American Red Cross

Scientific Advisory Council

ARC SAC SCIENTIFIC REVIEW
Pediatric Tourniquet Use

Questions to be addressed:

In the pediatric population is one tourniquet type compared with another tourniquet type favored for lower limit of age, success rate, outcome, ease of use, or adverse effects?

Introduction/Overview:

While tourniquets have become standard therapy for life threatening bleeding in adults, little data is available to guide the use of tourniquets in pediatric patients. Although the principles of bleeding control remain the same in both adult and pediatric patients, body size may limit the use of tourniquets in smaller limb circumferences. For instance, some tourniquets employ a rigid mechanical advantage system (e.g. windlass or ratchet) that precludes the ability to fit circumferences that are smaller than that mechanism. As tourniquets rely on the ability tighten enough to occlude distal blood flow, these circumference limitations may prevent successful use of certain tourniquets on the smaller limbs of pediatric patients. This question evaluates the pediatric trauma literature to determine if tourniquets can be successfully applied, and if there are lower age limits or tourniquet mechanisms recommended for pediatric casualties.

Search Strategy and Literature Search Performed

Key Words Used

2022

Search Complete: Tue Mar 15 22:06:45 2022
Search: ((("Tourniquets"[Mesh] OR Tourniquets) AND ("Child, Preschool"[Mesh] OR "Child"[Mesh] OR "Infant"[Mesh] OR CHILD OR CHILDREN OR PEDIATRICS OR KID OR KIDS OR "Pediatrics"[Mesh] OR "Pediatric Emergency Medicine"[Mesh])) AND ("Hemorrhage"[Mesh] OR BLEED OR BLEEDING OR BLOOD LOSS OR "Blood Loss, Surgical"[Mesh] OR "Blood"[Mesh])) OR ((((("Tourniquets/adverse effects"[Mesh] OR "Tourniquets/complications"[Mesh] OR "Tourniquets/methods"[Mesh])))) AND ("Child, Preschool"[Mesh] OR "Child"[Mesh] OR "Infant"[Mesh] OR CHILD OR CHILDREN OR PEDIATRICS OR KID OR KIDS OR "Pediatrics"[Mesh] OR "Pediatric Emergency Medicine"[Mesh])) Filters: English, Humans, from 2019 - 2022

39 selected items

4 articles selected for full text review.

2 articles selected for inclusion.

Gattere M, Scaffei N, Gozzetti L, Alessandrini M. Tourniquet use on a pediatric patient. J Spec Oper Med. 2021 Spring;21(1):120-123. PMID: 33721320.

Kelly JR, Levy MJ, Reyes J, Anders J. Effectiveness of the combat application tourniquet for arterial occlusion in young children. J Trauma Acute Care Surg. 2020 May;88(5):644-647. doi: 10.1097/TA.0000000000002594. PMID: 31977996.

Approved by ARC SAC June 2022

2019

PubMed

"Tourniquets"[Mesh] OR Tourniquets	
AND "Child, Preschool"[Mesh] OR "Child"[Mesh] OR "Infant"[Mesh] OR CHILD OR CHILDREN OR PEDIATRICS OR KID OR KIDS OR "Pediatrics"[Mesh] OR "Pediatric Emergency Medicine"[Mesh]	
AND "Hemorrhage"[Mesh] OR BLEED OR BLEEDING OR BLOOD LOSS OR "Blood Loss, Surgical"[Mesh] OR "Blood"[Mesh]	128
OR	
((("Tourniquets/adverse effects"[Mesh] OR "Tourniquets/complications"[Mesh] OR "Tourniquets/methods"[Mesh]))	
AND "Child, Preschool"[Mesh] OR "Child"[Mesh] OR "Infant"[Mesh] OR CHILD OR CHILDREN OR PEDIATRICS OR KID OR KIDS OR "Pediatrics"[Mesh] OR "Pediatric Emergency Medicine"[Mesh]	57
	128-10 DUPS
	164

EBSCO

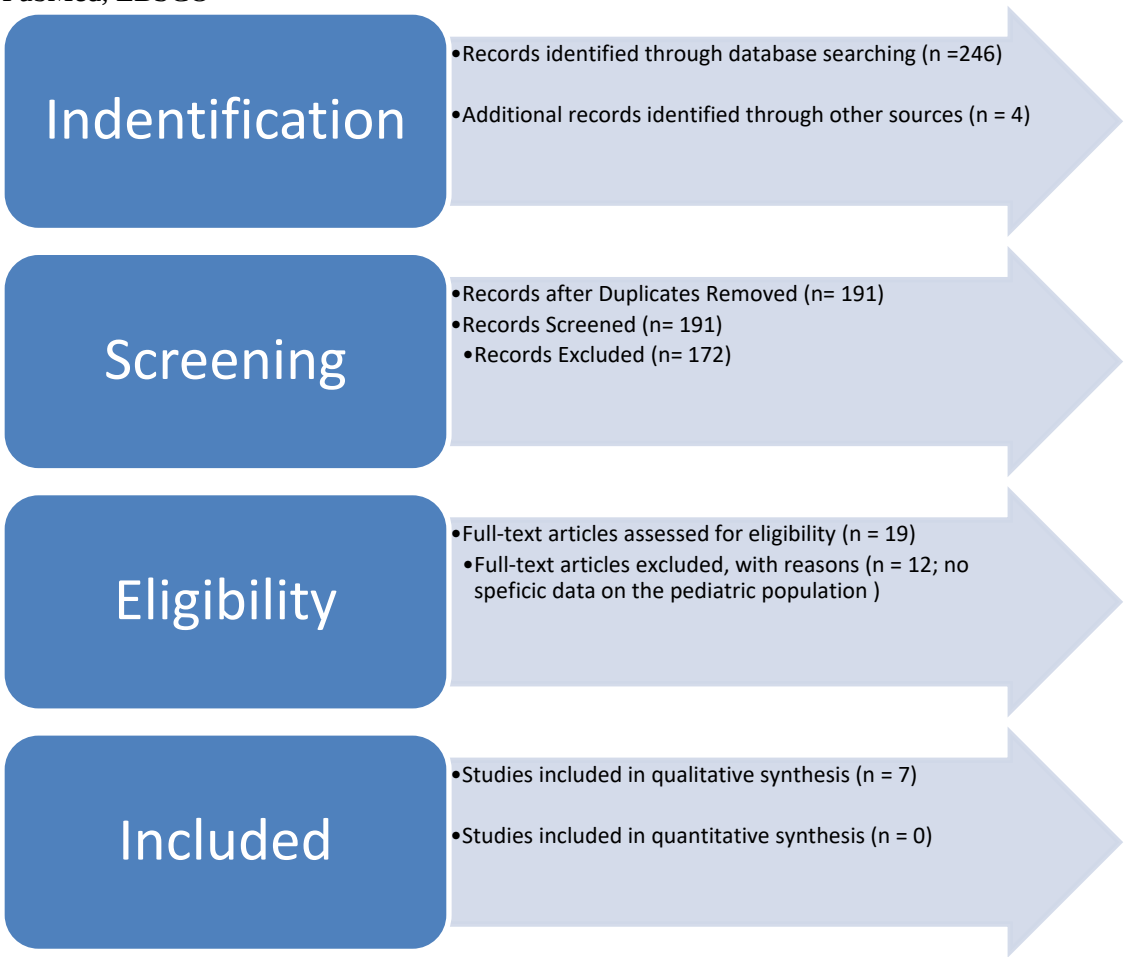
S 1 and 2 and 3	Interface - EBSCOhost Research Databases Database - CINAHL Complete;Global Health;Health Source - Consumer Edition;Health Source: Nursing/Academic Edition		82
S3	Hemorrhage OR BLEED OR BLEEDING or "Blood Loss" or Blood	Search modes - Boolean/Phrase	472,961
S2	tourniquet use OR tourniquet application OR tourniquet	Search modes - Boolean/Phrase	1,647
S1	Child OR Infant OR CHILD OR CHILDREN OR PEDIATRICS OR KID OR KIDS OR "Pediatric Emergency Medicine"	Search modes - Boolean/Phrase	761,729

EBSCO = 82 + PubMed=164 total 246 less 59 dups=187

Inclusion Criteria (time period, type of articles and journals, language, methodology)
All time periods, all article types, meeting abstracts if available.

Exclusion Criteria (only human studies, foreign language, etc…)
English language only

Databases Searched and Additional Methods Used (references of articles, texts, contact with authors, etc...)
PubMed, EBSCO



Scientific Foundation:

2022

Only two articles were selected for inclusion, 1 case report and the formal publication of the Kelly et al study included in the Red Cross 2019 SR.

In 2021, Gattere et al published a case report in with a 14-month-old infant sustained a traumatic below the knee amputation and was treated by emergency medical services with resolution of active bleeding. The infant had a Combat Application Tourniquet Gen 7 applied to the distal femur. It was noted that the tourniquet strap was wrapped multiple times around the leg to mitigate the risk of the Velcro losing grip. The windlass had to be twisted 5 times before obtaining effective hemorrhage control. The patient had a blood pressure of 54/32 with a pulse of 180 bpm after application. No complications are reported in the case report.

The second included article is the formal publication of the study by Kelly et al that was included in the 2019 Red Cross Pediatric tourniquet SR. In brief, this study was a convenience sample of 13 children age 2-7 years who were scheduled for elective orthopedic surgery. A Combat Application Tourniquet was used to occlude distal pulse by Doppler flow. Weights ranged from 12.8-23.9 kg, leg circumference 24.5-34.5 cm and arm circumference 13-24 cm. Eleven arms and 13 legs were tested in the participants. Arterial occlusion, by Doppler flow, was obtained in 100% of the limbs tested (95% CI 85.8-100%)

2019

A literature search identified 7 studies for inclusion. One was a observational trial in volunteers age 6-16 years, one observational trial in pediatric patients age 2-7 years of age undergoing elective orthopedic surgery, two used models of pediatric limb circumferences, two were epidemiologic studies of tourniquet in the pediatric population in conflict zones and one was a case report. One study on human volunteers demonstrated consistently successful application in both upper arms and upper legs of children ≥ 6 years of age (Harcke 2019). A second study in demonstrated successful application in human participants 2-7 years of age with a minimal limb circumference of 13 cm (Kelly 2019). Studies in manikin and PVC models generally demonstrate that some windlass and ratcheting tourniquets has increased failure rates as model circumferences, with failure rates becoming increasingly higher in sizes that would model the upper extremities of children under 5 years of age (El-Sherif 2019, Vretis 2018). It is possible that the pliability of human tissue made the mechanism less of a factor than with the less pliable materials used in the two model studies. No study in this review specifically evaluated ease of use or lay provider use in the pediatric population. The First Aid Sub-council placed a high value on the human studies that suggest a windless type tourniquet (specifically C-A-T® GEN7) can abolish distal pulses in both the upper and lower extremities, if applied appropriately, to a child as young as 2 (in this case with a limb circumference of 13 cm). In using manikins and PVC pipe models the overall trend was that the smaller the circumference of the model, the less likely the tourniquet was to be successfully applied, however the overall results were inconsistent, and the Sub-council chose to significantly downgrade the certainty of these studies. In our review the Sub-council considered the position statements from both the Pediatric Trauma Society and the Committee for Tactical Emergency Casualty Care Pediatric Working Group, both of which advocate for the use of tourniquets for life-threatening extremity hemorrhage in the pediatric population (Cunningham 2018, Joint Trauma System 2019).

In 2019, Harcke published an observational study with very low certainty evidence (downgraded for bias, indirectness and imprecision) evaluating the use of Combat Application Tourniquets (C-A-T®)_in school age children (6-16 years of age). Sixty participants were recruited as a convenience sample from an

orthopedic clinic and had a CAT Generation 7 applied to one upper extremity at the mid-biceps level and one lower extremity at the mid-thigh level. Height, weight and limb circumference were recorded. All tourniquets were applied by the researchers and no apparent blinding occurred. Successful application was determined by cessation of the distal pulse with a maximum of three windlass turns to limit pain. The CAT was successful in occluding arterial flow in 100% (60/60) of upper extremities and 93% (56/60) lower extremities. One participant withdrew due to pain and 3 applications failed to occlude pulses after 3 tourniquet turns. Upper extremity circumferences ranged from 16-37 cm, while lower extremity circumferences ranged from 26-55.5 cm. In this study the CAT Gen 7 windlass tourniquet was successful in occluding distal pulses in both upper and lower extremities of those children age 6 and over with a limb circumference ≥ 16cm.

In 2019 Kelly and colleagues presented data at the Special Operations Medical Association Scientific Conference regarding tourniquet use in the pediatric population. This was very low certainty evidence (downgraded for bias, indirectness, and imprecision). In this study patients undergoing elective orthopedic surgery had a tourniquet placed on one or more non-injured extremities in the operating room while under anesthesia. Thirteen patients age 2-7 years were enrolled. All tourniquets were placed by medical providers and were C-A-T® GEN7 tourniquets. Tourniquets were placed on 24 limbs (11 upper extremities and 13 lower extremities) with a 100% success rate in occluding distal pulses. The minimal limb circumference tested was 13 cm in a 2-year-old child.

In 2019 El-Sherif published a study with very low certainty evidence (downgraded for bias, indirectness and imprecision) evaluating the use of multiple types of tourniquets on two models of pediatric extremities. The tested tourniquets were the Combat Application Tourniquet Generation 6 (C-A-T® GEN6) and Generation 7 (C-A-T® GEN7), the SOF tactical tourniquet (SOFTT), the SOF tactical tourniquet wide (SOFTT-W), the Stretch Wrap and Tuck Tourniquet (SWAT-T) and the Emergency Trauma Dressing (ETD), a trauma pressure dressing. Four commercially available pediatric resuscitation manikins representing an infant, 1-year old child and two 5-year old children were used as models. Application sites on the models included the proximal humerus, mid-biceps area, the mid-forearm, the proximal femur, the mid-thigh and the mid-calf. Additionally, six sections of PVC pipe with an external circumference of 10.8-41.9 cm were used as models. Successful application was determined by inability to slip more than one finger under the tightened tourniquet and ability to tighten and secure the windlass. In the infant model, windlass tourniquets were only able to be appropriately used on the thigh, and while the SWAT-T and ETD were able to be appropriately tightened, they were deemed failures as their width made it impossible to isolate a specific location on the limb. In the 1-year old child model, all tourniquets were successful in the thigh area, however all windlass models were unsuccessful in the mid-biceps or forearm. Both the SWAT-T and ETD were successful in all areas tested. In the 5-year-old manikin models, tourniquets were able to be successfully placed on the proximal femur and mid-thigh; windless tightening allowed for success in the mid-biceps area, whereas there were failures in the forearm area. PVC model results varied depending on the circumference of the simulated extremity but in general the windlass tourniquets were unsuccessful when applied to PVC with an average limb circumference of ≤ 14.6 cm, which is equivalent to the average upper arm circumference of a 2-year-old child (Appendix A). For the C-A-T® GEN 6 & 7 , the windlass was not able to be secured on the PVC model of 19.7 cm circumference (10-year-old upper extremity, Appendix A). All windlass tourniquets were successful in PVC diameters equivalent to lower extremities of those at least 7 years of age, although there was a large gap in tested PVC diameter, with no representative lower extremity limb diameters between 1 and 7 years of age. While the SWAT-T was able to be used in all models of upper and lower extremities, their width prevented isolation of specific areas in the infant model, potentially limiting applicability.

TABLE I. TQ Efficacy, Simulaids SaniBaby Infant Manikin Model

	Thigh	Calf	Mid-Biceps	Mid-Forearm
CAT7	W/P	F	F	F
CAT6	F	F	F	F
SOFTT	F	F	F	F
SOFTT-W	W/P	F	F	F
SWAT-T	F	F	F	F
ETD	F	F	F	F

P: Pass.
F: Fail.
W: Windlass-enabled pass.
1st Letter: Ability to tighten TQ.
2nd Letter: Ability to secure the windlass (where applicable).

TABLE II. TQ Efficacy, Gaumard HAL S3004 1-Year-Old Manikin Model

	Thigh	Calf	Mid-Biceps	Forearm
CAT7	P/P	W/P	F	F
CAT6	P/P	W/P	F	F
SOFTT	P/P	F	F	F
SOFTT-W	P/P	F	F	F
SWAT-T	P	P	P	P
ETD	P	P	P	P

P: Pass.
F: Fail.
W: Windlass-enabled pass.
1st letter: Ability to tighten TQ.
2nd letter: Ability to secure the windlass (where applicable).

TABLE III. TQ Efficacy, Laerdal Resusci Junior 5-Year-Old Manikin Model

	High Leg	Mid-Thigh	Mid-Calf	Mid-Biceps	Mid-Forearm
CAT7	P/P	P/P	W/P	W/P	W/P
CAT6	P/P	P/P	W/P	W/P	W/P
SOFTT	P/P	P/P	P/P	P/P	W/P
SOFTT-W	P/P	P/P	W/P	P/P	F
SWAT-T	N/A*	P	P	P	P
ETD	N/A*	P	P	P	P

P: Pass.
F: Fail.
W: Windlass-enabled pass.
1st letter: Ability to tighten TQ.
2nd letter: Ability to secure the windlass (where applicable).
N/A*: Width of the elastic TQ resulted in placement in an area including both the high leg and the mid thigh.

TABLE IV. TQ Efficacy, Gaumard HAL S3005 5-Year-Old Manikin Model

	High Leg	Mid-Thigh	Mid-Calf	Mid-Biceps	Mid-Forearm
CAT7	P/P	P/P	W/P	W/P	F
CAT6	P/P	P/P	W/P	W/P	W/P
SOFTT	P/P	P/P	P/P	P/P	W/P
SOFTT-W	P/P	P/P	P/P	P/P	F
SWAT-T	NA*	P	P	P	P
ETD	NA*	P	P	P	P

P: Pass.
F: Fail.
W: Windlass-enabled pass.
1st letter: Ability to tighten TQ.
2nd letter: Ability to secure the windlass (where applicable).
N/A*: Width of the elastic TQ resulted in placement in an area including both the high leg and the mid thigh.

TABLE V. TQ Efficacy, PVC Pipe Model

PVC Circumference (CM)	Age (Mos) Equivalent UE	Age (Mos) Equivalent LE	CAT7	CAT6	SOFTT	SOFTT-W	SWAT-T	ETD
10.8	0–3	N/A	F	F	F	F	P	F
14.6	19–24	N/A	F	F	F	F	P	F
19.7	109–120	3–6	P/F	P/F	P/P	W/P	P	P
23.5	>156	10–12	P/F	P/F	P/P	W/P	P	P
33.7	>156	85–96	P/P	P/P	P/P	P/P	P	P
41.9	>156	133–144	P/P	P/P	P/P	P/P	P	P

P: Pass.
F: Fail.
W: Windlass-enabled pass.
UE: Upper extremity.
LE: Lower extremity.
1st Letter: Ability to tighten TQ.
2nd Letter: Ability to secure the windlass (where applicable).

Two different components were assessed for successful application: tightness of the TQ and ability to secure the windlass (where applicable). The ability to tighten the TQ strap around the limb without slack was graded as a pass (P). Slack was identified based upon the ability to easily slip more digits than an adult index finger beneath the TQ strap. The presence of a very small amount of slack removed by a single windlass revolution was classified as a windlass-enabled pass (W). Failure to remove slack with more than one windlass revolution was classified as a fail (F). Ability to secure the windlass (where applicable) was evaluated in a simple pass/fail (P/F) manner. If the TQ could not be tightened, the ability to secure the windlass was not assessed.

In 2018, Vretis published an abstract at the NAEMSP annual meeting with very low certainty evidence (downgraded for bias, indirectness and imprecision) that evaluated the efficacy of nine commercial tourniquets on PVC pipe with rubber tubing models of 6 different diameters. The tourniquets tested were the Stretch Wrap and Tuck Tourniquet (SWAT-T), TacMed K9 (TMK9), Rapid Application Tourniquet System (RATS), Combat Application Tourniquet (C-A-T®), Sam XT (SAMXT), Tactical Mechanical Tourniquet (TMT), the SOF Tactical Tourniquet – Wide (SOFTTW), the Child Ratcheting Medical Tourniquet (CRMT) and the Mechanical Advantage Tourniquet (MAT). Study investigators were unblinded. The SWAT, TMK9, RATS and CRMT were successful stopping the flow of water on all models (down to 3.81 cm diameter, 11.9 cm circumference). The MAT failed on PVC sizes 7.62 cm diameter (23.9 cm circumference) and smaller. The TMT and SOFTTW started failing on diameters 6.35 cm (19.9 cm circumference; 10-year-old upper extremity, Appendix A) and smaller. The C-A-T®, SAMXT, TMT, and SOFTTW failed on the 5.08 cm diameter (16.0 cm circumference; 5-year-old upper extremity, Appendix A) models. In this study elastic and ratcheting models were more successful in stopping simulated bleeding than windlass type models. It is mentioned in an online presentation that 100% of evaluators chose RATS as the tourniquet they would least like to carry for pediatrics and 100% of the evaluators chose the CRMT as the tourniquet they would most like to carry for pediatrics (raw data not shown).

	10.16 cm	8.89 cm	7.62 cm	6.35 cm	5.08 cm	3.81 cm
CAT	20 (100%)	20 (100%)	20 (100%)	20 (100%)	6 (30%)	0 (0%)
SAMXT	20 (100%)	20 (100%)	20 (100%)	20 (100%)	14 (60%)	0 (0%)
TMT	20 (100%)	20 (100%)	20 (100%)	0 (0%)	0 (0%)	0 (0%)
SOFTTW	20 (100%)	20 (100%)	20 (100%)	14 (60%)	0 (0%)	0 (0%)
CRMT	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)
MAT	20 (100%)	20 (100%)	14 (60%)	0 (0%)	0 (0%)	0 (0%)
SWAT	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)
TMK9	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)
RATS	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)	20 (100%)

Sokol published a retrospective chart review in 2015 with very low certainly evidence (downgraded for imprecision) from the Department of Defense Trauma Registry of pediatric injuries (less than or equal to 18-years-of-age) treated at Camp Bastion Afghanistan from 2004-2012. 766 patients were identified, with 74% having battle related injuries. A total of 125 patients had significant extremity injuries that were

determined to be amenable to a tourniquet however only 47 received a pre hospital tourniquet. There was no difference in mortality when corrected for injury severity. Lower extremity amputations treated with a pre hospital tourniquet required less intravenous fluids [2.4 (3.2) L vs 4.2 (4.0) L, p = 0.032], however there was no statistical difference in blood product requirements, nor in IVF or blood product requirements on upper extremity amputations.

In 2012 Kragh published a retrospective review with very low certainly evidence (downgraded for imprecision) from the Joint Trauma System's Joint Theater Trauma Registry examining the use of tourniquets in pediatric trauma care (less than 18 years of age). During the study period of May 17, 2003 to December 25, 2009, 88 patients were identified in which a tourniquet was applied, with an average age of 11 years. Explosions accounted for 64% of injuries, followed by gunshot wounds (30%), machinery accidents (3%), knife wounds (1%) and motor vehicle crashes (1%). The overall survival rate was 93% (74/81) with is similar to historic data from published tourniquet studies of adult patients (87%) (Kragh 2008, Kragh 2009, Brodie 2007).

Callaway published a case report with very low certainty evidence (downgraded for bias, and imprecision) in 2017 detailing a 7-year-old boy who was struck in the leg with an object expelled from a running lawn mower. The patient sustained a deep laceration to the upper thigh. On EMS arrival the patient displayed signs of shock with a weak radial pulse. EMS applied a Combat Application tourniquet (Generation not listed) to the proximal thigh. Vitals were recorded as a blood pressure of 90 by palpation and a heart rate 150 beats per minute. The patient received 350 cc of normal saline on transport to the hospital. On arrival his heart rate was 170 beats per minute and blood pressure was 117/93. Hemorrhage from a femoral artery laceration was noted to be controlled by the tourniquet. The patient was transfused 3 units of packed red blood cells as he had a hemoglobin of 10.8, an arterial vascular graft was performed by vascular surgery in the OR and the patient recovered and returned to normal activity.

The Pediatric Trauma Society published a position statement in 2017 regarding tourniquet use in the prehospital care of pediatric trauma patients. The society conducted a systematic review that included the literature reviewed above, and multiple pediatric operating room studies deemed too indirect for inclusion in this SAC review. The Pediatric Trauma Society recommended the use of tourniquets in the prehospital setting and during resuscitation of children from exsanguinating hemorrhage if direct pressure failed to control exsanguinating hemorrhage or if attempting direct pressure would be too resource intensive. This recommendation was based on grade C/D quality of evidence (Oxford Center for Evidence Based Medicine – case-series, case control studies, expert opinion).

In 2013 the Committee for Tactical Emergency Casualty Care assembled a Pediatric Working Group to recommend principles for pediatric care for traumatic injuries. The working group used adult tactical emergency casualty care guidelines as a framework and reviewed the pediatric literature to pertinent to the treatment of pediatric traumatic injury. Draft guidelines were presented and adopted at a full committee semiannual meeting. Tourniquets are recommended for life-threatening extremity hemorrhage as first line therapy in both direct threat care (care under fire) and indirect threat care. In the evacuation phase, tourniquets or pressure dressings with deep wound packing are recommended to control life-threatening treatment, tourniquets are recommended for all traumatic amputations. It is recommended that tourniquets are only applied for up to two hours if possible. Recommendations were based on similar low certainty evidence found in the above SAC review.

Recommendations and Strength (using table below):

2022

There is no new data from the 2019 scientific review to include in this triennial review. However, in group discussion there was concern that with stating a minimum age requirement, tourniquets may not be used on younger children in which they may be beneficial. It was noted in the initial SR that most thighs of children, even infants, are greater than 13 cm (~5 in) circumference, so the CAT Gen 7 should work on the lower extremities of most pediatric patients. It is more likely that the upper extremities of children less than 2 years old would be <13 cm (~5 in) circumference. There is still concern that some windlass tourniquets may have non-compressible parts that make them unable to be appropriately tightened on small limbs. In the available randomized studies, the youngest children that tourniquets were tested on were 2 years of age, minimal lower limb circumference was 24.5 cm (~9.5 in) and minimal upper limb circumference was 13 cm (~5 in). Revisions were made to allow for a broader application of tourniquets in children based on size, rather than a specific age.

Standards:

2019/2022

- None

Guidelines:

- **2019:** A manufactured windlass tourniquet should be used to treat life threatening extremity hemorrhage in children approximately 2-years-of-age and older. (LOE 3b)
- **2022:** A manufactured windlass tourniquet should be used to treat life threatening extremity hemorrhage in children approximately 2-years-of-age and older or with a limb circumference of 13 cm (~5 in) or greater. (LOE 3b)

Options:

2019:

- Direct pressure, with a hemostatic agent if available, should be used for children with life-threatening extremity bleeding when a windlass tourniquet is not available. (LOE 7)
- Direct pressure, with a hemostatic agent if available, should be used to treat life-threatening extremity bleeding in children less than 2-years-of-age. (LOE 7)

2022:

- Direct pressure, with a hemostatic agent if available, should be used for children with life-threatening extremity bleeding when a windlass tourniquet is not available or if a tourniquet fails to stop bleeding. (LOE 3b)
- Direct pressure, with a hemostatic agent if available, should be used to treat life-threatening extremity bleeding in children with a limb circumference of less than 13 cm (~5 in), which is more common for the upper extremities of children less than 2-years-of-age. (LOE 7)

***** The only tourniquet that was tested in humans was the C-A-T® GEN7.

Knowledge Gaps and Future Research:

In the studies reviewed the only tourniquet that was tested in humans was the C-A-T® GEN7. More human studies are needed to determine whether other tourniquet types are able to be used successfully in the pediatric population and the lower age limits to which these tourniquets can be successfully applied in both upper and lower extremities.

Implications for ARC Programs:

Instructors can teach providers to use of a windlass tourniquet for life-threatening extremity injuries for pediatric patients down to approximately age two and older or with a limb circumference of 13 cm (~5 in) or greater. They should understand while that additional data may emerge, the only product currently tested in the human population in this age group is the C-A-T® GEN7.. For those with a limb circumference of less than 13 cm (~5 in),direct pressure, with a hemostatic agent if available, will still be encouraged as the mainstay of therapy for life threatening bleeding.

Attach Any Lists, Tables of List of Recommendations Created As Part of This Review

None

American Red Cross

Scientific Advisory Council

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Pediatric Tourniquet Use

Summary of Key Articles/Literature Found and Level of Evidence/Bibliography:

Author(s)	Full Citation	Summary of Article (provide a brief summary of what the article adds to this review including which question(s) it supports, refutes or is neutral)	Methodology	Bias Assessment	Indirectness/ Imprecision/ Inconsistency		Support, Neutral or Oppose Question	Level of Evidence (Using table below)	Quality of study (excellent, good, fair or poor) and why
Kelly J, Levy M, Reyes J, Anders J.	Description of Penetrating Trauma in Children by Age and Location: A National Trauma Database Review. Special Operations Medical Association Scientific Conference. 2019 May; personal communication.	Supports. Studies the use of a CAT gen 7 tourniquet in a pediatric population down to age 2 and with a limb diameter of 13 cm.	Observational studies of 13 patients undergoing elective orthopedic surgery. All tourniquets applied by researchers. Success was abolishing distal pulses.	Serious	Serious indirectness and imprecision.	Tourniquets were placed on 24 limbs (11 upper extremities and 13 lower extremities) with a 100% success rate in occluding distal pulses.	Support	LOE 2a	Good, observation human data of successful tourniquet use.
Harcke HT, Lawrence LL, Gripp	Adult Tourniquet for Use	Supports. Studies the use of the CAT Gen 7 tourniquet in a	Observational study of 60 healthy pediatric patients	Serious	Serious indirectness and imprecision	Key results and magnitude of results	Support	LOE 2a	Good, observation human data of

EW, Kecskemethy HH, Kruse RW, Murphy SG.	in School-Age Emergencies. Pediatrics. 2019 May 7. pii: e20183447. doi: 10.1542/peds.2018-3447. [Epub ahead of print]	pediatric population down to age 6 years with a minimum limb circumference of 16 cm	aged 6-16 years presenting to a clinic. All tourniquets applied by researchers. Success was abolishing distal pulses within 3 windlass turns.			CAT was successful in occluding arterial flow in 100% (60/60) of upper extremities and 93% (56/60) lower extremities. One participant withdrew due to pain and 3 applications failed to occlude pulses after 3 tourniquet turns. Upper extremity circumferences ranged from 16-37 cm, while lower extremity circumferences ranged from 26-55.5 cm.			successful tourniquet use.
El-Sherif N, Lowndes B, Franz W, Hallbeck MS, Belau S, Sztajnkrycer MD	Sweating the Little Things: Tourniquet Application Efficacy in Two Models of Pediatric Limb Circumference. Mil Med. 2019 Mar 1;184(Supplement_1):361-366. doi: 10.1093/milmed/usy283.	Supports. Studies the use of multiple tourniquets in both manikin and PVC models.	Simulation study evaluating the use multiple tourniquets on four commercially available pediatric resuscitation manikins representing an infant, 1-year old child and two 5-year old children were used as models. Additionally, six sections of PVC pipe with an external circumference of 10.8-41.9 cm were used as models. Successful application was	Serious	Serious indirectness and imprecision	In the infant and 1 yo model, windlass tourniquets were only able to be appropriately used on the thigh. In the infant model while the SWAT-T and ETD were able to be appropriately tightened, they were deemed failures as their width made it impossible to isolate a specific location on the limb. In the 5-year-old manikin models,	Support	LOE 4	Poor, variable results. Difficult to extrapolate to clinical use.

			determined by inability to slip more than one finger under the tightened tourniquet and ability to tighten and secure the windlass. All tourniquets applied by the researcher.			tourniquets were able to be successfully placed on the proximal femur and mid-thigh; windless tightening allowed for success in the mid-biceps area, whereas there were failures in the forearm area. PVC model results varied depending on the circumference of the simulated extremity but in general the windlass tourniquets were unsuccessful when applied to PVC with an average limb circumference of ≤ 14.6 cm, which is equivalent to the average upper arm circumference of a 2-year-old child.			
Callaway DW, Puciaty A, Robertson J, Hannon T, Fabiano SE.	Case Report: Life Saving Application of Commercial Tourniquet in	Supports. Case report of a tourniquet placement for a possible life threatening extremity bleed in a child.	Case report detailing a 7 year old boy who was struck in the leg with an object expelled from a running lawn mower	Serious	Serious imprecision	EMS applied a Combat Application tourniquet (Generation not listed) to the proximal thigh. Hemorrhage from a femoral artery laceration was	Support	LOE 3b	Poor, case report.

	Pediatric Extremity Hemorrhage. Prehosp Emerg Care. 2017 Nov-Dec;21(6):786-788. doi: 10.1080/10903127.2017.1332126. Epub 2017 Jun 28.					noted to be controlled by the tourniquet.			
Vretis, J.	Comparison of commercial tourniquets in a pediatric trauma patient model. Prehosp Emerg Care. 2017 Oct 5:1-50. doi: 10.1080/10903127.2017.1377791. Abstracts for the 2018 NAEMSP Scientific Assembly.	Supports. Studies the use of multiple tourniquets in both manikin and PVC models.	Simulation study that evaluated the efficacy of nine commercial tourniquets on PVC pipe with rubber tubing models of 6 different diameters. Study investigators were unblinded. Success was determined by the ability to stop the flow of water distally.	Serious	Serious indirectness and imprecision	The SWAT, TMK9, RATS and CRMT were successful stopping the flow of water on all sized mannequins (down to 3.81 cm diameter, 11.9 cm circumference). The MAT failed on PVC sizes 7.62 cm diameter (23.9 cm circumference) and smaller. The TMT and SOFTTW started failing on diameters 6.35 cm (19.9 cm circumference) and smaller. The CAT, SAMXT, TMT, and SOFTTW failed on the 5.08 cm	Support	LOE 4	Poor, variable results. Difficult to extrapolate to clinical use.

	2018;22:101-150.					diameter (16.0 cm circumference) models			
Sokol KK, Black GE, Azarow KS, Long W, Martin MJ, Eckert MJ.	Prehospital interventions in severely injured pediatric patients: Rethinking the ABCs. J Trauma Acute Care Surg. 2015 Dec;79(6):983-9; discussion 989-90. doi: 10.1097/TA.0000000000000706.	Supports. Provides field data on the use of tourniquets in the pediatric population.	Retrospective chart from the Department of Defense Trauma Registry of pediatric injuries (less than or equal to 18 years of age) treated at Camp Bastion Afghanistan from 2004-2012.	Not serious	Serious imprecision	125 patients had significant extremity injuries that were determined to be amenable to a tourniquet however only 47 received a pre hospital tourniquet. There was no difference in mortality when corrected for injury severity. Lower extremity amputations treated with a pre hospital tourniquet required less intravenous fluids [2.4 (3.2) L vs 4.2 (4.0) L, p = 0.032], however there was no statistical difference in blood product requirements, nor in IVF or blood product requirements on upper extremity amputations.	Support	LOE 3b	Fair, provides some comparative data on outcomes for those pediatric patients with versus those without a tourniquet placed in the field.
Kragh JF Jr, Cooper A, Aden JK, Dubick MA, Baer DG, Wade CE,	Survey of trauma registry data on tourniquet use in	Supports. Provides field data on the use of tourniquets in the pediatric population.	Retrospective chart review from the Joint Trauma System's Joint Theater Trauma Registry examining	Not serious	Serious imprecision	88 patients were identified in which a tourniquet was applied, with an average age of 11	Support	LOE 3b	Poor. Provides epidemiologic data on pediatric patients with

Blackbourne LH.	pediatric war casualties. Pediatr Emerg Care. 2012 Dec;28(12):1361-5. doi: 10.1097/PEC.0b013e318276c260.		the use of tourniquets in pediatric trauma care (less than 18 years of age). During the study period of May 17, 2003 to December 25, 2009.			years. Explosions accounted for 64% of injuries, followed by gunshot wounds (30%), machinery accidents (3%), knife wounds (1%) and motor vehicle crashes (1%). The overall survival rate was 93% (74/81) with is similar to historic data from published tourniquet studies of adult patients (87%)			filed placement of a tourniquet.

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Level of Evidence	Definitions (See manuscript for full details)
Level 1a	**Experimental and Population based studies -** population based, randomized prospective studies or meta-analyses of multiple higher evidence studies with substantial effects
Level 1b	**Smaller Experimental and Epidemiological studies -** Large non-population based epidemiological studies or randomized prospective studies with smaller or less significant effects
Level 2a	**Prospective Observational Analytical** - Controlled, non-randomized, cohort studies
Level 2b	**Retrospective/Historical Observational Analytical** - non-randomized, cohort or case-control studies
Level 3a	**Large Descriptive studies** – Cross-section, Ecological, Case series, Case reports
Level 3b	**Small Descriptive studies** – Cross-section, Ecological, Case series, Case reports
Level 4	**Animal studies or mechanical model studies**
Level 5	**Peer-reviewed Articles -** state of the art articles, review articles, organizational statements or guidelines, editorials, or consensus statements
Level 6	**Non-peer reviewed published opinions -** such as textbook statements, official organizational publications, guidelines and policy statements which are not peer reviewed and consensus statements
Level 7	**Rational conjecture** (common sense); common practices accepted before evidence-based guidelines
Level 1-6E	**Extrapolations** from existing data collected for other purposes, theoretical analyses which is on-point with question being asked. Modifier E applied because extrapolated but ranked based on type of study.