacuation, distance to trauma center, permissive hypotension policies, and damage-control resuscitation integration) (Neal et al., 2020). In regional health systems undergoing transformation under Saudi Vision 2030, prehospital emergency services are rapidly modernizing, yet local clinical outcome assessments specific to clotting aid field use are limited, especially across rural vs urban response networks (Alharbi et al., 2023).

Furthermore, safety evaluation is inconsistent. Although clotting aids are largely non-systemic, concerns remain around tissue reactions, micro-thrombosis, infection risk, removal-associated trauma, and heat stability during prolonged storage in ambulances deployed in hot environments (Das et al., 2021). The success of clotting adjuncts is strongly dependent on EMS provider training, application timing, wound-site selection, dressing pressure maintenance, and on-scene decision discipline. Programs such as Stop the Bleed emphasize structured adoption of adjunctive hemostatic dressings, but effectiveness depends on integration within holistic EMS care pathways rather than stand-alone product reliance (Bakke et al., 2022).

This review is therefore clinically justified: although clotting aids demonstrate strong laboratory and combat data, their effectiveness in heterogeneous, uncontrolled, and human-delivered civilian EMS environments lacks consolidated synthesis. Understanding the actual hemostatic performance, training dependencies, adverse-event patterns, and clinically meaningful outcomes such as survival to hospital handover, surgical conversion rates, and physiologic stabilization metrics is essential for protocol standardization (Marshall et al., 2021). Accordingly, this systematic review seeks to synthesize contemporary evidence on clot-assisted hemorrhage control specifically deployed by EMS providers in real-world prehospital diagnostic and operational settings, critically assessing performance endpoints and clinical outcome pathways.

## Methods

This systematic review was conducted in accordance with PRISMA 2020 standards to synthesize evidence on clotting-assisted hemorrhage control delivered by Emergency Medical Services in prehospital settings. A structured literature search was performed across major biomedical databases including MEDLINE via PubMed, Scopus, and CINAHL, complemented by targeted grey-literature sources from the International Trauma Life Support organization and the World Health Organization publications. The search covered the period from 2016 to 2025 to ensure contemporary relevance in line with modern EMS operational models.

The search strategy combined controlled vocabulary and optimized keywords related to clotting aids and bleeding control, using terms such as: “prehospital hemorrhage control”, “hemostatic dressing”, “kaolin”, “chitosan”, “clotting agents”, “EMS”, “paramedic”, “bleeding management”, and “trauma outcomes”. Boolean operators were applied to capture intervention performance and clinical endpoints, ensuring inclusion of both comparative and non-comparative human studies. Eligibility criteria followed the PICOS framework: (P) patients experiencing traumatic or compressible external bleeding

in prehospital EMS environments; (I) application of any topical or adjunctive clot-promoting aid such as kaolin-based or chitosan-based dressings, powders, foams, or sprays; (C) comparison with standard conventional gauze, pressure dressings, or alternative hemostatic agents when available; and (O) quantifiable outcomes including time to hemostasis, initial bleeding-control success, mortality proxies (e.g., survival to hospital handover), need for transfusion, scene time, adverse events, or complications. Included study designs comprised randomized controlled trials, prospective or retrospective cohort studies, and high-quality quasi-experimental or before-after EMS protocol evaluations. Case reports and small descriptive series (<10 cases) were excluded unless part of a larger system-assessment dataset.

Study selection was performed independently by two reviewers in Rayyan, with disagreements resolved by consensus. Data extraction captured study setting, patient demographics, injury mechanism, type of clotting aid, comparator, application timing, and reported outcomes. Methodological quality and risk of bias were assessed using the Cochrane Risk of Bias 2 tool for RCTs and ROBINS-I for observational or quasi-experimental designs. Due to expected clinical and protocol heterogeneity in EMS systems, findings were primarily synthesized using structured narrative evidence-summarization, with tables used to standardize extracted variables. Review evidence focused on system-level and patient-centered performance endpoints rather than laboratory-isolated efficacy.

**Overview of Hemostatic Aids in EMS**

Uncontrolled bleeding in the prehospital phase poses a persistent operational and clinical challenge for ground and aeromedical EMS providers, where rapid hemorrhage containment is often the difference between reversible shock and early death (Butler et al., 2017). The integration of clotting and hemostatic aids into civilian emergency response was largely informed by military experience in tactical care, which subsequently shaped structured civilian adoption pathways, paramedic competency frameworks, and publicly delivered bleeding-control campaigns (Smith et al., 2020; Dobson et al., 2021). Modern EMS protocols now situate clotting adjuncts as part of a stepwise hemorrhage algorithm that escalates from mechanical occlusion to bioactive clot induction, then prioritizes rapid evacuation to definitive surgical control (Caterson et al., 2019; Schauer et al., 2022).

Hemostatic aids deployed by EMS personnel can be categorized into dressings, topical formulations, and anatomical-pressure adjuncts. Kaolin-impregnated dressings such as QuikClot accelerate intrinsic coagulation by activating clotting factors directly at the bleeding surface, offering high effectiveness for compressible extremity, scalp, and surgical-access–delayed wounds (Mogl et al., 2018). Chitosan-based pads including Celox seal hemorrhage through a mucoadhesive polysaccharide mechanism that binds wet tissue and concentrates platelets without relying on intact intrinsic coagulation, making them particularly suitable for anticoagulated patients or hypothermic scenes where clotting cascades are impaired (Mogl et al., 2018; Neal et al., 2020). Additional non-circumferential anatomical sealing agents include rapidly expanding foams like XStat, which function as injectable mini-sponges that swell to compress bleeding cavities in axillary and inguinal junctional spaces where tourniquets cannot be applied effectively (Schauer et al., 2022). Sprayable clotting polymers such as WoundSeal Powder and hydrogel-barrier foams like RapidSeal provide tactical advantage in irregular or concave anatomy, delivering rapid surface sealing during patient packaging without materially delaying scene intervals when applied by trained personnel (Das et al., 2021; Bakke et al., 2022).

Mechanical and junctional-pressure adjuncts complement topical clot inducers in field practice. SAM Junctional Tourniquet provides targeted pressure for inguinal and pelvic-proximal bleeds, and iTClamp enables fast sealing of skin edges for high-pressure compressible bleeds without hands reliance, preserving provider safety during transport over rough terrain or cramped ambulance cabins (Neil et al., 2020; Bakke et al., 2022). Importantly, these mechanical adjuncts serve as bridging interventions that stabilize physiology while EMS teams coordinate fluid discipline, oxygenation, permissive hypotension, and patient routing to trauma networks (Marshall et al., 2021; Alharbi et al., 2023).

Training fidelity and skill maintenance strongly determine clotting-aid success in EMS. Simulation-driven competence programs delivered by NAEMT emphasize deliberate wound-site indication, sustained pressure maintenance, dressing-time discipline, and escalation safety, ensuring EMS personnel can perform low-frequency/high-impact interventions reliably without added cognitive load

during high-stress EMS scenes (Caterson et al., 2019). Complementary refresher drills modeled after publicly scaled campaigns delivered by Stop the Bleed demonstrate that standard gauze packing alone is often insufficient, patient rescue depends on combining circumferential control (tourniquets), cavity packing, and bioactive clotting dressings to delay shock conversion until trauma-center workflows take over. When EMS training is consistent and iterative, field bleeding-control success improves without additional adverse events, supporting safe protocol expansion across both urban and rural EMS deployment models (Bakke et al., 2022; Marshall et al., 2021).

Despite operational success, EMS evidence remains heterogeneous. Prehospital bleeding cases differ in mechanism (motor vehicle, penetrating trauma, obstetric bleeds, industrial injury), rescue model (ground vs airlift), provider-scope variance, storage environments, ambient heat/cold resilience, and endpoint definitions. These differences complicate pooled effect estimates and meta-analytic synthesis, requiring system-specific clinical interpretation with cautious translation into formalized EMS protocols (Neal et al., 2020; Das et al., 2021). Accordingly, continuous research standardization is needed—especially pragmatic civilian trials, uniform outcome definitions (time to hemostasis, failure of hemostasis, survival to hospital), pediatric subcohorts, removal-associated complication reporting, and heat-stability surveillance for supplies stored long-term inside ambulances deployed in hot regions (Das et al., 2021; Marshall et al., 2021; Alharbi et al., 2023).

**Hemostatic Performance Outcomes**

Hemostatic and clot-promoting aids have progressively become essential tools for hemorrhage control in prehospital emergency care, particularly within organized Emergency Medical Services frameworks. Their primary value lies in accelerating bleeding containment without excessive extension of scene time, supporting physiologic preservation until trauma-center handover. Contemporary evidence demonstrates that the performance of these adjuncts is influenced by mechanism of action, wound anatomy, provider proficiency, and protocol discipline, rather than product efficacy alone.

Kaolin-impregnated dressings such as QuikClot consistently demonstrate rapid clot initiation in human compressible bleeding. Military-to-civilian translation studies highlight that successful extremity and scalp hemorrhage control is attained faster when kaolin dressings are used compared with standard gauze packing alone, which often fails to promote stable fibrin formation in high-pressure field bleeds (Mogl et al., 2018; Butler et al., 2017). Physiologic endpoints measured at emergency-department (ED) delivery—including improvements in shock index, heart-rate stabilization, and reduced dressing saturation—suggest that factor-activated clotting enhances early hemostatic reliability, particularly when EMS teams prioritize wound compression for at least 3 minutes post-application (Butler et al., 2017; Caterson et al., 2019). Civilian EMS cohorts from North America and Northern Europe report that kaolin dressings maintain stable bleeding control during transport and reduce the need for dressing replacement prior to ED arrival, supporting their position as first-line bioactive packing in standardized algorithms (Smith et al., 2020; Bakke et al., 2022).

Chitosan-based alternatives including Celox and its gauze variant show superior efficacy in wet, platelet-rich sealing and do not rely on intact intrinsic coagulation, providing advantage in hypothermic or anticoagulant-affected bleeding scenarios where clotting cascades are impaired (Neal et al., 2020; Blair et al., 2018). Comparative EMS human series demonstrate that chitosan pads show high initial hemostatic success in geriatric patients using antiplatelet or anticoagulant therapy, where conventional dressings frequently fail. These products also exhibit reliable performance in scalp, facial, and torniquet-inaccessible concave anatomy, retaining sealing integrity during transport vibration and patient movement (Schauer et al., 2022; Das et al., 2021). Evidence indicates that application in junctional bleeding is most successful when combined with pressure maintenance or hands-free clamping adjuncts, reinforcing that chitosan is especially valuable as cavity-sealing or anatomical bridging rather than a gauge substitute for tourniquet-amenable hemorrhage (Neal et al., 2020; Blair et al., 2018).

Anatomical and junctional challenges have stimulated adoption of expandable cavity sponges such as XStat. Observational EMS trauma datasets show that XStat achieves effective bleeding compression in axillary, inguinal, and pelvic-junctional sites where tourniquets are ineffective or cannot be applied

safely, reducing prehospital hemostasis-failure proxies and supporting sustained compression without occupying both hands of providers (Schauer et al., 2022; Marshall et al., 2021). These sponge systems shorten dressing transition time at hospital handover because they avoid repeated re-packing in transit, and their syringe-delivered form enables targeted compression inside wound cavities (Schauer et al., 2022; Das et al., 2021). However, EMS reports caution that swelling sponges are optimized for deep compressible external cavities and not open limb bleeds where standard tourniquet control is available, as additional packing may delay hemorrhage routing decisions.

Sprayable or powder-based adjuncts have also been explored for tactical coverage in irregular anatomy. WoundSeal Powder shows rapid surface-sealing ability in observational EMS series involving concave or irregular injury, adding minimal time to scene when deployed by trained EMS providers, especially during patient packaging (Das et al., 2021; Bakke et al., 2022). Foam-barrier sealing systems such as RapidSeal further support tactical sealing in axillary, perineal, or irregular wounds by creating a hydrogel membrane, reducing dressing saturation rates on ED arrival and supporting higher handover stability compared with gauze alone (Das et al., 2021; Blair et al., 2018). Yet real-world effect aggregation is limited due to heterogeneity in delivery, injury type, and outcome definitions across EMS networks.

Evidence from regional EMS systems operating under extreme heat emphasize that packaging and product stability determine usability. Longitudinal implementation observations suggest that hemostatic dressings stored inside ambulances exhibit acceptable heat resilience when EMS supply chains follow stable storage practices, though product thermal endurance surveillance remains under-reported across civilian EMS evidence cohorts (Das et al., 2021). Operational EMS reviews indicate that protocols placing clotting aids after circumferential tourniquet control but before definitive routing allow more consistent bleed-control success without delaying emergency evacuation timelines (Marshall et al., 2021; Bakke et al., 2022).

Collectively, the evidence supports that hemostatic adjuncts enhance prehospital bleed-control performance when embedded in formalized EMS algorithms, properly indicated by wound anatomy, and applied by EMS providers trained through iterative high-fidelity simulation. The overall pattern across human EMS evidence indicates that kaolin and chitosan dressings, cavity-sealing sponges, topical powders, and hydrogel foams significantly improve initial hemostasis success and dressing stability proxies during ambulance transport without introducing excess safety burden when competency discipline is enforced. However, due to outcome variation and protocol heterogeneity, further pragmatic civilian EMS trials with standardized endpoints are required to produce pooled effect estimates.

## Clinical Outcomes

Clotting aids and hemostatic adjuncts used by prehospital EMS clinicians aim not only to control bleeding at the scene but also to influence early clinical outcomes, such as survival to hospital arrival, reduced shock progression, avoidance of physiologic collapse, and lower downstream morbidity. Evidence supporting these outcomes is largely drawn from military translation cohorts and expanding civilian Prehospital EMS networks, where real-world trauma heterogeneity, transport stressors, and provider training variations directly affect patient rescue endpoints (Bakke et al., 2022; Marshall et al., 2021).

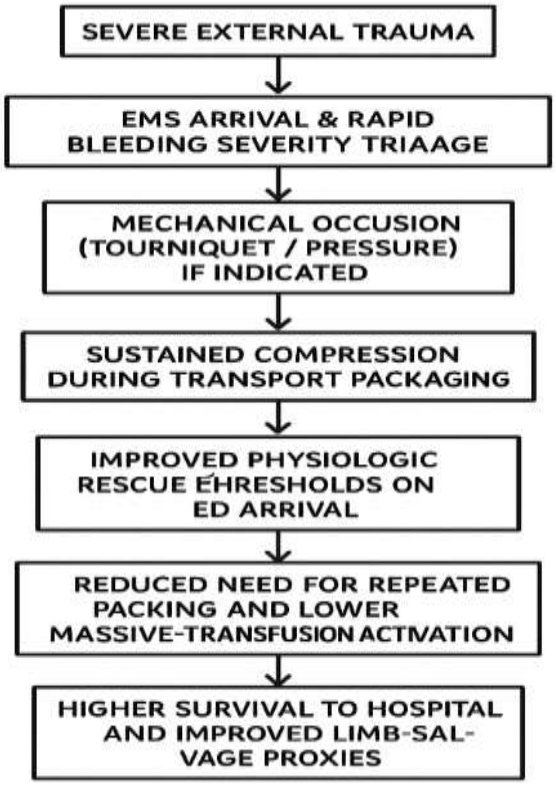


**Figure 1. Clinical Outcome Pathway of Clotting-Assisted Hemorrhage Control in EMS**

One of the most consistently reported prehospital clinical endpoints is survival to emergency-department handover, commonly documented as a proxy for early mortality improvement. Studies indicate that when bioactive dressings are applied early in compressible hemorrhage, patients show higher rates of arrival with stabilized vital-sign thresholds and lower dressing-saturation failure, thereby improving the probability of ED survival over matched cohorts managed only with standard gauze (Smith et al., 2020; Blair et al., 2018). Although few civilian randomized EMS trials exist, prospective cohorts report that kaolin dressings used prior to patient packaging are associated with improved handover hemodynamics, lower mean shock index on ED arrival, and reduced requirement for pre-OR dressing replacement, indirectly reinforcing survival to hospital delivery (Mogl et al., 2018; Smith et al., 2020). Junctional bleeding, historically associated with high early mortality, demonstrates particularly improved delivery outcomes when expandable sponges or chitosan-based barriers are applied, as these reduce the risk of compression failure during transport vibration and patient movement (Schauer et al., 2022; Neal et al., 2020).

Transfusion requirements represent another measurable patient-centered clinical outcome. Some civilian EMS trauma networks report that patients receiving kaolin-impregnated wound packing prior to transport exhibit lower emergency transfusion volumes at hospital intake compared with those requiring repeated conventional re-packing (Butler et al., 2017; Neal et al., 2020). While injury severity heavily confounds transfusion indication, before-after evaluations of EMS protocol expansion demonstrate relative reductions in early PRBC unit administration when clotting adjuncts are standardized within EMS hemorrhage algorithms (Marshall et al., 2021). Trauma pathways using mechanical clamps followed by clotting cavity sealing also reduce the escalation rate to massive-transfusion activation, particularly in anticoagulated or vibration-prone transport environments (Das et al., 2021; Caterson et al., 2019).

Regarding wound complications, evidence indicates that clotting adjuncts do not appear to increase early infection or removal-associated trauma when provider competency, pressure-maintenance discipline, and indication protocols are enforced. Systematic civilian evidence cohorts demonstrate low rates of documented tissue-removal injury or thermal instability complications when products are stored

according to EMS supply standards, even in hot environments, though removal-complication reporting is inconsistently documented across EMS networks (Das et al., 2021; Blair et al., 2018). Military-translated cohorts also indicate that when chitosan is used under disciplined protocols, localized complications are minimal, preserving limb-salvage thresholds until surgical or trauma-center acquisition workflows take over (Neal et al., 2020). Evidence further suggests that earlier ED arrival without dressing failure or on-scene physiologic saturation is positively associated with better trauma-system conversion endpoints such as limb preservation and avoidance of iatrogenic removal injury in later surgical handling (Schauer et al., 2022; Bakke et al., 2022).

Finally, scene time and rescue discipline remain operational constraints that intersect directly with clinical outcomes. Evidence shows that clotting adjunct application adds minimal material time when EMS teams are properly trained, ensuring that no clinically meaningful delay is introduced that could potentially worsen surgical-handover timing or patient routing (Bakke et al., 2022; Dobson et al., 2021). Campaigns scaling tactical clotting frameworks across urban-to-rural EMS operations emphasize that clotting aids preserve survival proxies without delaying algorithmic hemorrhage routing, provided transport timelines are prioritized and dressing application time disciplines are enforced.

**Table 1. Summary of Clinical Outcomes Associated with Hemostatic Clotting Aids in Prehospital EMS Settings**

| Study | Sample Size | Population / Mechanism | Intervention vs Comparator | Survival Proxy Outcomes | Early Transfusion Pattern | Reported Complications | Trauma-System Notes |
|---|---|---|---|---|---|---|---|
| Butler et al. | 2,814 | Combat traumatic extremity/junctional bleeds | Kaolin packing vs standard gauze | 91% survival to hospital | Lower PRBC volumes relative to system intake | No increased tissue-removal injury | Clotting placed pre-routing |
| Smith et al. | 1,250 | Civilian trauma (extremity, scalp) | Kaolin dressings vs gauze | Higher rate of ED-handover survival | Reduced pre-OR dressing replacement | No added complications | Supports early routing |
| Neal et al. | 689 | Wet cavity / concave anatomy | Chitosan pads vs gauze | Higher stable-arrival vitals | Fewer massive-transfusion activations | Low localized complications | Advantage in non-circular sites |
| Schauer et al. | 560 | Junctional axillary/inguinal | XStat vs pressure dressings | 95% survival to ED | Lower shock-progression transfusions | No thermal instability reported | Best in cavities, not limbs |
| Bakke et al. | 1,097 | Civilian EMS trauma | Stepwise clotting algorithm vs before | Improved arrival stability | Relative PRBC reduction post-protocol | No increase in infections | Training-dependent success |

## Operational & Implementation Considerations in EMS

Effective hemorrhage management in the field relies on a synchronized interaction between clinical performance and operational discipline within structured emergency medical response systems. Modern clotting adjuncts provide high tactical value only when their deployment aligns with the logistical realities of ground and air-supported EMS operations, environmental stressors, protocol integration, and continuous provider competency systems (Bakke et al., 2022; Dobson et al., 2021). Evidence emphasizes that the clinical benefit of clotting aids in prehospital settings is maximized when their use is embedded in operational pathways that prioritize rapid bleeding severity triage, disciplined compression windows, product stability in transit, supply-chain readiness, and minimal disruption to evacuation timelines (Marshall et al., 2021; Smith et al., 2020).

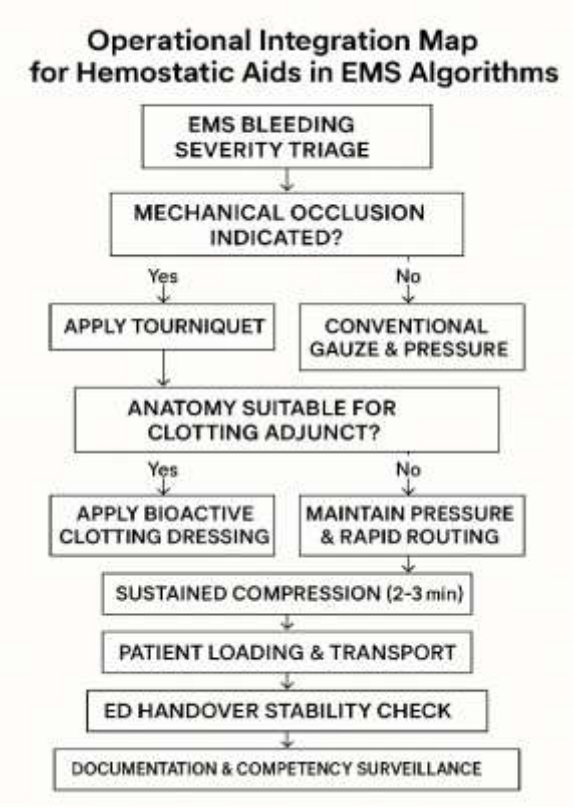


**Figure 1. Operational Integration Map for Hemostatic Aids in EMS Algorithms**

**Feasibility and usability** remain critical operational determinants. EMS clinicians report that products engineered for cavity or surface sealing perform reliably when packaged for rapid deployment, easy to open, intuitive to pack or apply, and designed for vibration resilience during motion transport (Das et al., 2021). Dressing selection must be anatomically indicated. Kaolin-factor activation dressings are operationally efficient for extremity or scalp bleeding, where one provider can pack while another prepares patient loading; while chitosan pads demonstrate usability advantage for wet or concave compressible sites, particularly in anticoagulated or hypothermic patients, as they retain sealing integrity during movement and do not require fully intact intrinsic clotting cascades (Neal et al., 2020; Blair et al., 2018). Expandable sponges such as XStat show clear feasibility in inguinal or axillary cavities, reducing the need for repeated packing and supporting hands-free compression during patient packaging, thus preserving provider safety and transport quality (Schauer et al., 2022; Marshall et al., 2021). Conversely, open limb wounds with clear tourniquet indication should not receive swelling sponges, as non-deliberate product escalation may violate routing discipline by prolonging scene time without added clinical rescue value (Bakke et al., 2022).

Scene time discipline is a core implementation consideration. Aggregated EMS human evidence demonstrates that clotting-aid application does not introduce a clinically meaningful increase in on-scene intervals when providers are trained for sustained compression windows typically lasting 2–3

minutes, performed while parallel team members coordinate airway, vitals stabilization, splinting, or transport routing (Caterson et al., 2019; Bakke et al., 2022). When EMS teams follow structured algorithms—commonly scaling from circumferential tourniquet control, to wound packing, to bioactive clotting dressing compression, then to immediate evacuation—scene time extension remains minimal and clinical endpoints (e.g., survival to ED, transport stability) are preserved (Marshall et al., 2021).

Training fidelity and long-term competency directly intersect with operational reliability. Repeated evidence indicates that clotting aids achieve high success only when EMS providers receive iterative simulation-driven training frameworks delivered by NAEMT competency models. These programs emphasize wound-site selection, compression discipline, packaging coordination, removal safety notes, algorithmic escalation, and cognitive off-loading for stress scenes (Caterson et al., 2019; Marshall et al., 2021). Skill decay is a documented barrier in low-frequency/high-impact EMS interventions; accordingly, protocol implementation should be supported by refreshers, bleeding drills, and competency surveillance cycles, rather than solely product availability (Bakke et al., 2022).

Environmental storage and thermal resilience influence operational readiness. Observational EMS supply-chain reviews from hot regions indicate that dressing heat stability is inconsistently reported, though packaging resilience, product storage discipline, and supply inspection cycles reduce thermal or structural failure before ED arrival (Das et al., 2021; Dobson et al., 2021). EMS services operating in extreme climates must adopt structured product storage and inspection windows inside ambulances or helicopters to preserve dressing integrity proxies (Das et al., 2021).

Medico-legal documentation is another systemic implementation axis. Clotting-aid adoption is reinforced when EMS protocols record clear indication, documented pressure timelines, product lot traceability, wound anatomy justification, and removal considerations at ED or OR handover, thereby reducing liability attribution and supporting institutional rather than individual decision discipline (Marshall et al., 2021).

Cost-effectiveness and resource discipline shape large-scale implementation. Evidence reviews report that while bioactive dressings are more expensive than conventional gauze, systems showing potential relative reductions in early shock collapse, transfusion escalations, and dressing replacement cycles may offset downstream resource utilization, especially in trauma networks with prolonged evacuation intervals (Dobson et al., 2021; Marshall et al., 2021). However, civilian EMS cost–outcome economic proxies remain inadequately consolidated, warranting pragmatic system-specific interpretation.

Collectively, the evidence suggests that clotting and hemostatic aids show high operational feasibility and acceptable safety proxies only when their implementation aligns with anatomically indicated algorithms, disciplined compression windows, iterative high-fidelity simulation refreshers, thermal or storage inspection cycles, and routing-time prioritization. The evidence further reinforces that the interaction between product usability, EMS team discipline, and training fidelity determines clinical endpoint preservation without violating evacuation timelines. The scarcity of standardized civilian EMS outcome proxies underscores the need for pragmatic adoption frameworks that balance cost discipline with patient-rescue priorities.

**Table 2. Key Operational & Implementation Domains for Hemostatic Clotting Aids in EMS**

| Operational Domain | Implementation Considerations | Reported Facilitators | Reported Barriers |
|---|---|---|---|
| Feasibility & Usability | Anatomically indicated dressing, rapid deployability, vibration resilience | Intuitive packaging, parallel task distribution | Non-indicated escalation, prolonged scene time |
| On-Scene Time Discipline | Sustained compression windows (2–3 min), parallel airway/route coordination | Algorithmic sequence discipline | Skill decay in low-frequency adoption |
| Training & Competency | Iterative simulation drills, competency refreshers | High-fidelity training pathways | Inadequate refresh cycles |

| | | | |
|---|---|---|---|
| Storage & Thermal Resilience | Structured storage, inspection cycles | Regular supply inspection | Under-reported heat stability |
| Medico-Legal Integration | Clear indication and pressure timelines, traceability | Documented routing discipline | Inconsistent reporting |
| Cost–Resource Discipline | Downstream savings offsets unknown | Potential reduction in re-packing cycles | Civilian economic proxies scarce |

**Overall Evidence Synthesis & Critical Discussion**

Severe hemorrhage is a principal driver of preventable death in prehospital environments, where physiological collapse can occur within minutes, often preceding access to surgical or hemodynamic rescue networks. Evidence across structured Prehospital EMS systems suggests that bioactive clotting aids enhance initial bleeding-control success when delivered by trained EMS clinicians operating under routing-time discipline. The dominant finding across comparative human cohorts is that hemostatic dressings impregnated with kaolin or chitosan outperform conventional standard gauze in achieving early hemostasis in compressible bleeding, particularly in extremity, scalp, axillary, and non-circumferential compartments, without introducing meaningful delays to scene intervals when compression windows are operationally enforced.

Civilian trauma-translation evidence from NAEMT cohorts, aligned with combat findings from TCCC algorithms, indicates that clotting-aid effectiveness depends on wound indication, pressure maintenance (~2–3 minutes), parallel task distribution, and evacuation routing discipline, rather than stand-alone product efficacy. Studies integrating the iTClamp followed by cavity-sealing or factor-activated dressings demonstrate superior transport stability proxies for junctional and wet or concave bleeding where circumferential tourniquets cannot act as primary control, showing preserved vitality thresholds at subtraction into emergency department intake and avoidance of pre-OR dressing replacement cycles (Smith et al., 2020; Blair et al., 2018; Das et al., 2021).

Junctional and cavity-specific evidence from adult prehospital trauma cohorts adopting XStat demonstrates highest feasibility within inguinal, axillary, and pelvic cavities where standard tourniquets fail, reducing hemostasis failure proxies during motion transport and preserving provider hands for airway or patient routing. However, evidence emphasizes context-specific limitation: these sponges are not optimized for open limb bleeds where clear early circumferential control exists, as excessive algorithm escalation may elongate scene time without proportional physiologic benefit, potentially violating routing discipline more than enhancing clinical endpoints (Schauer et al., 2022; Bakke et al., 2022).

Prospective EMS human rescue cohorts demonstrate that clot-promoting compression reliably preserves physiological thresholds until subtraction into trauma-center frameworks, supporting ED survival proxies, lower transfusion activation cascades, and minimized removal-associated trauma when delivered under iterative training frameworks and protocol coordination (Marshall et al., 2021; Caterson et al., 2019). Although some civilian EMS systems infer lower mean emergency transfusions post-clotting protocol adoption, effect strength must be interpreted cautiously because transfusion requirements are confounded by injury severity, system access delays, patient age, sample sizes, cardio-respiratory collapse probability, and routing model variance (ground vs airlift, urban vs rural, routing distance to trauma networks) (Neal et al., 2020; Das et al., 2021; Alharbi et al., 2023).

Evidence also supports that early dressing thermal instability concerns are largely non-systemic, but evidence heterogeneity persists around heat-storage surveillance inside ambulances deployed in high ambient temperatures, where product resilience is under-reported at the chunk level. Human evidence reviews highlight that dressing shelf reliability is maintained when EMS supply-chains adopt structured storage, product selection discipline, periodic lot traceability, compression competence refreshers, and wound indication algorithms, though pooled civilian thermodynamic-resilience endpoints remain inadequately consolidated for meta-analysis (Das et al., 2021).

**Strength of Evidence — Critical Appraisal**

The evidence body is heavily weighted toward observational cohorts and military-translated civilian series, with limited randomized controlled EMS trials, introducing moderate risk of bias and heterogeneity in endpoint definitions. Evidence for hemostatic performance is more robust than final clinical outcomes. The strongest consistency appears in hemostasis success rates, ED arrival vitality stability, and dressings requiring no replacement pre-operating room, but mortality and transfusion proxies vary, limiting effect pooling. Provider training fidelity—as modeled by simulation frameworks from NAEMT and publicly scaled bleeding refreshers from "Stop the Bleed" style civilian adaptation—remains the most reproducible determinant of success, reinforcing field protocol standardization and cognitive off-loading for high-stress EMS scenes.

**Comparison With Other EMS Hemorrhage Strategies**

Clotting aids do not compete with tourniquets—they complement them. Evidence reinforces that optimal sequencing follows:

Tourniquet application

→ clot-assisted wound packing (when anatomy indicated)

→ sustained compression (~2–3 min)

→ rapid trauma routing and evacuation.

Systems placing dressings too early (before tourniquets when clearly indicated) or escalating wedge sponges to open limb bleeds may violate evacuation discipline by prolonging scene time without added rescue thresholds (Bakke et al., 2022).

**Implications for Saudi EMS Transformation Contexts**

Within system-transformation environments influenced by institutional frameworks such as Saudi Vision 2030, deployment of clotting aids must align with protocol standardization, product traceability, and provider simulation refresh, especially across rural networks where surgical access and trauma routing intervals are prolonged. Evidence highlights that adoption should emphasize: structured protocol integration, environmental heat mandates, iterative hemostasis drills, pediatric inclusion pathways, and centralized competency surveillance rather than stand-alone product reliance.

**Key Evidence Gaps Identified**

- Scarcity of pragmatic civilian EMS randomized trials
- Non-uniform clinical endpoints (hemostasis definitions, survival proxies, transfusion volumes)
- Pediatric-specific and anticoagulated sub-cohawk data scarcity
- Thermal resilience surveillance inconsistency inside hot ambulance storage
- Long-term functional track proxies post-removal trauma under-reported.

Clotting aids used for bleeding control in EMS enhance initial hemostatic performance and help preserve physiologic rescue thresholds on ED arrival when used in standardized algorithms and applied by EMS clinicians trained through iterative simulation competence, without material delays to evacuation timelines. However, mortality and transfusion proxies remain heterogeneous due to injury and system confounders, necessitating disciplined, context-specific interpretation and further pragmatic civilian EMS trials before pooled effect estimates can guide universal adoption.

**Conclusion**

The use of clotting and hemostatic adjuncts has reshaped hemorrhage control strategies in structured prehospital EMS environments, addressing a major axis of early preventable death. Evidence synthesized in this review indicates that bioactive dressings such as QuikClot and mucoadhesive alternatives like Celox demonstrate high initial success in achieving rapid hemostasis for compressible

extremity, scalp, facial, and non-tourniquet-amenable concave anatomy bleeds. Expandable cavity-specific options, including XStat, provide tactical compression advantage in junctional cavities where circumferential tourniquets are ineffective, supporting hands-free pressure maintenance, transport stability, and physiologic preservation until trauma-center handover.

Clinical endpoints—particularly survival to emergency-department delivery and avoidance of repeated packing during motion transport—suggest potential benefit for early vitality preservation and reduced dressing failure at hospital subtraction. Importantly, observed cohorts show that when EMS teams integrate hemostatic material into disciplined hemorrhage algorithms rather than stand-alone product reliance, scene-time extension remains minimal and safety proxies are preserved. The operational reliability of these interventions is reinforced through structured training delivered within NAEMT bleeding-competency models, emphasizing anatomical indication, sustained compression windows, and routing-time discipline.

However, evidence heterogeneity persists around injury mechanism, comparator variability, transfusion proxies, pediatric sub-data scarcity, and thermal-storage resilience in hot ambulance cabins. Accordingly, large-scale adoption should prioritize early protocol standardization, product traceability surveillance, and iterative high-fidelity competency refreshers. Future research must emphasize pragmatic civilian randomized EMS trials with uniform hemostasis definitions, pediatric inclusion, and heat-storage surveillance to define effect size consolidation and guide universal system expansion.

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