

Adult Tourniquet for Use in School-Age Emergencies

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abstract

BACKGROUND: Gunshot injuries are a leading cause of morbidity and mortality in the pediatric population. The Pediatric Trauma Society supports the use of tourniquets for exsanguinating hemorrhage in severe extremity trauma. The Combat Application Tourniquet (CAT) used with success in adults has not been prospectively tested in children. Our objective with this study was to determine if the CAT is successful in arresting extremity arterial blood flow in school-aged children.

METHODS: Sixty school-aged volunteers (ages 6–16 years) recruited by age cohort had the CAT applied to an upper arm and thigh while peripheral pulse was monitored by Doppler. The number of windlass turns (maximum allowed: 3 [1080°]) required to arrest arterial pulse was recorded. Success was analyzed by BMI percentile for age and extremity circumference.

RESULTS: The CAT was successful in occluding arterial blood flow as detected by Doppler pulse in all 60 (100%) of the upper extremities tested. In the lower extremity, 56 (93%) had successful occlusion. The 3-turn maximum allowed by the protocol was not adequate in some obese, older subjects (BMI >30). In both the upper and lower extremity, the number of turns required to occlude blood flow gradually increased with an increase in arm and thigh circumference.

CONCLUSIONS: Prospective testing of a cohort of school-aged children 6 to 16 years revealed the CAT tourniquet to be suitable for use in both the upper and lower extremity.



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Dr Harcke conceptualized and designed the study, conducted testing, drafted the initial manuscript, and reviewed and revised the manuscript; Mr Lawrence conducted testing, performed data analysis, and reviewed and revised the manuscript; Ms Gripp assisted in study design, conducted testing, and reviewed and revised the manuscript; Mrs Kecskemethy assisted in study design, performed data analysis, and reviewed and revised the manuscript; Drs Kruse and Murphy assisted in study design, conducted testing, and critically reviewed the manuscript for important intellectual content; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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WHAT'S KNOWN ON THIS SUBJECT: The US military experience with control of bleeding in severe extremity trauma led to the acceptance of the Combat Application Tourniquet as its standard-issue tourniquet.

WHAT THIS STUDY ADDS: This study reveals that the Combat Application Tourniquet is also suitable for use in school-aged children.

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Gunshot injuries are a leading cause of morbidity and mortality in the United States' pediatric population.¹ Of the 7 most common traumatic injuries in children, patients with gunshot wounds are the most likely to die in the field or in the hospital, require major surgery, and require a blood transfusion.¹ With increased attention to the occurrence of school shootings, emergency response plans in the United States are being reviewed and updated. Trauma response packages are being considered for use in schools. First responders are being instructed on casualty care with attention to hemorrhage control. This activity will undoubtedly focus on equipment to be used to arrest bleeding in pediatric cases.

For gunshot and blast wounds, the US military has tested and fielded the Combat Application Tourniquet^{2,3} (CAT; C.A.T. Resources, LLC, Rock Hill, SC) (Fig 1). This has proven effective in reducing mortality due to exsanguination in adults.⁴ Stop the Bleed is an available civilian emergency training program designed to teach bleeding control.⁵ The CAT is used in this program. Stop the Bleed is currently being used to teach school staff, faculty, and students how to use tourniquets and is stocking schools with emergency bleeding response kits that include the CAT.⁶

The Pediatric Trauma Society supports the use of tourniquets in the prehospital setting and during the resuscitation of children with exsanguinating hemorrhage in severe extremity trauma.⁷ To date, no prospective study has been performed to evaluate the suitability of the CAT for use in school-aged children. Authors of 1 retrospective report using a trauma registry examined tourniquet use and outcomes in children in military war zones. The authors suggested that the use of tourniquets, including the CAT, was as effective in children as in



FIGURE 1

The CAT as configured for carrying (wrapping for shipment removed). Two colors are produced for the civilian versions: orange for clinical application and blue for training. The military version is black.

adults.⁸ Our objective of this study is to determine if the adult-designed CAT is effective in occluding blood flow to extremities in school-aged children (aged 6–16 years). Our hypothesis is that the CAT will successfully arrest arterial blood flow at arm and leg circumferences found in schoolchildren when applied as prescribed for adults.

METHODS

The study protocol was approved by the hospital institutional review board. Sixty volunteers 6 to 16 years of age were recruited from an orthopedic clinic providing fracture care. Subjects were verbal and had no

anatomic or vascular deformity of the extremity. Those 7 years and older gave written assent in addition to the consent of a parent or guardian. Many participants were siblings of the patients receiving care. Both boys and girls were stratified by age into 5 groups of 12 subjects (6–7, 8–9, 10–11, 12–13, and 14–16 years). Height, weight, and limb circumference were recorded. Each subject was fitted with a CAT GEN 7 tourniquet on 1 arm (of their choice) at the midbicep level (Fig 2A) and 1 leg (of their choice) at midhigh level (Fig 2B). In the lower extremity, midhigh placement avoided the subject's genital area. In the case in which light clothing was worn, the tourniquet was placed over the clothing. The tourniquet was fitted snugly around the extremity in accordance with manufacturer recommendations. Stepwise tightening of the windlass in half-turn (180°) increments was made while pulse was monitored by vascular Doppler ultrasound (Life Doppler, Summit Doppler, Gordon, CO). Upper-extremity radial pulse and lower extremity posterior tibial pulse were used in all subjects. The turn number to the nearest half-turn at which audible pulse became absent was recorded. Protocol design allowed

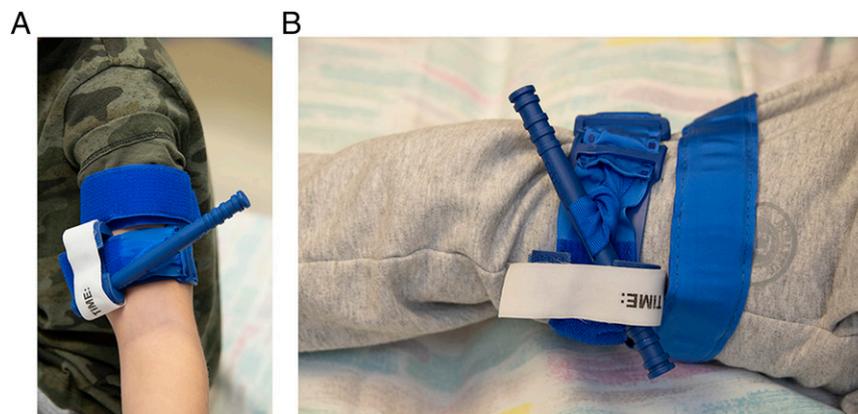


FIGURE 2

A, The CAT applied to the upper extremity of a 6-year-old boy. The excess length of the band has been loosely wrapped around the arm above the tightened element. B, The CAT applied to the lower extremity of a 6-year-old boy. Although preference is for application on the skin, the tourniquet can be applied over clothing. The excess length of the band has been loosely wrapped around the leg above the tightened element.

TABLE 1 Age Cohort Demographic Data

Age Range, y	Boy, n	Girl, n	Arm Circumference, cm	No. Turns	Thigh Circumference, cm	No. Turns
6–7	7	5	19.0 (16.0–26.0)	1.0 (0.5–1.5)	35.25 (26.0–48.5)	1.5 (1.5–3.0)
8–9	9	3	21.5 (17.5–24.0)	1.0 (1.0–1.5)	38.0 (32.5–45.5)	1.5 (1.5–2.0)
10–11	7	5	22.0 (17.5–30.0)	1.0 (1.0–1.5)	39.5 (32.0–54.0)	1.5 (1.5–2.5)
12–13	8	4	25.0 (19.5–35.5)	1.25 (1.0–2.0)	47.0 (37.5–55.5)	2.5 (1.0–2.5)
14–16	5	7	29.75 (25.0–37.0)	1.5 (1.0–2.0)	50.5 ^a (47.5–54.0)	2.25 ^a (1.5–2.5)
Total	36	24	22.25 (16.0–37.0)	1.0 (0.5–2.0)	40.25 ^b (26.0–55.5)	1.5 ^b (1.0–3.0)

Group median circumference (range) and median turns (range).

^a Only subjects with successful occlusion of blood flow were included ($n = 8$).

^b Only subjects with successful occlusion of blood flow were included ($n = 56$).

TABLE 2 Subject Classification by BMI-for-Age and Sex Percentile (BMI)

BMI Classification (Percentile)	n	Arm Circumference, cm	No. Turns	Thigh Circumference, cm	No. Turns
Underweight (<5)	2	17.25 (16.0–18.5)	1.0 (0.5–1.5)	30.5 (26.0–35.0)	1.75 (1.5–2.0)
Healthy (5–<85)	38	21.0 (17.5–30.0)	1.0 (0.5–1.5)	39.25 (32.0–54.0)	1.5 (1.0–2.5)
Overweight (85–<95)	5	25.0 (19.0–32.0)	1.0 (0.5–2.0)	39.5 (31.5–54.5)	1.5 (1.5–2.5)
Obese (≥ 95)	15	29.5 (21.5–37.0)	1.5 (1.0–2.0)	46.5 ^a (39.0–55.5)	2.5 ^a (1.5–3.0)

Group median circumference (range) and group median turns (range).

^a Only subjects with successful occlusion of blood flow were included ($n = 11$).

a subject or parent or guardian to stop the study by verbal request at any time, and a maximum of 3 windlass turns (1080°) was allowed. The limitation to 3 turns was instituted to avoid subject pain. Experience with the CAT in protocol development established likely adequacy of 3 turns for occlusion and a tolerable level of discomfort.

Our power calculation, based on a 90% confidence level and 10% margin of error, yielded a sample size of 60. This was based on a population size of 520 cast room visits per month by children ages 6 to 16 years. The limb circumferences and number of windlass turns were classified by median values. Participants' BMIs were classified by percentile for age and sex.⁹

RESULTS

Demographics

Recruiting and grouping by age cohorts resulted in a representative size distribution of arm and leg circumferences reflecting a range of normal development, irrespective of sex (Table 1). Our subjects included 36 boys and 24 girls. Participants'

BMIs were distributed through all categories including underweight (less than fifth percentile) (Table 2). As would be expected, a considerable number of children were in the overweight and obese range. Our study sample is reflective of school populations in the United States.

Upper Extremity

The CAT was successful in occluding arterial blood flow as detected by Doppler pulse in all 60 of the upper extremities tested. No subject requested the procedure be stopped. Upper-extremity circumference (Fig 3) ranged from 16 to 37 cm with median values increasing as age and

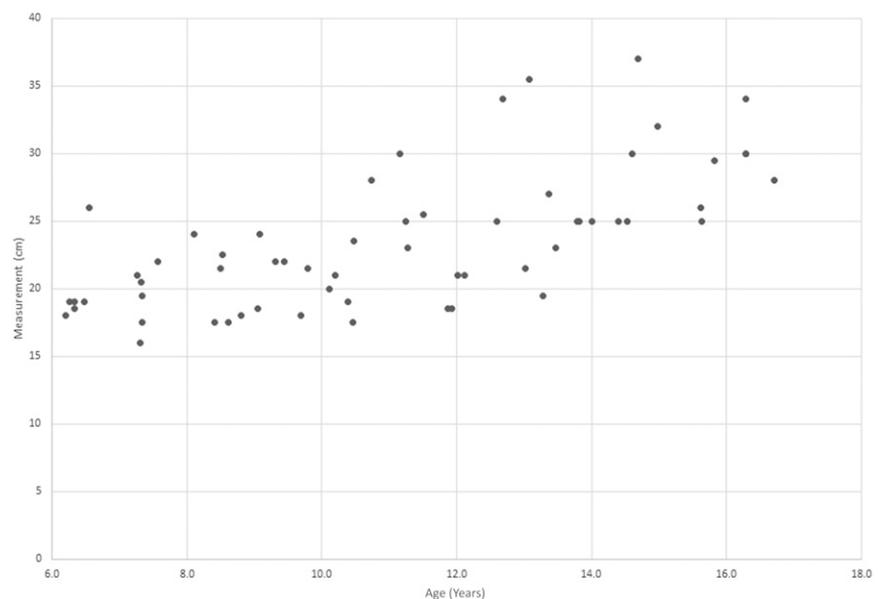


FIGURE 3 Middle upper-arm circumference by age ($n = 60$).

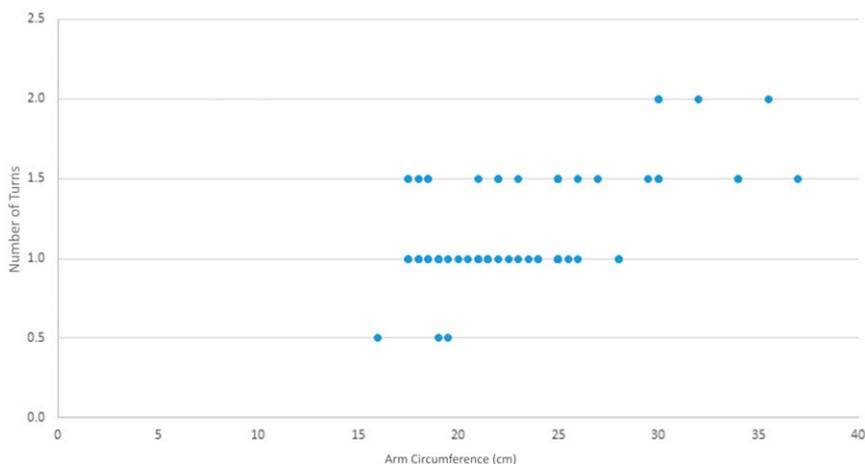


FIGURE 4
CAT windlass turns to occlusion by arm circumference ($n = 60$).

BMI increased. The number of windlass turns ranged from a half-turn (180°) in an underweight child to a maximum of 2 turns (720°) in the older, overweight, and obese subjects (Tables 1 and 2). As we expected, the number of turns required to occlude blood flow gradually increased with an increase in arm circumference (Fig 4).

Lower Extremity

The CAT was successful in occluding arterial blood flow as detected by

Doppler pulse in 56 of 60 lower extremities tested. Lower extremity circumference ranged from 26 to 55.5 cm (Fig 5) with median values increasing as age and BMI increased (Tables 1 and 2). In 1 case, the subject stopped the test because of pain after 2.5 turns (900°) of the windlass. Three subjects completed the maximum 3 windlass turns (1080°) allowed by the protocol, and Doppler pulse was still audible. For the 56 successful occlusions, the number of windlass turns ranged

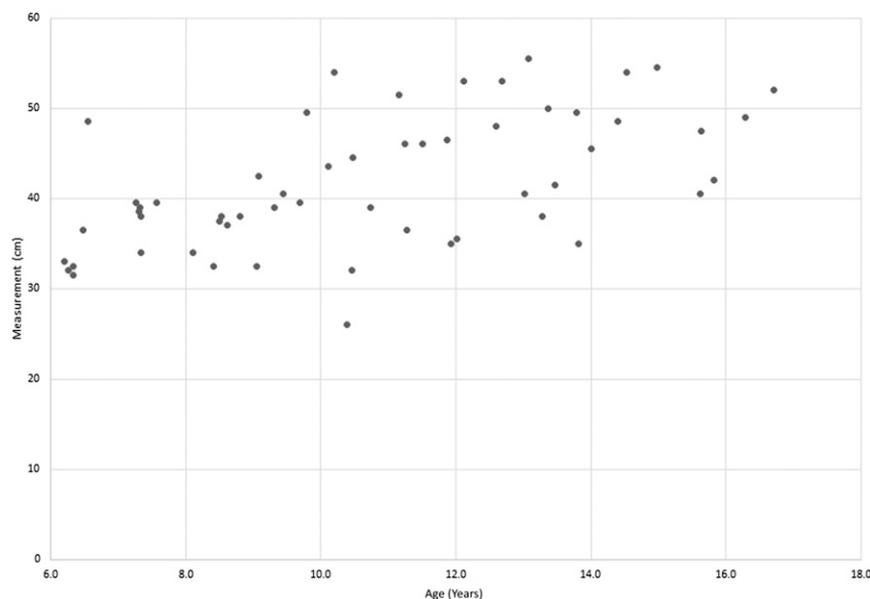


FIGURE 5
Midhigh circumference by age. Only subjects with successful occlusion of blood flow were included ($n = 56$).

from 1 (360°) in an underweight child to our protocol maximum of 3 turns. The 3 subjects whose pulse remained present after 3 turns had BMIs of 35, 38, and 35 and thigh circumferences of 60, 58, and 61 cm, respectively. All were in the oldest age group (14–16 years). The subject who stopped at 2.5 turns because of pain also had a high BMI (33) and large thigh circumference (54 cm). Following the same pattern as described in the upper extremity, the number of turns required to occlude blood flow gradually increased with an increase in thigh circumference (Fig 6).

DISCUSSION

This study of tourniquet use in children would seem to have its greatest impact on prehospital care. It has relevance to all pediatricians, however, because they serve as advisors or participants in the organizations that plan and provide prehospital care. Authors of the recent policy statement of the American Academy of Pediatrics, “Pediatric Readiness in the Emergency Department,”¹⁰ call on those involved in emergency care of children to collaborate with out-of-hospital community and/or regional emergency medical services. In this capacity, pediatricians need to be familiar with tourniquets and their use in children. They can ensure that the development of guidelines for training and application are appropriate and medically correct for children of all ages.

The success of the CAT in adults,^{4,11} the adaptability of the device in children suggested by the military,^{8,12} and a case report¹³ led us to hypothesize that the device would be suitable for schoolchildren. This was confirmed by a 100% pulse cessation success rate in applications in the upper extremity and a 93% success rate in the lower extremity. The failures in the lower extremity do not

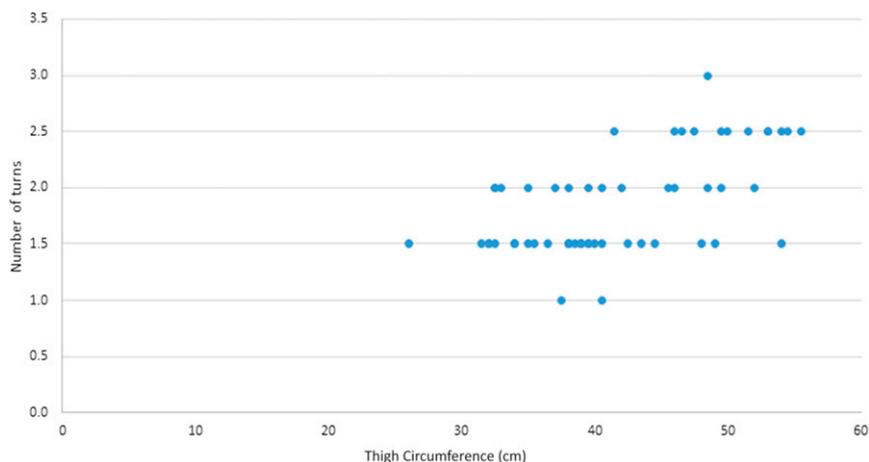


FIGURE 6 CAT windlass turns to occlusion by thigh circumference. Only subjects with successful occlusion of blood flow were included ($n = 56$).

reveal that the tourniquet would not be effective in a real-life application but instead reflect the limitation of 3 windlass turns specified in our study design. The 4 subjects who did not show occlusion were all adult-sized, and it is expected that performing more than 3 turns as necessary to control hemorrhage would result in occlusion.¹¹ In a true emergency, windlass turns are taken beyond 3, and no consideration of pain would be made. The criterion for stopping tourniquet tightening is based on the observation of bleeding cessation. It should also be noted that adult protocol recognizes that when 1 tourniquet does not stop hemorrhage, a second is to be applied above the first.¹⁴

Our concern with the adult tourniquet was mainly with younger ages at which extremity circumference, particularly of the upper arm, could be less than that of

a small adult female. The reason we achieved 100% success is attributed to careful application of the tourniquet in accordance with the manufacturer's guidelines. When the device is first placed, it should be tight enough that fingers cannot be inserted between the band and the skin. For arms and legs with small circumferences, flexing the base plate into a concave configuration at the time the strap is threaded through the buckle slot facilitated achieving a snug position. We think this technique explains why relatively few turns were required to eliminate the audible pulse. Placement over loose, lightweight clothing appeared to have no negative consequences when the band was placed snugly. In clinical application, it is preferable to place directly on the skin when possible, but placement over clothing can also be effective.

The correlation of the number of windlass turns and extremity circumference is noted in both upper and lower extremities. In the arm, most occlusions required 1 to 1.5 turns (360°–540°) (Fig 4). In the thigh, most occlusions required 1.5 to 2.5 turns (540°–900°) (Fig 6). These data can serve as a guideline for those training for pediatric emergencies. However, in any live subject training, we recommend careful monitoring of peripheral pulse by palpation or Doppler and listening to the subject's reporting of pain. In training, occlusion of flow should be followed by immediate release. In a training environment, learning can be focused on proper CAT application with limited windlass turns. It may not be necessary to occlude arterial pulse in practice. Those applying a tourniquet should be taught that the observation of bleeding is the determinant of windlass turns.

CONCLUSIONS

Prospective testing of a cohort of school-aged children 6 to 16 years of age revealed the CAT tourniquet to be suitable for use in both the upper and lower extremity. Those developing protocols for pediatric emergencies can be confident that the CAT is suitable for hemorrhage control in the school-aged population.

ABBREVIATION

CAT: Combat Application Tourniquet

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