

BLEED TIME Simulation Study – Bleeding Limb, Effectiveness and Efficiency in Determining Time to Intervene on Mangled Extremity

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Purpose: Simulation-based education plays a pivotal role in preparing healthcare providers for rare, high-acuity emergencies such as hemorrhagic extremity trauma. Advances in simulation fidelity, including hemorrhagic pumping systems (HPS), may enhance realism, urgency, and clinical decision-making. However, evidence on how such enhancements affect provider performance remains limited.

Patients and Methods: In this randomized case-control study at a rural Level I trauma center simulation learning laboratory, emergency care providers (n = 146) managed a simulated extremity trauma scenario using either standard moulage (Group A; No HPS) or an active HPS (Group B). Participants were stratified by profession/licensure prior to recruitment. Within each professional stratum participants were randomized to ensure balanced representation, into the two groups and the timed endpoints included (i) First Intervention, (ii) Tourniquet-only Application, and (iii) Scenario Completion. Subgroup analyses were conducted by healthcare license (Emergency Medical Technician (EMT), Registered Nurse (RN), Others (neither EMT or RN licensure)) and years of licensure (<5 vs ≥5 years).

Results: Participants using the HPS performed the first intervention significantly faster (mean = 54.9s) than those with No HPS (mean = 71.9s; $p=0.002$). EMTs and “Others” showed significant time improvements with HPS use, while RN performance did not differ. Tourniquet-only and Scenario Completion times were unaffected by HPS presence. Among RNs, those with <5 years of experience performed significantly faster in the first intervention than their more experienced peers ($p=0.039$); no other timing differences reached statistical significance based on licensure length.

Conclusion: Enhanced realism within simulation-based education incorporating dynamic bleeding systems improves response time in initial trauma interventions, particularly among EMTs and less-experienced providers. While total scenario times and tourniquet application did not differ, early engagement appears positively influenced by simulation fidelity. Integrating high-fidelity elements like HPS into trauma training may strengthen learner urgency, decision-making, and improve real-world provider readiness.

Plain Language Summary:

This study explored how realistic bleeding simulations affect emergency care providers’ response times to a serious leg or arm injury. The goal was to see if adding a system that mimics real bleeding (called a hemorrhagic pumping system, or HPS) could improve how quickly and effectively providers react in a training scenario.

Researchers tested 146 emergency workers at a rural trauma center. About half of them used a standard setup with no active bleeding (Group A), while the rest used a more realistic system that included simulated bleeding (Group B). They measured how long it took participants to start treating the injury, apply a tourniquet, and complete the full scenario.

The study found that those who used the bleeding system started treatment faster, about 17 seconds quicker on average. This improvement was especially true for Emergency Medical Technicians (EMTs) and providers without specific nursing or EMT licenses. Nurses did not show a difference overall, but newer nurses (with less than five years of experience) responded faster than more experienced ones.



Adding realistic bleeding did not change how fast tourniquets were applied or how long the entire scenario took to complete. However, it did make a difference in how quickly providers reacted at the start.

In summary, using more realistic bleeding in trauma simulations helps improve early response times, especially for newer or non-nurse providers. This suggests that adding lifelike features such as active bleeding to training could better prepare emergency workers for real-world trauma situations.

Keywords: medical simulation training, emergency medical services, clinical decision-making, dynamic bleeding models, high fidelity simulation training, trauma education

Introduction

Simulation-based education has become a critical component of medical training, particularly in the preparation for low-frequency, high-acuity events¹ such as life-threatening traumatic limb injuries.² It provides a controlled and risk-free environment in which healthcare professionals can systematically identify and address potential challenges in clinical practice.³ Timely intervention in hemorrhagic extremity trauma is well established as a critical determinant of patient outcomes, with much of the foundational evidence originating from military medicine.^{4,5} While such injuries are rare, approximately 1% of all extremity traumatic injuries in civilian practice,⁶ they carry substantial morbidity and mortality when they do occur,⁷ and are largely preventable.⁸ This led the American College of Surgeons to develop civilian strategies to improve victim survival with input from medical, law enforcement, fire/ rescue, emergency medical service first responders, and military experts,⁹ which steered the “Stop the Bleed” initiative.¹⁰

The degree to which moulage is used in the simulated environment is varied; that is, there is no guide for how authentic it is required to be.¹¹ Given the combination of low incidence and high risk, simulation provides a unique opportunity to bridge the educational gap¹² and prepare providers for rare but life-saving interventions. Advances in simulation technology have opened the door to more realistic and immersive training modalities. Among these is the use of dynamic bleeding systems, which simulate active bleeding, potentially increasing learner engagement and altering clinical decision-making behavior.¹³

Repetition and deliberate practice in realistic environments has been shown to improve both individual performance and patient outcomes.¹⁴ However, there remains a relative paucity of research exploring how differing simulation approaches, particularly those involving bleeding control, impact learner behavior and training effectiveness. One related study¹⁵ informed this project development and underscores the emerging interest in the area.

This study explores whether enhanced realism through the use of an active bleeding pump system influences emergency care providers’ response times in a simulated extremity trauma scenario. We hypothesized that participants exposed to active bleeding would demonstrate a shorter time to intervention compared to those using traditional moulage. Moreover, experienced medical practitioners assess patient status in distinct ways compared to novices, potentially impacting the effectiveness of simulated bleeding control interventions.¹⁶

This study compares traditional moulage with a high-fidelity bleeding system in trauma simulation. Our objectives are: (A) to evaluate learner performance using time-based measures, time to first intervention, time to tourniquet application, and total scenario time, across the two simulation methods; and (B) to examine differences in learner behavior and decision-making among emergency care professionals to guide the effective use of bleeding simulators in medical training. By integrating objective performance data with behavioral insights, this study aims to apprise the strategic use of bleeding simulators in emergency medical education.

Materials and Methods

Study Design

This randomized case-control study (Figure 1) was conducted at a simulation learning laboratory in a rural Northwestern US Level I trauma center.

This study was reviewed and deemed exempt by the Billings Clinic Institutional Review Board Privacy & Exemption Committee (Protocol #23.003). Verbal informed consent was obtained from all participants following a thorough

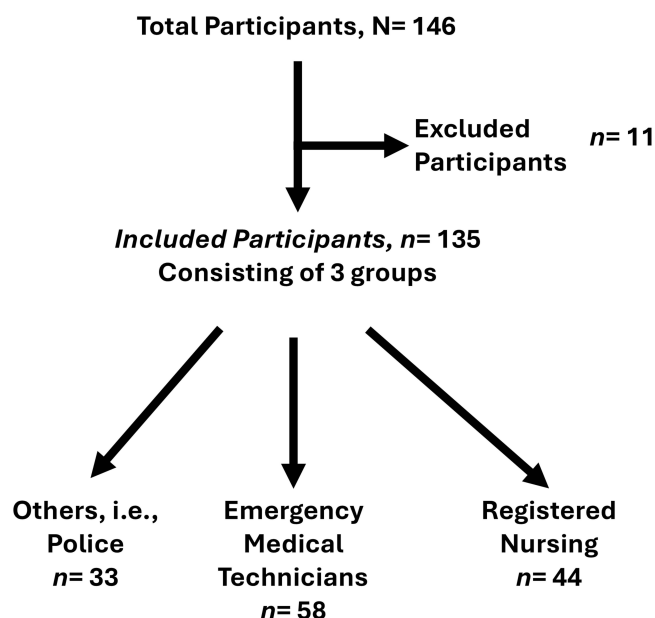


Figure 1 Diagrammatic representation of the Study Participants.

explanation of the study's purpose, procedures, potential risks, and benefits, prior to participation. Consent was documented by the research team at the time of the interview, confirming participants' understanding and voluntary agreement to participate, in accordance with the Declaration of Helsinki, with confirmation recorded in study logs. To protect participant privacy, written consent was waived due to the use of digital recordings and the associated risk to confidentiality.

Participants were randomized into two task groups (Figure 2):

Group A: Managed a standard moulage mannequin. A silicone wound ([Supplemental Materials Figure S1](#)) was affixed to the right thigh, with simulated blood manually applied.

Group B: Managed the same mannequin, but the silicone wound was connected to an active hemorrhagic pump system (HPS; Stops Medical, San Diego, Ca) ([Supplemental Materials Figure S2](#)), producing continuous simulated bleeding.

Upon entering the simulation room, each participant received a standardized scenario prompt ([Supplemental Materials Box S1](#)) from a facilitator, describing a young male patient who sustained a traumatic limb injury during an industrial accident. No additional verbal cues or feedback were provided after the initial prompt. This moment marked the start of the scenario and the initiation of the intervention timer ("time zero").

Participants had access only to visual cues, including the wound, simulated blood, and a single set of vital signs placed next to the patient (tachycardic, hypotensive, GCS 14) ([Supplemental Materials Figure S3](#)). The simulation concluded either at the 5-minute mark or once the participant verbally indicated completion of assessment and intervention.

All scenarios were video and audio recorded to allow for blinded post-hoc performance analysis. Metrics included time to first intervention, time to tourniquet placement, and total scenario duration. Interventions were defined as any action to control bleeding, including direct pressure, wound packing, or tourniquet placement.

Setting

This study was conducted at a simulation learning laboratory (SLL) in a rural Northwestern US Level I trauma center that consists of multiple simulation rooms equipped with audio/ visual recording systems, a control room, and a conference space for debriefing. This center supports training for a wide range of learners, including healthcare professionals, emergency responders, and community members across a broad rural area.

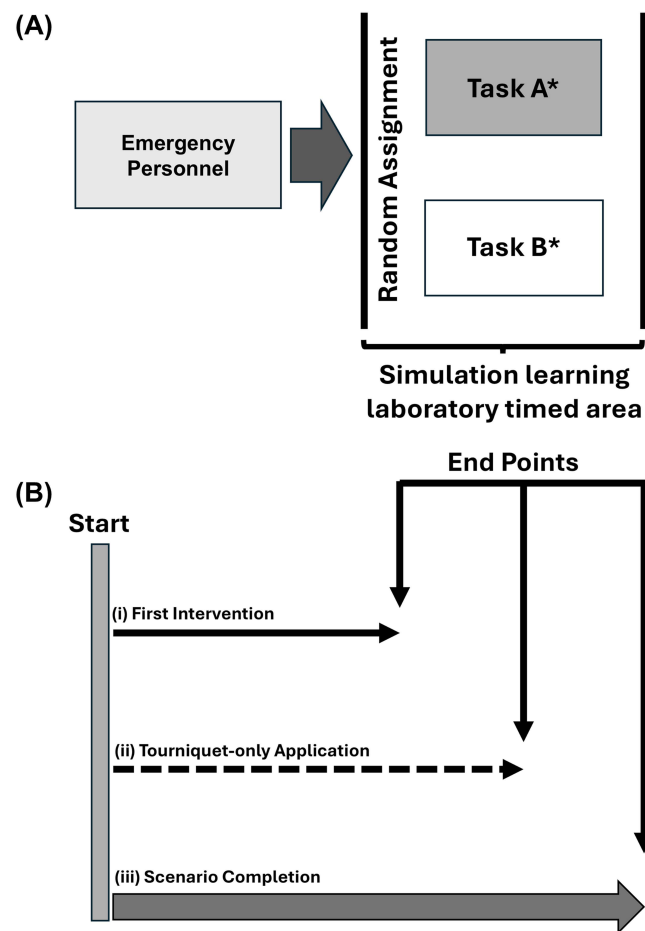


Figure 2 Diagrammatic Representation of the Study and Outcome Time Points. **(A)** Representation of the Training Simulation. Emergency personnel ie, EMS, Fire, Emergency Nurses & Police. Task completion recorded, observed and timed within the simulation learning laboratory, by independent observers. *Task A and B differ in presentation to the participants, ie Task A is more abstract classical mannequin simulation scenario. Task B is more “life-like”, with a Hemorrhagic Pumping System (HPS). **(B)** Timing End Point Diagrammatic Representation. First intervention refers to Finger, knee or tourniquet applied to wound.

Participant Confidentiality

The SLL was specifically designed with the intent of participant confidentiality: Encrypted visual recordings are stored within the control room on isolated servers without network or internet integration. Participants’ names were not stored in records, only a subject number. Thus, visual recordings were not accessible outside of the physical entity of the simulation lab, and study observers who timed the individuals during the scenarios had to be physically within the control room to review. Visual recordings were deleted after the evaluation review.

Participants

A total of 146 individuals voluntarily participated in the study without compensation (Figure 1). All participants filled in the questionnaire (Figure 3) and had prior formal training in emergency wound care and tourniquet application. Participants represented a diverse group of emergency care professionals, including (Table 1):

- Police officers and Special Weapons and Tactics (SWAT) personnel
- Firefighters
- Paramedics and Emergency Medical Technicians (EMTs)
- Emergency department Registered Nurses (RNs)
- Medical students

Participant Questionnaire	
Participant Number: _____	Date: _____
1. What is your highest level of license?	
a. EMT-Basic	
b. EMT-Advanced	
c. EMT-Paramedic	
d. RN	
e. Other _____	
2. Have you received advanced trauma training (PHTLS, ATLS, TNCC, etc.)?	
a. Yes	
b. No	
3. When did you last receive massive hemorrhage or tourniquet training?	
a. 1-3 months ago	
b. 3-6 months ago	
c. 6-12 months ago	
d. 12-24 months ago	
e. Greater than 24 months ago	
4. What degree best describes your current trauma training?	
a. Inadequate	
b. Slightly better than inadequate	
c. Adequate	
d. Slightly better than adequate	
e. Excellent	
5. How long have you had your current license?	
a. 1 year or less	
b. 1-2 years	
c. 2-5 years	
d. 5-10 years	
e. Greater than 10 years	

Figure 3 Participant Questionnaire.

Abbreviations: EMT, Emergency Medical Technician; RN, Registered Nurse; PHTLS, Prehospital Trauma Life Support; ATLS, Advanced Trauma Life Support; TNCC, Trauma Nursing Core Course.

Irrespective of specific job/role, the participants were divided into three specific groups dependent upon their personal healthcare license.

Others: Any participant without either an EMT or RN healthcare license.

EMTs: Participants with a current EMT license.

RNs: Participants with a current RN license.

The majority of individuals in the “Others” group had training in tactical medicine with some individuals trained in basic first aid. For the purposes of this project, all levels of EMT certification, including paramedics, are grouped under the general classification of “EMT” to streamline analysis and reflect their shared role in pre-hospital emergency care. In addition, it should be noted that EMT licensure is not exclusive to medical personnel, as it is a prerequisite for certain pre-hospital roles.

Table 1 Participant Demographics

	n	Mean Age (±SD)	Hemorrhagic Training ^a	Healthcare License (n)	Mean Time with License, Years (±SD)	Included in Study (n)
Police officers and SWAT	29	33.3 (±4.3)	Yes	EMT (2)	2.3 (±1.3)	29
Firefighters	28	37.8 (±5.8)	Yes	EMT (28)	7.8 (±3.8)	27
Paramedics & EMTs	31	36.5 (±4.4)	Yes	EMT (32)	4.0 (±3.7)	28
Registered Nurses	51	45.2 (±12.2)	Yes	RN (51)	7.1 (±3.7)	44
^b Ancillary	7	28.6 (±5.3)	Yes	EMT (1)	1.0 (N/A)	7

Notes: ^aFor example, “Stop the Bleed”, Prehospital Trauma Life Support (PHTLS), Advanced Trauma Life Support (ATLS) or Trauma Nursing Core Course (TNCC). ^b Certified nursing assistants, medical technicians and/ or medical students.

Abbreviations: SD, Standard Deviation; SWAT, Special Weapons and Tactics; EMTs, Emergency Medical Technicians; RN, Registered Nurse; N/A, Not applicable.

Table 2 Performance Differences Using a Hemorrhagic Pumping System Among All Participants and Grouped by Healthcare Licensure

Combined	All Participants		
Mean Time, Seconds [95% CI] (n)	No Hemorrhagic Pumping System	Hemorrhagic Pumping System	p value
(i) First Intervention	71.9 [65.3, 78.5] (60)	54.9 [46.8, 63.0] (71)	0.002^a
(ii) Tourniquet Only	87.2 [75.8, 98.5] (61)	83.7 [74.4, 93.1] (70)	0.643
(iii) Scenario Completion	194.2 [176.1, 212.3] (61)	188.8 [173.9, 203.6] (71)	0.643
No Licensure	Others		
(i) First Intervention	70.0 [58.7, 81.3] (15)	44.6 [31.0, 58.2] (15)	0.006^a
(ii) Tourniquet Only	69.9 [60.6, 79.3] (18)	56.4 [46.8, 66.0] (15)	0.048^a
(iii) Scenario Completion	181.2 [133.6, 228.8] (15)	187.3 [157.8, 216.9] (15)	0.822
EMT Licensure Only	EMTs		
(i) First Intervention	69.9 [60.4, 79.5] (25)	43.7 [36.1, 51.4] (32)	<0.001^a
(ii) Tourniquet Only	90.0 [74.6, 105.4] (25)	84.2 [69.5, 98.8] (32)	0.585

(Continued)

Table 2 (Continued).

Combined	All Participants		
Mean Time, Seconds [95% CI] (n)	No Hemorrhagic Pumping System	Hemorrhagic Pumping System	p value
(iii) Scenario Completion	190.4 [165.4, 215.4] (25)	168.1 [150.1, 186.0] (33)	0.139
RN Licensure Only	RNs		
(i) First Intervention	75.8 [61.4, 90.1] (20)	77.7 [59.4, 96.1] (23)	0.866
(ii) Tourniquet Only	100.4 [69.5, 131.4] (18)	101.0 [84.6, 117.4] (23)	0.973
(iii) Scenario Completion	208.0 [177.2, 238.8] (21)	219.4 [188.7, 250.1] (23)	0.598

Notes: ^aBolded text, Two-tailed Student's t-test, $p < 0.05$.

Abbreviations: EMT, Emergency Medical Technician; RN, Registered Nurses.

Recruitment occurred via Email invitations and peer-to-peer recruitment ([Supplemental Materials Box S2](#)), leveraging the lab's longstanding relationships with local institutions and emergency services. Participants were stratified by profession/licensure prior to recruitment due to logistical considerations. Each professional group was engaged during pre-scheduled training periods specific to their discipline: RNs were recruited during hospital training days, fire service personnel during multiple departmental training sessions, EMT providers during their regular training days, and law enforcement officers over several allocated days corresponding with shift downtime. Randomization was conducted within each professional stratum to ensure balanced representation and to accommodate scheduling constraints inherent to each discipline. Enrollment was completed over a few months due to strong interest from the community.

Outcome Measures

Three primary outcome measures were evaluated and detailed in [Figure 2](#):

- (i) First Intervention - time to initial intervention, defined as the first hemorrhagic control maneuver (eg, direct pressure, wound packing, or tourniquet placement).
- (ii) Tourniquet-only Application - time measured from scenario start to the application of a tourniquet.
- (iii) Scenario Completion - total scenario duration, measured from the start of the scenario to its conclusion, either at five minutes or at participant-declared completion.

Participants' actions were assessed using standardized criteria during blinded video review. Not every participant could be timed on each of the three measures, eg, some felt they had completed the exercise without applying the tourniquet thus were not timed for that intervention.

The majority of participants had completed hemorrhagic control training in the form of foundational education, tactical medicine training, or "Stop the Bleed" courses which emphasizes a stepwise approach: pressure, packing, and ultimately tourniquet application.¹⁷

Exclusion Criteria: (a) Received inappropriate feedback from "bystander"; (b) verbalized intervention, as opposed to physical placement; or (c) failed to apply adjuncts in a manner consistent with real-world practice.

Statistics

The statistical analysis was conducted using R statistical software version 4.5.1 (R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were calculated for all variables. Continuous variables were summarized using means with 95% confidence intervals (CIs). A two-tailed Student's *t*-test was used for continuous variables. Interaction between licensure duration and HPS was examined using two-way Analysis of Variance (ANOVA). Statistical significance was established at $p < 0.05$.

Results

Of the enrolled participants (N=146), a total of 135 participants were included in this study.

Utilization of a Hemorrhagic Pumping System in a Simulation Environment

Initially, time to interventions (Figure 2) compared those scenarios using simple moulage and those using the HPS. In Table 2, results are presented in seconds. For the first intervention, participants using the HPS completed the task significantly faster (mean = 54.9 seconds; 95% CI [46.8, 63.0]) compared to those without the system (mean = 71.9 seconds; 95% CI [65.3, 78.5]), with the difference reaching statistical significance ($p = 0.002$). For both the tourniquet-only intervention and scenario completion, there was no statistically significant difference between groups.

Performance Differences Among Participants Grouped by Healthcare Licensure

A subgroup analysis was conducted to evaluate performance differences among participants grouped by role (Table 2): Others, EMTs, and RNs. Mean times (in seconds) with 95% confidence intervals (CI) and sample sizes (n) are reported for each group, comparing those using the HPS versus those without (No HPS). First Intervention: in the Others group, participants using the HPS completed the first intervention significantly faster (mean = 44.6 seconds; 95% CI [31.0, 58.2]) than those without HPS (mean = 70.0 seconds; 95% CI [58.7, 81.3]), ($p = 0.006$). Similarly, among EMTs, HPS use resulted in a significantly faster completion time (mean = 43.7 seconds; 95% CI [36.1, 51.4]) compared to No HPS (mean = 69.9 seconds; 95% CI [60.4, 79.5]), ($p < 0.001$). In contrast, RNs showed no significant difference between groups. Tourniquet-Only Intervention: in the Others group, HPS use was associated with a significantly faster application time (mean = 56.4 seconds; 95% CI [46.8, 66.0]) versus No HPS (mean = 69.9 seconds; 95% CI [60.6, 79.3]), ($p = 0.048$). Among either EMT or RNs, there was no statistically significant difference between groups. Scenario Completion: there were no statistically significant differences in times across all three (Others, EMTs, or RNs) groups.

Analysis by Length of Healthcare Licensure

Performance times were compared based on years of healthcare licensure, grouped into less than 5 years (<5 years) and 5 years or more (≥ 5 years). Analyses were conducted for combined EMT and RN groups, and separately within EMTs and RNs (Table 3).

Combining EMTs and RNs participants with <5 years of licensure demonstrated slightly faster times across all interventions, though none reached statistical significance compared to ≥ 5 years licensure, in any of the three intervention endpoints.

Among EMTs only, differences between license duration groups were not statistically significant at any of the timed end points.

For RNs only, a significant difference was observed in the first intervention. At First Intervention: RNs with <5 years of licensure performed significantly faster (mean = 59.8 seconds; 95% CI [46.5, 73.1]) than those with ≥ 5 years (mean = 85.0 seconds; 95% CI [69.8, 100.3]), ($p = 0.039$). No significant differences were found in the subsequent measures.

Interaction Between Years of Licensure and Hemorrhagic Pumping System Use

A two-way ANOVA was also conducted to evaluate whether years of licensure (<5 years vs ≥ 5 years) influenced the effectiveness of the HPS vs no HPS, resulting in four groups to be compared (Table 4).

Table 3 Timing Analysis by Length of Healthcare Licensure

Mean Time, Seconds [95% CI] (n)	Length of Healthcare License		p value
	<5 Years	≥5 Years	
Combined EMTs & RNs			
(i) First Intervention	59.2 [51.4, 67.0] (46)	68.7 [58.5, 78.9] (54)	0.153
(ii) Tourniquet-only	83.9 [73.3, 94.6] (46)	100.3 [86.4, 114.1] (52)	0.072
(iii) Scenario Completion	189.7 [170.7, 208.6] (48)	196.6 [179.0, 214.2] (54)	0.595
EMT Licensure Only			
(i) First Intervention	59.0 [49.1, 68.9] (32)	49.8 [40.8, 58.8] (25)	0.179
(ii) Tourniquet Only	84.8 [70.7, 98.9] (33)	89.4 [73.1, 105.6] (24)	0.670
(iii) Scenario Completion	180.6 [158.5, 202.7] (33)	173.8 [154.5, 193.1] (25)	0.653
RN Licensure Only			
(i) First Intervention	59.8 [46.5, 73.1] (14)	85.0 [69.8, 100.3] (29)	0.039^a
(ii) Tourniquet Only	81.8 [67.8, 95.7] (13)	109.6 [87.7, 131.4] (28)	0.102
(iii) Scenario Completion	209.5 [172.3, 246.8] (15)	216.2 [189.3, 243.1] (29)	0.769

Notes: ^aBolded text, Two-tailed Student's t-test, $p < 0.05$.

Abbreviations: EMT, Emergency Medical Technician; RN, Registered Nurse.

Combining EMT and RN Participants, there was no significant interaction between years of licensure and HPS use ($p = 0.186$; Table 4). However, HPS use significantly improved performance when measured by time to the first intervention ($p = 0.023$; 95% CI for No HPS vs HPS [2.05, 27.62]). Among the four groups being compared, the fastest performance occurred in participants with <5 years of licensure using HPS (mean = 48.5 seconds, 95% CI [39.3, 57.7]), compared to those without HPS (mean = 72.5 seconds, 95% CI [61.6, 83.4]). For participants with ≥5 years, the time difference was statistically the same (HPS: 65.7 seconds, 95% CI [49.8, 81.5]) vs No HPS: 72.5 seconds, 95% CI [60.1, 84.9]). No significant interactions and effects of either HPS or years of Licensure were found for tourniquet-only ($p = 0.562$) or scenario completion measures ($p = 0.192$); Table 4).

Table 4 Interaction Between Years of Licensure and Hemorrhagic Pumping System Use Mean Values and 95% CI Including Two-Way ANOVA *p* values

Mean Time, Seconds [95% CI] (n)	<5 Years		≥5 Years		Two-Way ANOVA <i>p</i> values		
	No HPS	HPS	No HPS	HPS	HPS Use	Years of Licensure	Intersection
Combined EMTs & RNs					Yes vs No	<5 vs ≥5 Years	
(i) First Intervention	72.5 [61.6, 83.4] (21)	48.5 [39.3, 57.7] (26)	72.5 [60.1, 84.9] (24)	65.7 [49.8, 81.5] (30)	0.023^a	0.143	0.186
(ii) Tourniquet Only	88.9 [74.6, 103.1] (20)	80.2 [64.3, 96.0] (26)	99.2 [72.8, 125.6] (23)	101.1 [86.3, 115.9] (29)	0.074	0.075	0.562
(iii) Scenario Completion	204.5 [176.2, 232.9] (22)	177.1 [151.3, 202.3] (26)	192.8 [165.7, 220.0] (24)	199.6 [175.6, 223.6] (30)	0.472	0.595	0.192
EMT Licensure Only							
(i) First Intervention	76.9 [63.9, 89.9] (15)	44.1 [33.7, 54.5] (18)	59.5 [46.6, 72.4] (10)	43.3 [31.2, 55.3] (15)	<0.001^a	0.121	0.170
(ii) Tourniquet Only	89.9 [72.4, 107.5] (15)	80.5 [58.1, 102.9] (18)	90.1 [58.4, 121.8] (10)	88.9 [69.4, 108.3] (14)	0.580	0.675	0.711
(iii) Scenario Completion	200.7 [165.8, 235.6] (15)	163.9 [135.8, 192.0] (18)	174.9 [137.2, 212.6] (10)	173.1 [149.7, 196.4] (15)	0.147	0.649	0.253
RN Licensure Only							
(i) First Intervention	61.7 [39.2, 84.2] (6)	58.4 [38.2, 78.5] (8)	81.8 [63.3, 100.3] (14)	88.1 [62.5, 113.7] (15)	0.779	0.044^a	0.696
(ii) Tourniquet Only	85.6 [53.5, 117.7] (5)	79.4 [62.0, 96.8] (8)	106.2 [63.5, 148.8] (13)	112.5 [90.5, 134.6] (15)	0.876	0.111	0.719
(iii) Scenario Completion	212.7 [152.5, 272.9] (7)	206.8 [149.0, 264.5] (8)	205.6 [166.0, 245.3] (14)	226.1 [186.7, 265.6] (15)	0.602	0.772	0.570

Notes: ^aBolded text, Two-way ANOVA, *p*<0.05.

Abbreviations: HPS, Hemorrhagic Pumping System; vs, Versus; EMT, Emergency Medical Technician; RN, Registered Nurses.

Likewise, among the EMTs Only group, HPS use significantly improved first intervention times (*p* < 0.001; 95% CI for No HPA vs HPS [13.93, 37.45]), though no significant interaction with licensure years of licensure was found (*p* = 0.170). The fastest performance was among EMTs with ≥5 years of licensure using HPS (mean = 43.3 seconds, 95% CI [31.2, 55.3]). No significant main effects or interactions were observed for tourniquet-only or scenario completion times.

Among registered nurses only there was no significant interaction between years of licensure and HPS use (*p* = 0.696), and HPS alone did not significantly impact performance (*p* = 0.779) either. However, years of licensure did significantly affect the first intervention time (*p* = 0.044; 95% CI for RNs with ≥5 vs <5 [0.78, 49.17]), with a trend toward longer times among more experienced nurses. RNs with <5 years had similar times regardless of HPS (HPS: 58.4 seconds, 95% CI [38.2, 78.5]; vs No HPS: 61.7 seconds, 95% CI [39.2, 84.2]). RNs with ≥5 years took longer (HPS: 88.1 seconds vs No HPS: 81.8 seconds), though these differences were not statistically significant. Further, no significant interactions between years of licensure and HPS use were found for tourniquet-only (*p* = 0.719) or scenario completion outcomes (0.570). Likewise, for both tourniquet-only and scenario completion outcomes, main effects were also not significant for both years of licensure and HPS use.

Discussion

Classical clinical experience with informal teaching is insufficient for developing skilled healthcare professionals, making standardized, structured practice with outcomes-based evaluation essential.¹⁸ Repeated immersive simulation, with feedback, improves learners' knowledge and self-efficacy regardless of method,¹⁹ and higher-fidelity mannequins further enhance immediate post-training performance in knowledge and psychomotor skills.²⁰ Thus, simulation-based

education has become an essential element of medical training, particularly for rare but critical situations¹ such as life-threatening traumatic limb injuries.² It offers a unique and safe environment, a “sandbox”, where healthcare providers can identify and address potential challenges without risk to patients.³

Few studies to date have explored the impact of dynamic bleeding models in trauma simulation. Our study builds on foundational work such as the pilot study by Mills et al (2018).¹⁵ While that study focused primarily on paramedic students and the effects of realistic moulage, our study extended the concept by involving a broader group of emergency and prehospital providers and by directly integrating a dynamic bleeding control system into the simulation. That allowed for not only a comparison of learner experience, but also an assessment of objective clinical performance metrics, such as time to intervention and tourniquet placement.

This study explored the effect of incorporating an active bleeding pump system into trauma simulations and its influence on provider response and possible clinical decision-making.

As shown in [Table 2](#), when considering all participants the HPS implementation significantly reduced time to first intervention, corroborating previous high-fidelity simulation literature.²¹

However, the majority of the existing literature in this realm focuses solely upon discrete participant’ roles, most specifically EMT¹⁵ or RN²¹ healthcare students. As opposed to real-world active law enforcement, fire service and healthcare professionals where each have separate but collaborative roles focusing on scene safety, initial medical stabilization, transport and advanced life support. In [Table 2](#) HPS is shown to reduce time to intervention for both Others and EMTs. In addition, time to tourniquet was also reduced for the Others group. Interestingly however, there was no apparent impact on time with or without HPS with RNs, this was unexpected and contrary to the literature utilizing RN students.²¹

Thus, this RN observation was further explored in [Table 3](#), which examined varying levels of experience (defined by licensure duration). RNs with 5 or more years’ experience demonstrated statistically longer times to first intervention compared to those with less than five years. This finding, although initially unexpected, is likely attributable to the more measured and strategic clinical reasoning of experienced providers and is corroborated in the literature.¹⁶ These individuals may be less reactive to an obvious injury and more inclined to assess for other potential life threats, indicating a higher-level cognitive approach that may ultimately improve overall patient care.²²

To better understand this observation within the RN group, an additional subgroup analysis was conducted to jointly evaluate the effects of years of licensure and the impact of the HPS. Overall, though no significant interaction was observed between the years of licensure and HPS use ([Table 4](#)), participants with <5 years of experience combined with HPS consistently resulted in faster times to the first intervention ([Table 4](#)). Combining EMTs and RNs with less than <5 years licensure, HPS reduced time to first intervention. When further delineated, this was also shown in the EMTs only group. With the RN focused group, in contrast, no significant impact of HPS use was observed. However, what can be discerned is the more experienced RNs took a relatively longer time to complete the task with the HPS than those RNs with less than five years’ experience.

This recurring theme with experience may also be due to historical teaching of the trauma ABCs (airway, breathing, circulation) that guide trauma care in provider courses like Advanced Trauma Life Support (ATLS) and Trauma Nursing Core Course (TNCC). This standard has recently been reassessed with more recent combat casualty data, prioritizing massive hemorrhage control, shifting the classical trauma dogma to CABs (circulation, airway, breathing; exsanguination-first (x-ABC) model).²³ This move has influenced civilian trauma care, progressing from public education initiatives like “Stop the Bleed”,¹⁰ to in-hospital protocols.²⁴ Ultimately leading to a hypothesis for a future study, that the possible juxtaposition where nurses with 5 or more years’ experience intrinsically follow ABCs, and newer nurses with less than 5 years following the x-ABC model, thus reducing time to intervention in exsanguination simulations compared to their more experienced brethren.

Our findings suggest that active bleeding cues significantly increase perceived urgency, leading to earlier intervention when compared to traditional moulage-only simulations. Importantly, this difference in urgency did not translate into faster tourniquet placement, likely due to more complex real-world behaviors, such as donning personal protective equipment (PPE), applying direct pressure, or pausing for broader assessment.

Limitations

Despite its strengths, the study had several limitations:

- (a) **Lack of Dynamic Feedback:** Participants noted frustration due to the absence of dynamic scenario feedback, particularly in the moulage-only group. This decision was intentional to limit confounding variables, but it may have influenced engagement and perceived realism.
- (b) **PPE and Scenario Consistency:** Early participants varied in their use of gloves, which impacted time metrics. This was mitigated partway through the study by standardizing glove use prior to room entry; however, early variability may have influenced outcomes.
- (c) **Volunteer Bias:** All participants were volunteers. The absence of incentives may have led to variable levels of motivation, potentially affecting performance. Some participants may have approached the simulation more casually than they would a real clinical situation.
- (d) **No Post-Simulation Self-Evaluation:** We did not assess participants' self-perceived competence before or after the simulation. Future studies could evaluate the impact of dynamic simulation on learner confidence, retention, and real-world performance over time.
- (e) **Although all analyses met appropriate statistical assumptions, the relatively limited sample size may have reduced the power to detect significant differences. Future studies with larger cohorts to jointly evaluate the effects of years of licensure and the impact of the HPS may clarify whether the observed trends reach statistical significance.**

Participant Feedback

A notable theme emerged in participant feedback, many expressed frustrations with the lack of dynamic, scenario feedback. Participants were accustomed to high-fidelity simulation experiences involving facilitator interaction, changing vital signs, and responsive mannequins. In contrast, this study design intentionally limited variability by providing only a single set of vital signs at the beginning of the scenario and relying solely on static or visual cues. This constraint was necessary to preserve study validity but led to dissatisfaction, especially in the static moulage group, where there was no visual cue to indicate treatment effectiveness.

Interestingly, this frustration was far less common in the active bleeding group, where successful application of a tourniquet resulted in visible cessation of bleeding. This immediate visual feedback reinforced the value of dynamic simulation tools in learner engagement and perceived training effectiveness.

Future Directions

These findings suggest several avenues for future investigation. One possible study could involve crossover design, allowing participants to engage in both simulation arms and self-report, to measure which experience was more valuable for their learning. Additionally, longitudinal follow-up assessing retention and confidence in hemorrhagic control skills (eg, at 3- or 6-month intervals) could help determine whether dynamic realism enhances long-term training outcomes. We hypothesize that high-fidelity simulation will produce a more durable educational impact.

Conclusion

Simulation-based education remains essential for preparing providers to manage high-stakes, low-frequency emergencies. This study demonstrates that dynamic bleeding models enhance clinical urgency and engagement in extremity trauma scenarios. From our first objective, time-based measures showed differences with the use of the HPS. HPS significantly reduced time to first intervention, particularly among EMTs and providers with less than five years of experience, although it did not significantly impact tourniquet application or overall scenario completion times. To the second objective, longer response times among experienced RNs may reflect more deliberate clinical reasoning shaped by traditional trauma paradigms. However, future studies will be needed to examine these nuanced results about this objective. As trauma care shifts toward exsanguination-first approaches, simulation fidelity must evolve accordingly.

High-fidelity tools like dynamic bleeding models can reinforce current trauma protocols, may enhance clinical decision-making, and potentially improve long-term skill retention and patient outcomes.

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Disclosure

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