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Assessing Hemorrhage Control and Tourniquet Skills in School-Aged Children

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Abstract

Objectives: Uncontrolled hemorrhage is the most preventable cause of death following traumatic injury; children may be called to act as bystanders when hemorrhage control is necessary. The earliest age that children can learn hemorrhage control remains undetermined. We aimed to identify whether children aged 8 to 12 years can identify when and how to use a combat application tourniquet (CAT) and can appropriately place and tighten it to achieve hemorrhage control.

Methods: We conducted a prospective study of children aged 8 to 12 years old. A trained facilitator taught hemorrhage control and CAT placement on manikins in small group sessions. After each session, we assessed the comprehension and application skills of each participant using a standardized 4-question tool. If at least 60% of children within each age group correctly performed both comprehension (cognitive) and skills (psychomotor) assessments, the group was considered successful. We compared success rates between age groups and analyzed the association between performance and participant age, sex, and body mass index (BMI).

abstract continues

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Abstract (continued)

Results: Of 326 eligible children, 322 completed the training and assessment (99%). Overall, 70% (225/322) of participants completed all 4 assessment questions correctly, 88% (284/322) of participants were able to answer both comprehension (cognitive) questions correctly, and 76% (246/322) of participants were able to accurately demonstrate both CAT placement skills (psychomotor) correctly. All age groups exceeded the 60% success rate in both assessments. Age, sex, and BMI were not significantly associated with assessment performance.

Conclusion: Children as young as 8 years old can successfully learn hemorrhage control techniques and combat application tourniquet application, suggesting this training can begin as early as third grade.

Keywords: *tourniquet, combat application tourniquet, bystander, prehospital, children*

1 INTRODUCTION

1.1 Background

Uncontrolled hemorrhage from traumatic injury is a leading cause of death in the United States.[1,2] A majority of bystanders are willing to attempt hemorrhage control to help a family member, an unknown person involved in a car crash, or victims of a mass shooting scenario when it is safe to do so.[3] In 2015, the American College of Surgeons Committee on Trauma launched the "Stop the Bleed" campaign to teach bleeding control to laypersons, including tourniquet placement.[4] Given the rise in mass shooting events, including school shootings, and the recent finding that firearm deaths surpassed motor vehicle collisions as the leading cause of death among children in 2020, there is debate nationally on whether to teach hemorrhage control techniques to children and what age to start.[5–9]

1.2 Importance

Uncontrolled hemorrhage is a leading cause of traumatic deaths among civilians, and nearly 50% of those deaths are deemed preventable.[10–15] Previous studies have suggested that children in grades 5 to 12, beginning at 10 years old, can learn hemorrhage control techniques and apply these skills in simulation.[16–18] Currently, the earliest age at which children can learn and apply hemorrhage control techniques, including successful tourniquet placement, is unknown.

1.3 Goals of This Investigation

We aimed to determine whether children as young as 8 years can identify when and how to use a tourniquet (cognitive domain) and demonstrate the motor strength and coordination to place and tighten a tourniquet adequately (psychomotor domain) to achieve hemorrhage control.[19] We hypothesized that older children would be more successful than younger children at (1) understanding the indications for tourniquet placement, (2) identifying the correct placement for a tourniquet on a limb, and (3) tightening a tourniquet adequately for hemorrhage control.

2 METHODS

2.1 Design and Setting

We conducted a prospective cohort study in a local suburban public elementary and middle school system (grades 3-8) in Cincinnati, Ohio, with students from both urban and suburban areas. Race and ethnicity reported by the schools included 80% White, 7.9% Black, 7.2% Multiracial, 3.1% Hispanic/Latino, and 1.8% Asian; 36% of students received free or reduced school lunch. The Cincinnati Children's Hospital Medical Center institutional review board (IRB) (2022-0826) reviewed and approved the study in November 2022.

2.2 Selection of Subjects

Before IRB submission, the study team met with a community advisory research board comprising local parents and guardians to present the research concept. Feedback was obtained from this board and incorporated into the study design. We also obtained support and approval from the school principals and the district nurse.

Recruitment began in January 2023. The study was completed in May 2023. Parents and guardians were notified in advance of their child's eligibility for the study via school email with a study information sheet outlining the study purpose, procedures, data collection, and potential benefits and risks. Parents could opt to not have their children participate. The study took place during the student's physical education class. School administration approved the training for all students as part of their education, but only students who met inclusion criteria (ages 8-12 years old and present during training sessions) and did not opt out were enrolled in the study (Fig). Any children who met the exclusion criteria (opting out before the training session or being identified as having a developmental disability by their teacher) were

The Bottom Line

Uncontrolled hemorrhage is a preventable cause of death. Given the rise in gun violence nationally, bystander training is critical as part of a larger harm reduction strategy. The earliest age at which children can learn hemorrhage control techniques, including tourniquet placement, is unknown. We evaluated whether children aged 8 to 12 years can understand key concepts of hemorrhage control training and physically place and tighten a combat application tourniquet. Children as young as 8 years old can successfully learn hemorrhage control techniques and tourniquet application, suggesting training can begin as early as third grade.

invited to participate in the training session but were not enrolled in the study.

2.3 Interventions

The overall intervention consisted of a large group didactic talk and tourniquet demonstration, small group hands-on practice, and individual assessment of each child. The study team created a 10-minute educational presentation to train children in (1) the principles of recognition of severe hemorrhage requiring control (cognitive domain) and (2) the procedure of tourniquet placement (psychomotor domain) and collaborated with a child life specialist to ensure that all content was age-appropriate. An assessment form was developed to test cognitive and psychomotor skills. The primary investigator (CC) delivered the didactic content at each session. CC trained 15 facilitators (physicians and nurses) to instruct the small group sessions and perform individual assessments.

We held 16 1-hour didactic training sessions over 5 separate days from January to May 2023. Each session was held by school grade (eg, third, fourth, and fifth grades). Each session began with a large group (30-60 students) didactic educational presentation and hands-on demonstration of placement of a combat application tourniquet (CAT; C.A.T. Resources, LLC,) on a manikin arm. The CAT was chosen because it is commonly available and approved by the Committee on Tactical Combat Casualty Care for hemorrhage control. In a situation where a child would have to apply a tourniquet to another child, a CAT has been demonstrated in observational studies to occlude arterial flow in school-aged children.[5,6,20] Trained facilitators then instructed groups of 4 to 6 students. Facilitators reviewed hemorrhage control concepts and provided hands-on instruction on CAT placement on the arm or leg of a medical training manikin. We chose full-sized Laerdal 3G adult manikin models (Laerdal Corp) given their realistic weight, articulation, and palpable anatomical landmarks. Moulage to simulate wounds was applied over the manikins' arms and legs.[4,21]

Facilitators reviewed applying pressure to bleeding wounds, indications for packing wounds, and indications for tourniquet usage. Facilitators demonstrated correct CAT placement (at least 2 inches above the wound, using the width of their hand to estimate distance, and avoiding joints) and tightening (completion of all steps including tightening the

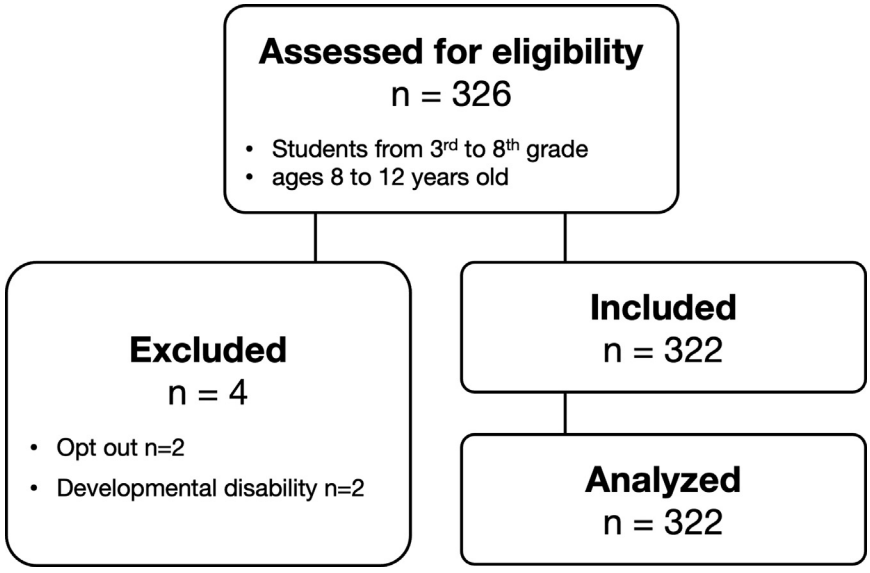

FIGURE. Participant eligibility.

band and securing it onto the VELCRO, twisting the windlass rod, and securing it onto the clip). Students were then supervised as they practiced on a manikin arm and leg at least once. After training, the students were assessed individually. At least one turn of the windlass was required. To determine whether the CAT was sufficiently tight, study investigators attempted to slide a thin instrument (tongue depressor) between the CAT and the limb, as previously described.[22] Tightness was deemed sufficient if the thin instrument could not be advanced.

In addition to hemorrhage control training, the full session also included a cardiopulmonary resuscitation (CPR) station for hands-only CPR teaching and another build-a-first-aid kit station to help students learn other valuable skills in between their hemorrhage control training and testing. A local firefighter was also present at every session to teach students about calling for help and fire safety.

2.4 Measures and Outcomes

After training, facilitators assessed each child individually, which included verbally asking each child 2 cognitive questions ('What is the first step to control bleeding in someone with a bleeding wound' (pressure) and 'If pressure cannot control the bleeding in an arm/leg, what should be used next' (tourniquet)) and then evaluating 2 psychomotor skills (placing the tourniquet in the correct location at least 2 inches above the wound and not on the joint and being able to tighten the tourniquet adequately (at least 1 windlass turn, unable to slide the tongue depressor beneath after the windlass was secured). Assessments were done privately. Students were allowed to attempt CAT placement twice within 120 seconds without prompting or help from the facilitators. Facilitators documented the assessment data for each student on paper forms; a research coordinator entered the data into the study site Research Electronic Data Capture (REDCap) database on the same day.[23,24] We recorded and managed all study data using REDCap. The primary investigator (CC) reviewed every entry for accuracy. All paper forms were discarded in confidential waste bins.

The primary outcome was the proportion of students within each age group who correctly performed all 4 assessments. A priori, we defined success as at least 60% of individuals in each age group correctly performing all 4 assessments (cognitive and psychomotor domains) to consider an age group capable of understanding and applying bleeding control techniques. For the secondary analysis, we separately evaluated the success rates by age group within the cognitive and psychomotor domains. We further evaluated whether overall success was impacted by age, sex, and/or body mass index (BMI).

2.5 Data Analysis

For our primary analysis, we used Fisher's exact test to evaluate for differences in proportions between age groups. In our secondary analysis, we used Fisher's exact tests to evaluate for differences in proportion between age groups within the cognitive and psychomotor domains, respectively. We also used univariate and multivariable logistic regressions to evaluate the associations between the primary outcome and age groups by adjusting for both sex and BMI percentile. All tests utilized a significance level of P-value $< .05$. We report descriptive statistics as means with standard deviations (±SDs), medians with interquartile ranges, and frequencies with proportions. Statistical analyses were performed using SAS version 9.4.[25]

To detect differences in age groups based on our primary outcome (correctly performing all 4 assessment questions), a sample size calculation was estimated using Fisher's exact test to determine the outcome by age group. There is currently no definitive data on younger students' ability to correctly place a tourniquet; 80% to 90% of high school students achieve mastery in tourniquet placement after training.[17] We assumed our type I error rate at 5% and estimated that we needed at least 28 participants in each age group to have 80% power to detect a 10% difference by age group.

3 RESULTS

We assessed 326 children for eligibility. Of these, 2 children opted out before the study, and 2 children received the training but were not included in the study given that they were identified by their teachers as having a developmental disability (Fig). To increase our overall sample size for the 8-year-old age group, school nurses and trainers offered second-grade 8-year-old children an after-school session using the same didactic structure during a scout meeting; an additional 7 children were recruited. A total of 322 children were included in the study; demographics are listed in Table 1.

Of 326 eligible children, 322 completed the training and assessment (99%). All age groups 8 to 12 years met our preestablished acceptable success rate of 60% of the age cohort achieving success in both cognitive and psychomotor assessment. There were no statistically significant differences in the primary outcome between age groups. Overall, 70% of participants successfully completed all 4 assessment questions correctly; 88% (284/322) of participants were able to answer both cognitive questions correctly; and 76% (246/322) of participants were able to accurately demonstrate both motor skills (Table 2).

For the cognitive domain, 90% (291/322) of children were able to identify applying pressure as the first step to control bleeding, and 95% (305/322) identified that tourniquet placement is indicated if bleeding is not controlled by pressure. For the psychomotor domain, 91% (294/322) of children were able to place the CAT in the correct position in a simulated extremity, and 81% (262/322) of children were able to tighten the CAT correctly (Table 2). There were 2 areas for which there was a significant difference in responses or actions by age: (1) response to the question: "If pressure cannot control the bleeding in an arm or a leg, what should be used next?" and (2) the ability to adequately tighten the tourniquet ($P < .01$). When we analyzed by domain, there was no statistical difference by age for the cognitive or the psychomotor

TABLE 1. Participant demographic characteristics.

Characteristic	8-y-old (%)	9-y-old (%)	10-y-old (%)	11-y-old (%)	12-y-old (%)	Total (%)
Males	16 (8.7)	36 (19.7)	37 (20.2)	51 (27.9)	43 (23.5)	183 (57)
Male BMI (in kg/m^2), percentile, Median (Q1, Q3)	68.7 (16.8, 88.1)	67.3 (36.2, 94.3)	83.5 (47.3, 93.7)	70.0 (38.4, 93.3)	63.2 (33.7, 96.4)	
Females	24 (17.3)	27 (19.4)	39 (28.1)	37 (26.6)	12 (8.6)	139 (43)
Male BMI (in kg/m^2), percentile, Median (Q1, Q3)	44.0 (22.1, 82.4)	51.0 (25.7, 79.0)	60.4 (32.4, 96.1)	65.4 (40.8, 82.5)	69.2 (45.8, 83.5)	
All participants	40 (12.4)	63 (19.6)	76 (23.6)	88 (27.3)	55 (17.1)	322 (100)

BMI, body mass index; Q, quartile.

domain (Table 2). In a logistic regression model, increasing age, sex, or BMI was not associated with increased odds of overall success. (Table 3).

Facilitators noted that reasons for failure in the cognitive portion of the assessment included children being overly excited to use a CAT first on the simulated wound rather than applying pressure first. Incorrect CAT application was primarily due to a lack of tension, difficulty tightening the VELCRO strap adequately and wrapping it around the limb, or not enough turns on the windlass. These challenges are consistent with the ones that adult learners face when learning how to use a CAT.[26,27]

4 LIMITATIONS

There are several limitations in this study. While we attempted to simulate real patients by using full-size adult manikins with limbs that simulated the weight of an adult arm and leg, we were unable to simulate cessation of bleeding or loss of pulses as markers of adequate CAT placement in our low-fidelity manikins. Further, our study was conducted in a controlled and familiar environment for children, so success rates in a research study may not predict performance in real-life scenarios, and a CAT may not be readily available. We only taught and tested students on using a CAT; other commercial tourniquets are available, and this may limit generalizability. Our sample size was calculated based on what is known of high school students' ability to master placing a tourniquet for hemorrhage control; there is no published data on the ability of younger children to place tourniquets, which may have affected accurate sample size calculation. However, we enrolled significantly above our sample size in all age groups, which may mitigate this limitation. This study was also limited to children in the specified age groups that we selected, and therefore conclusions about performance in younger children

TABLE 2. The summary success rate of students by age on individual questions and both cognitive and psychomotor domains.

Domain and question	Overall success n (%)	8-y-old n (%)	9-y-old n (%)	10-y-old n (%)	11-y-old n (%)	12-y-old n (%)	*P*-value Fisher's exact tests
Cognitive domain 1 What is the first step to control bleeding in someone with a bleeding wound? Answer: pressure	291 (90)	35 (88)	55 (89)	72 (95)	81 (92)	47 (85)	0.37
Cognitive domain 2 If pressure cannot control the bleeding in an arm or a leg, what should be used next? Answer: tourniquet	305 (95)	36 (90)	57 (90)	73 (96)	88 (100)	51 (93)	0.01
The success rate of students by age (y) across both cognitive domains	284 (88)	34 (85)	54 (86)	69 (91)	81 (92)	46 (84)	0.43
Psychomotor domain 1 Placed tourniquet in the correct location	294 (91)	35 (88)	61 (97)	68 (89)	83 (94)	47 (85)	0.12
Psychomotor domain 2 Able to tighten tourniquet adequately	262 (81)	30 (75)	49 (78)	55 (72)	80 (91)	48 (87)	0.01
The success rate of students by age in both psychomotor domains	246 (76)	27 (68)	47 (75)	53 (70)	76 (86)	43 (78)	0.06
The summary success rate of students by age across all domains	225 (70)	25 (63)	40 (63)	51 (67)	70 (80)	39 (71)	0.15

TABLE 3. Overall univariate and multivariable analysis.

Parameters	Univariate analysis OR (95% CI)	*P*-value for all univariate analyses	Multivariable OR OR (95% CI)	*P*-value for all multivariable analyses
9 vs 8 y	1.04 (0.46, 2.37)	.1758	1.19 (0.53, 2.68)	.1623
10 vs 8 y	1.22 (0.55, 2.72)		2.39 (1.04, 5.51)	
11 vs 8 y	2.33 (1.02, 5.32)		1.60 (0.65, 3.90)	
12 vs 8 y	1.46 (0.62, 3.47)		1.09 (0.47, 2.49)	

OR, odds ratio.

cannot be made. Training for different age groups was conducted at different times during the school day based on the school schedule (beginning versus end of the school day), which may have impacted child engagement and learning. We did not assess for retention of skills; further research is needed to assess for retention and to establish how often training should occur to maintain skills. Finally, our study did not address whether this training emotionally impacts children. We observed during sessions that children were very excited to learn the basics of hemorrhage control and how to use a tourniquet. We purposefully emphasized during our training that injuries that lead to bleeding can happen anywhere, such as at home or school, and did not specifically address firearm violence. Although our experience was very positive and children welcomed the learning, further research is needed to assess the emotional readiness of children to help someone who is injured.

5 DISCUSSION

In this prospective study, we found that children as young as 8 years old can learn bleeding control techniques and apply a CAT correctly. While our results suggest that older children have an increased ability to tighten a CAT adequately, all children aged 8 to 12 years old met our minimum acceptable success rate. No prior study has demonstrated success among younger school-aged children in applying a CAT for hemorrhage control.

Similar to how bystander CPR increases survival in out-of-hospital cardiac arrest,[28] bystander hemorrhage control has been identified as a key driver in empowering the general public to stop life-threatening bleeding before emergency medical services arrival.[3] A prospective study done on trauma patients found that 81% of bleeding individuals had a bystander attempt hemorrhage control in the field; bystanders with prior first-aid experience gave better care to those injured.[29] Our results add to the growing body of research attempting to determine when hemorrhage control training should be introduced to children. A study looking at children as young as 7 years showed that they can successfully apply pressure to manage severe bleeding after receiving at least 3 adequate classroom first-aid sessions.[30] Another study looking at children aged 11 to 15 years old found that 97% of the children were able to apply a CAT, but 15% of them required coaching.[16] We aimed in our study to not prompt or coach children through CAT placement during the assessment portion. To our knowledge, this is the first study evaluating the ability of children as young as 8 years in the use of a CAT and the first study investigating an anthropometric value such as BMI as a potential marker of increased success in CAT application. In our study, we did not find any correlation between BMI and increased success of CAT tourniquet application. However, our study may not have been powered to detect a difference in this secondary outcome.

Studies have shown that children as young as 6 years can learn the basics of first aid, including CPR.[31] The American Heart Association does not mandate a minimum age to begin learning CPR, but they do mention that children as young as 9 years can learn and retain CPR skills.[32] However, there have been studies that report that age and anthropometry affect the quality of CPR and that 13 years is the minimum age to be able to achieve a minimum CPR quality similar to the ones an adult can achieve.[33]

Children are seen and valued as "multipliers," particularly in CPR training, meaning that they can share knowledge gained with adults within their social circle or family.[34–38] Children may also not be called on to perform the skill until they are older; therefore, it is important to determine how early we can start teaching hemorrhage control techniques and at what age children can understand tourniquet concepts and be able to use one appropriately. We established the minimum acceptable success rate at 60%, surmising that if concepts can be taught successfully to more than half of the students in a classroom, then teaching hemorrhage control concepts as early as third grade based on our study may be justified, and classes can be repeatedly taught yearly through the next school years to encourage retention of skills and allow for training to build on itself.

Bystander hemorrhage control is a key link in the chain of survival. Similar to how CPR is taught in schools and is a high school graduation requirement in the majority of US states,[39] our study suggests that hemorrhage control training can begin as early as third grade. Our study found that children as young as 8 years can cognitively understand the principles of bleeding control and are physically able to apply a CAT correctly. Our training may serve as a model for future educational programs. Further research is needed to address emotional readiness as well as to assess knowledge retention.

In summary, uncontrolled hemorrhage is one of the leading causes of death in traumatic injuries, and it is preventable. Early hemorrhage control has the potential to save

lives, and bystander action is of utmost importance. Our study demonstrated that children as young as 8 years old can learn hemorrhage control techniques and apply a CAT correctly. These findings suggest that hemorrhage control training can begin as early as third grade.

AUTHOR CONTRIBUTIONS

CDC, NB, MGH, SS, and ME conceived and designed the study. CDC and ME supervised the conduct of the study and data collection. CDC, ME, BS, MW, and RM recruited participants and conducted the study at participating centers. CDC and ME managed participant data, including quality control. NH and YZ provided statistical advice on study design and analyzed the data. CDC drafted the manuscript, and all authors contributed substantially to its revision. CDC and ME take responsibility for the paper as a whole.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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