American Red Cross Scientific Advisory Council

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Scientific Review
Improvised Tourniquets for Life-Threatening Hemorrhage

Questions to be addressed:

Is application of improvised tourniquets by trained or untrained first aid providers recommended for life-threatening bleeding from an extremity when a manufactured tourniquet is not available?

Introduction/Overview:

Traumatic injury is a major source of morbidity and mortality, and in the United States is the leading cause of death in people under 45 years of age (Centers for Disease Control and Prevention). Hemorrhage is cited as the primary cause of death in 35% of traumatic mortalities and often contributes to death ultimately attributed to other causes (Kauvar 2006). The launch of the White House's Stop the Bleed campaign highlights the importance of hemorrhage control in traumatic civilian injury and mass casualty events and has highlighted the importance of tourniquets in life-threatening hemorrhage (https://www.dhs.gov/stopthebleed).

Tourniquets have become a mainstay of hemorrhage control for life threatening extremity hemorrhage. In a multivariable analysis, Scerbo demonstrated a 4.5, fold increased risk of death if tourniquet placement was delayed until arrival at the hospital (OR 4.5, 95% CI 1.23-16.4) and Teixeira demonstrated that the use of tourniquets was associated with an increased chance of survival (adjusted OR 5.86; 95% CI 1.41-24.47) (Scerbo 2017, Teixeira 2018). In addition, tourniquets are advocated by the American Red Cross Scientific Advisory Council for the treatment of life-threatening extremity hemorrhage (ARC SAC Scientific Advisory). However, commercially available tourniquets represent an additional cost that may reduce feasibility on both a small and large scale some areas and, therefore, may not be readily available for all providers.

Improvised tourniquets present a potential solution to this problem and could be made from available resources at the area of the incident. Improvised tourniquets were used after the Boston Marathon bombings with seeming efficacy (King 2015), however, there is a concern that improvised tourniquets may not be as efficacious as manufactured tourniquets and could result in more adverse events than commercially available products.

This review was conducted to determine whether or not improvised tourniquets are as efficacious as manufactured tourniquets for both trained and untrained providers in adults and children in the treatment of life-threatening extremity hemorrhage.

Search Strategy and Literature Search Performed

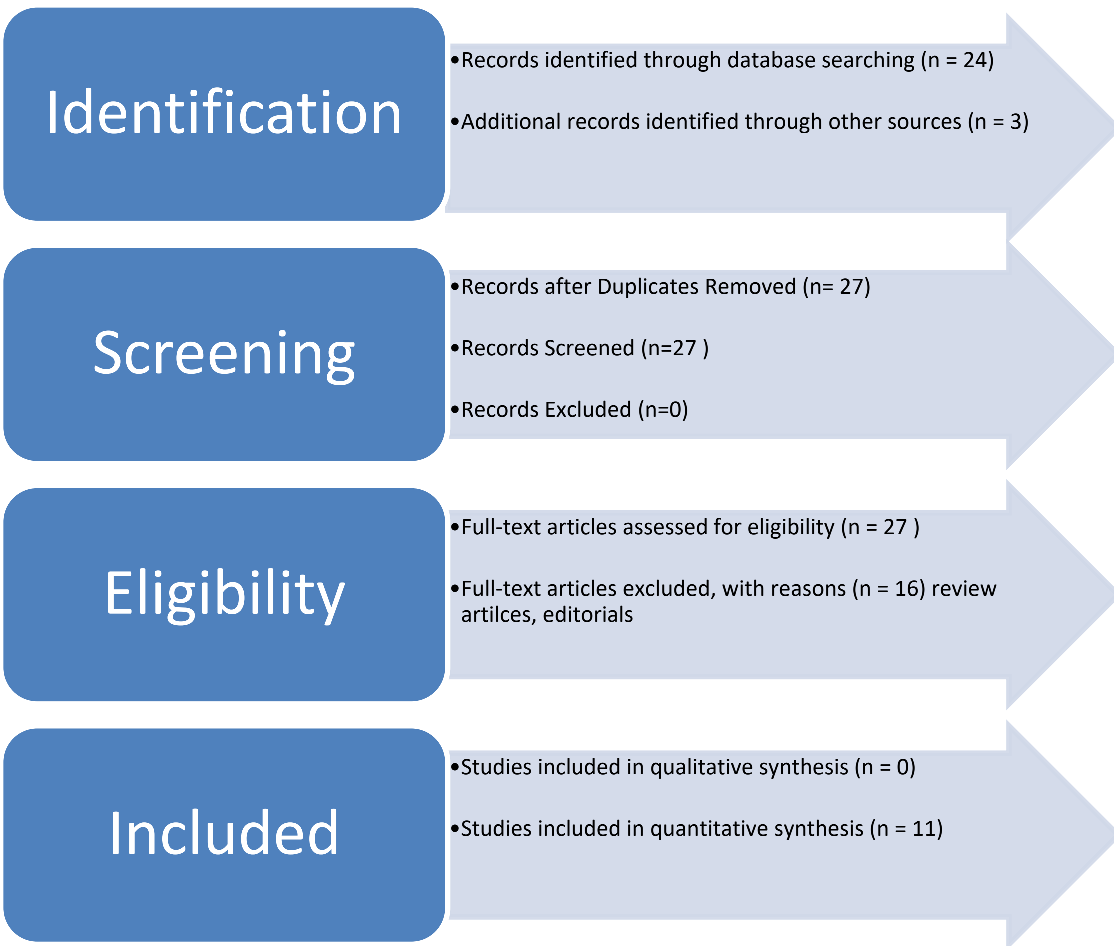
Key Words Used

"Improvised tourniquets" and (hemorrhage or bleeding) - too narrow-only PubMed [7 hits] OneSearch [5 hits]; Changed strategy to just "Improvised tourniquets" and Language = English, All years. Russian language tourniquet had about 30 hits but only 3 in English and they were duplicates. Same for Google Scholar sort by year.

Inclusion Criteria (time period, type of articles and journals, language, methodology)
All dates, all articles and study types, English language only

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

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



Review Process and Literature Search of Evidence Since Last Approval Performed

Updated 2022

Search Conducted July 12, 2021

Search: "Tourniquets"[MAJR] AND Improvise Filters: in the last 5 years
17 selected items

Search: improvised tourniquets Filters: from 2018/1/1 - 2021/7/31
24 selected items

Searches combined: 28 articles after duplicates removed; 17 full text reviewed; 7 articles included

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

Scientific Foundation:

Overall, there is limited data to compare improvised with manufactured tourniquets and to assess the feasibility of using improvised tourniquets when manufactured tourniquets are not available. A literature search was performed on PubMed, IU Onesearch and Google Scholar. Eleven studies were found for inclusion (Appendix D) which were of very low certainty evidence (Appendix C). Comparative studies were primarily based on health human volunteers or simulation studies. No trials were found that specifically compared the effectiveness of improvised tourniquets and manufactured tourniquets as separate variables to direct manual pressure. These studies generally suggest that manufactured tourniquets are more efficacious than improvised tourniquets. However, efficacy of any tourniquet appears to be variable depending on the type of tourniquet and likely on education.

The primary types of improvised tourniquets evaluated were cloth and windlass tourniquets and rubber tubing wrapped multiple times in succession around the extremity. Two human case series in the civilian population suggest efficacy for the use of improvised tourniquets for the treatment of life threatening hemorrhage (Kue, King). King reported no deaths when 27 improvised tourniquets (multiple types) were applied to victims of the Boston marathon bombing who had recognized life-threatening extremity hemorrhage. In addition, Kue reported that flexible rubber surgical tubing when used as a tourniquet was successful in controlling prehospital hemorrhage in 94 of 98 cases (95.9%). Two small comparative observational studies in wounded military personnel demonstrated a similar rate of efficacy for improvised tourniquets when compared with manufactured tourniquets (Lakstein, Passos). In one small observational study (Lakstein) improvised cloth and windlass tourniquets were effective in controlling hemorrhage 72% (13/18) of the time [(RR) of 0.83 (95% CI 0.34-2.05)]. In another small study (Passos), improvised tourniquets (cloth, belt type or unknown) had equal survival rates to those of early hospital placed manufactured tourniquets. (4/4 compared with 4/4; RR of 1.00 (95% CI 0.02-41.22)).

Simulation studies typically demonstrated a reduced efficacy when comparing improvised tourniquets with manufactured tourniquets (King, Swan, Guo, Heldenberg, Lyles). Simulation studies all comparatively demonstrate a lower effectiveness of improvised cloth and windlass tourniquets compared with manufactured, and no study reports a greater effectiveness of an improved cloth and windlass over a manufactured cloth and windlass. Only one improvised belt-type tourniquet was tested. King demonstrated a RR for failure to eliminate a Doppler pulse of 1.40 and 0.01 for the improvised cloth and windlass tourniquet and surgical tubing compared with a self-applied tourniquet system, respectively (95% CI 1.11-1.77 and 0.0006-0.16, respectively). Swan reported a RR of failure to eliminate distal pulses by Doppler signal of 1.00 (95% CI 0.15-6.76) and 0.50 (95% CI 0.05-5.30) for rubber surgical tubing and improvised cloth and windlass groups, respectively, when compared with a sphygmomanometer. Heldenberg reported failure rates for improvised cloth and windlass tourniquet of 35% compared with 23% for the CAT manufactured tourniquet and 21% for the SOFTT manufactured tourniquet, however these differences were not statistically significant. Lyles reported CAT effectiveness, as measured by cessation of simulated pulses, of 100% (20/20) compared with 45% (9/20) (RR 23.00 95% CI 1.45-365.62) for an improvised triangle bandage tourniquet and 10% (2/20) for an improvised bandana tourniquet (RR 37.00 (95% CI 2.38-574.83). When testing improvised belt-type tourniquets, Guo reported success rates for elimination of Doppler pulse as: improvised belt tourniquet 21/20 (52.5%), rubber tubing 27/40 (67.5%) cargo strap 31/40 (77.5), manufactured windlass tourniquet 36/40 (90%). This translated to a RR of 4.75 (95% CI 1.7736-12.7214) and 4.33 (95% CI 1.569-11.9666) for improvised belt tourniquet and surgical tubing compared with manufactured windlass tourniquets for failure to eliminate distal pulses, respectively.

Overall, in simulation studies improvised cloth and windlass tourniquet effectiveness averaged 56.2% (range 10-100), improvised belt type tourniquet 52.5%, improvised rubber tubing 80.0% (range 60-95%) and manufactured windlass 80.3% (range 50-100%). This data suggests that while improvised tourniquets generally are less efficacious than manufactured tourniquet, there is variation in success rates of both types. In some studies, improvised tourniquets are 100% efficacious, suggesting that both design and training plays a role in tourniquet efficacy. In these studies, the majority of the participants appeared to have prior training with tourniquets or were formality trained during the studies. As efficacy approaches 100% in some trained individuals, it appears that providers could potentially be adequately trained to successfully apply an improvised tourniquet, although at this time it is unknown what training would involve to attain mastery of this skill.

In studies evaluating tightening mechanisms, windlass use was associated with better efficacy than cloth alone (Altaminano) and the windlass thickness was inversely associated with breakage percentage (Kragh). Elastic tubing, wrapped multiple times in succession around the extremity has also demonstrated efficacy is stopping distal pulses and blood flow (King, Swann, Guo, King, Kue). Typically, a mechanical tightening mechanism (windlass, elastic tubing) is needed to obtain the pressures needed to occlude arterial flow.

Human Case Series

In 2015, King published a case series with very low certainty evidence (downgraded for risk of bias and imprecision) evaluating 35 patients with recognized life-threatening extremity injury after explosion at Boston marathon. Twenty-seven had tourniquets applied to the wound pre-hospital, all were improvised. **Eight patients with life-threatening extremity wounds presented to the ED without a tourniquet. No deaths occurred in either group. A subset of 10 patients with major vascular injury, 5 with pre-hospital tourniquet and 5 without a tourniquet were analyzed. No deaths occurred in either group.** All patients had a similar injury severity score with no significant difference in SBP, HR or GCS.

In 2015, Kue published a case series with very low certainty evidence (downgraded for risk of bias, and imprecision) of 98 cases of prehospital tourniquet use in the pre-hospital setting from 2005-2012. The majority were placed by emergency medical services. Sixty-sixty of the 98 were placed for penetrating trauma and 15 were place for a bleeding hemodialysis shunt. A flexible **rubber surgical tubing** was used 94/98 cases. One BP cuff was used, which was successful in hemorrhage control. In three cases of bystander-placed tourniquets the type was not recorded. **Eighty-seven of 95 (91.6%, 95% CI 85.9-97.3%) with available data resulted in successful hemorrhage control.**

Human Observational Studies

In 2002, Lakstein published an observational study with very low certainty evidence (downgraded for imprecision) retrospectively evaluating charts for all cases of tourniquet use in the military prehospital setting from 1997-2001. Effective tourniquet use was defined as cessation of all hemorrhage distal to the injury site. One-hundred-ten tourniquets were applied to 91 patients during this time period. During this time-period elastic silicone tourniquets were the standard, however, improvised cloth and windlass tourniquets and other unclear improvised tourniquets were also reported. **Of data reported, 13/18 (72%) improvised cloth and windlass tourniquets were effective compared with 20/30 (66%) silicon band tourniquets when applied to the thigh (RR 0.83; 95% CI 0.34-2.05).** The overall complication rate was 5.5%, although no other data is reported comparing improvised with manufactured.

In 2004, Passos published an observational trial with very low certainty evidence (downgraded for risk of bias, indirectness and imprecision) that in a subgroup analysis evaluated 8 patients at two level one trauma centers that had arterial injuries after extremity trauma. **Four patients had an improvised pre-hospital tourniquet and 4 had manufactured tourniquet placed in early after hospital arrival (pneumatic BP cuff). No deaths occurred in either group (RR 1.00; 95% CI 0.02-41.22).** This was a subset analysis of early tourniquet placement from the main study population.

Simulation Studies

In 2006, King published a simulation study with very low certainty evidence (downgraded for risk of bias, indirectness and imprecision) testing 5 different tourniquet systems with 10 healthy volunteers who were junior medics in the military. The tourniquets tested were: improvised cloth and windlass (IT), self-applied tourniquet system (SATS) (ratcheting system), one-hand tourniquet (OHT) (belt type), pneumatic emergency medical tourniquet (EMT), latex surgical tubing (ST). All participants reported understanding of each tourniquet system prior to beginning the study, although it is unclear if formal training occurred. Five two-person teams applied each tourniquet system; team members applied each tourniquet to each other than rotated, teams rotated through twice, once with summer uniform and once with winter uniform (applied over uniform) resulting in 100 different applications. Applications only occurred on the lower extremities. Successful application was noted by lack of palpable pulse with subsequent measurement of Doppler signal. **The improvised tourniquet eliminated a palpable pulse and Doppler pulse 70% and 30% of the time for summer and winter uniforms, respectively. Surgical tubing eliminated a palpable pulse and Doppler pulse 100% and 90% of the time for summer and winter uniforms, respectively. This was compared to 60% and 50% for the manufactured self-applied tourniquet system. Relative risk for failure to eliminate of Doppler pulse was 1.40 (95% CI 1.11-1.77) for the improvised tourniquet compared with self-applied tourniquet system. Relative risk for elimination of Doppler pulse was 0.0099 (95% CI 0.0006-0.16) for the surgical tubing compared with self-applied tourniquet system.** There was a significant difference between pain scores for the different types of tourniquets (p< 0.001). Of note, the ST was noted to be the second most painful after the IT by a small margin.

Table 3 Success and Time to Application under Ideal and Winter Conditions

Tourniquets	Palpable Pulse Success	Doppler Pulse Success	Time to Application (Mean, Seconds)	Time Standard Deviation
Ideal conditions				
IT	70%	30%	31.8	10.2
SATS	60%	50%	34.6	10.6
OHT	20%	0%	29.8	10.8
EMT	80%	80%	33.6	8.5
ST	100%	90%	23.8	5.6
Overall *p* values	0.004	<0.001	—	—
Winter conditions				
IT	80%	50%	38.5	15.3
SATS	70%	40%	35.1	18.8
OHT	30%	10%	38.1	17.3
EMT	80%	70%	40.8	12.7
ST	100%	90%	24.5	6.6
Overall *p* values	0.01	0.005	—	—

Success percentages and application times for ideal and winter conditions.

Table 4 Questionnaire Data

Questions Mean (SD)	IT	SATS	OHT	EMT	ST
Q1: Difficulty to learn	4.8 (0.4)	4.2 (0.6)	4.1 (1.0)	4.7 (0.5)	4.9 (0.3)
Q2: Ease of application under ideal conditions	4.1 (0.7)	3.9 (1.0)	4.3 (0.7)	4.5 (0.7)	4.5 (1.0)
Q3: Ease of application under winter conditions	4.4 (0.5)	4.0 (1.0)	3.4 (1.4)	4.0 (0.8)	4.4 (0.7)
Q4: Perceptions of effectiveness	3.2 (1.1)	3.1 (1.4)	1.9 (1.5)	4.3 (0.9)	4.5 (0.7)
Q5: Pain during use	3.9 (0.9)	3.0 (0.7)	2.1 (1.3)	0.9 (1.1)	3.7 (0.9)
Q6: Durability	3.7 (1.2)	3.2 (1.0)	3.0 (1.8)	2.8 (1.1)	3.7 (1.5)
Q7: Portability	3.3 (1.4)	3.8 (0.6)	3.8 (1.5)	3.0 (1.1)	4.9 (0.3)
Q8: Medic preference	4.2 (0.8)	3.2 (0.8)	4.1 (0.7)	1.6 (0.8)	1.9 (0.5)

Numeric scores for questionnaire data shown as score means and standard deviations (SD) for the tourniquets tested. Number scores for Q1 to Q7 were: 0, extremely difficult/harmful; 1, several difficulties/not at all effective; 2, some difficulties/partially effective; 3, moderately easy/moderately effective; 4, very easy/very effective; 5, extremely easy/outstanding. Pain was rated as: 0, no pain; 1, minor discomfort; 2, minor pain; 3, moderate pain; 4, severe pain; 5, could not tolerate. For Q8, operators were asked to rate the tourniquets in rank order for overall preference, with a score of 1 representing their favorite tourniquet and 5 the least favored.

In 2009, Swan published a simulation study with very low certainty evidence (downgraded for risk of bias, indirectness and imprecision) enrolling 10 volunteers that tested three improvised tourniquets: a sphygmomanometer, half inch rubber tubing, and a cloth strap with a windlass. The tourniquets were applied sequentially to the arm, forearm, thigh and leg for a total of 120 iterations. It is unclear if training occurred, although it seems likely that some did. Participants tightened the windlass, inflated the BP cuff, or wrapped the rubber tube until distal pulse was lost with Doppler signal. The blood pressure at occlusion was recorded in the sphygmomanometer group. **All devices successfully eliminated distal pulses by Doppler signal with a few exceptions: application was aborted in 2 attempts in the rubber tubing group and 1 attempt in the cloth and windlass group due to pain, and two attempts were unsuccessful in the sphygmomanometer group due to the participant's thigh being**

too large for the cuff. This resulted in a relative risk for unsuccessful application of RR 1.00 (95% CI 0.15-6.76) for rubber tubing and RR 0.50 (95% CI 0.05-5.30) for cloth and windlass when compared with a sphygmomanometer, respectively. Ease of application on a 0-3 scale (3 = easiest) was significantly different in the cloth with windlass compared with rubber tubing p<0.005. However, no other significant differences were present for ease of application or pain.

In 2011, Guo published a simulation study with very low certainty evidence (downgraded for risk of bias, indirectness and imprecision) enrolling 20 healthy military personnel. Five types of tourniquets were tested including pneumatic, commercial windlass, commercial "cargo strap", rubber tubing, and improvised canvas belt. Participants were given 15 minutes of training on tourniquet use as well as practice. Each volunteer applied each tourniquet to the non-dominant arm and to 1 leg for 200 iterations. Doppler signal was used to assess successful application. Participants were also asked to rate their experience on 0-3 scale. **Relative risk for unsuccessful application of an improvised tourniquet compared with commercial windlass was 4.75 (95% CI 1.77-12.72). Relative risk for unsuccessful application of surgical tubing compared with commercial windlass was 4.33 (95% CI 1.57-11.97).**

Table 3. Successful application rates in the upper extremity and lower extremity (*n*=20)

Types	Upper extremity (%, cases)	Lower extremity (%, cases)	X^2	*P*
Bladder tourniquet	75% (15)	100% (20)	5.714	0.047
Windlass tourniquet	80% (16)	100% (20)	2.057	0.342
Cargo-strap tourniquet	70% (14)	85% (17)	1.290	0.451
Rubber tube	60% (12)	75% (15)	1.026	0.501
Improvised tourniquet	45% (9)	60% (12)	0.476	0.731

Table 4. Application time in upper extremity and lower extremity (s, $\bar{x}$±*s*)

Types	Upper extremity	Lower extremity	*t*	*P*
Bladder tourniquet	25.78±7.87	19.59±7.52	2.362	0.024
Windlass tourniquet	18.46±4.87	16.61±4.36	1.188	0.243
Cargo-strap tourniquet	7.22±2.30	6.48±2.40	0.876	0.388
Rubber tube	14.02±3.36	13.35±3.62	0.493	0.627
Improvised tourniquet	20.96±4.43	14.74±4.22	2.465	0.033

Table 5. Subjective evaluation scores of five tourniquets by participants ($\bar{x}$±*s*)

Types	Pain	Numbness	Portability	Easiness of application
Bladder tourniquet	0.95±0.86	1.25±0.97	1.35±0.67	2.62±0.61
Windlass tourniquet	1.25±0.56	1.65±1.05	2.55±0.61	2.54±0.41
Cargo-strap tourniquet	1.50±1.61	1.20±0.75	2.40±0.88	2.80±0.47
Rubber tube	2.40±1.27	1.45±1.28	2.95±0.22	2.28±0.89
Improvised tourniquet	1.90±1.52	1.95±0.76	2.70±0.47	2.10±0.70

In 2015, Heldenberg published a simulation study with very low certainty evidence (downgraded for risk of bias, indirectness and imprecision) enrolling 23 health military volunteers who performed application of two manufactured tourniquets (CAT and SOFTT) and 1 improvised strap and windlass tourniquet (IRT). Eleven participants were non-medics and 12 were medics, and additional training was given. Participants performed application of all three tourniquet types on one partners, and self-applied the CAT and SOFTT. Applications occurred in both wet and dry conditions. 828 total applications occurred during the study, although it is unclear on how this allocation occurred. Failure was defined as palpable pulse, present Doppler signal or mechanical failure of the tourniquet. Assessment scores on a 1-5 scale for overall ease of use were as follows: CAT 4.6±10.6, SOFTT 4.0±11.0, IRT 2.1±1.0; p=<0.0001. CAT and SOFTT thigh application occurred more quickly than IRT (19±7 sec and 24± 7 sec compared with 53±23 sec). **Failure rates for IRT were higher compared with both CAT and SOFTT (35% compared with 23% and 21%) although these results were not statistically significant. For application on the thigh, the CAT had less failure than IRT (21% compared with 40%, p=0.019).**

In 2015, Altaminano published a simulation study of very low certainty evidence (downgraded for risk of bias, inconsistency, indirectness and imprecision) that compared improvised tourniquets with a windlass to improvised tourniquets without a windlass. In this study two researchers applied the tourniquets to a mannequin (HapMed tourniquet trainer). Participants were listed as "one experienced and on inexperienced in tourniquet use." It is unclear if other training occurred. The strap used was a T-shirt and windlass was chopsticks. Forty tests were performed per group per user for a total of 160 tests. **Tourniquets without a windlass failed to stop stimulated bleeding 79/80 (99%; 95% CI: 93-100%) compared to with a windlass 26/80 (32%;95% CI, 23-43%), p<0.0001.** Mean pressure applied with a windlass tourniquet was 114 mmHg (95% CI 92-136 mmHg).

In 2015, Lyles published a simulation study with very low certainty evidence (downgraded for risk of bias, inconsistency, indirectness and imprecision) involving 2 participants testing one commercial windlass tourniquet (CAT) and 2 improvised windlass tourniquets: one triangular bandage and one bandana, both with 8 chopsticks used as windlass. Participants were listed as one user with "extensive tourniquet experience" and one who was a "US Army Special Forces nonmedical officer," it seems likely that this participant had some prior knowledge of tourniquet use. It is unclear if other training occurred. Participants performed 10 tests with each type of tourniquet on a mannequin (HapMed tourniquet trained) for a total of 60 tests. **CAT effectiveness, as measured by cessation of simulated blood loss, was 100% (20/20) compared with 40% (8/20) for the triangle bandage RR 25.00 (95% CI 1.58-395.50) and 10% (2/20) RR 37.00 (95% CI 2.38-574.84) for the bandana. Pooled RR 31.24; 95% CI 2.01-486.08. CAT effectiveness as measured by cessation of simulated pulses was 100% (20/20) compared with 45% (9/20) (RR 23.00 95% CI 1.45-365.62) for the triangle bandage and 10% (2/20) for the bandana (RR 37.00 (95% CI 2.38-574.83). Pooled RR 30.22; 95% CI 1.94-470.51. CAT was applied faster (25 secs) compared with either the triangle bandages (196 secs or bandana 178 secs; p <0.0001).** Simulated blood loss was less for the CAT (159mL) compared with the triangle bandage or bandana (548ml and 567 mL, respectively; p<0.0001). No components of any tourniquet broke.

In 2015, Kragh published a simulation study with very low certainty evidence (downgraded for risk of bias, inconsistency, indirectness and imprecision) involving two participants testing multiple windlass types with a triangular bandage with windlass improvised tourniquet on mannequin simulator (HapMed tourniquet trainer). Participants were listed as two investigators "familiar with military tourniquet training and clinical use of tourniquets."   Effectiveness was determined by cessation of simulated blood loss and absence of simulated distal pulse. Windlass types including chopsticks, pencils and craft sticks, with increasing numbers of each item taped together. When only two chopsticks were used as a windlass the tourniquet was 100% effective for both users. The number of items taped together was associated inversely with breakage percentage (p<0.0001). **Craft sticks had the highest percentage of breakage followed by pencils and chopsticks (53.2%, 26.1% and 20.7%; p<0.005).**

Table 1. Effective tests by windlass type, windlass number, and user

Windlass type	*Windlass number*	*Tests per user (n)*	*Effective tests, user 1 (n)*	*Effective tests, user 2 (n)*	*Effectiveness percentage (total tests, n)*
Chopstick	1	20	10	7	42% (40)
	2	20	20	20	100% (40)
Pencil	1	20	19	2	52% (40)
	2	20	19	18	92% (40)
	3	20	20	13	82% (40)
	4	20	NA	20	100% (20)
Craft stick	1	20	0	0	0% (40)
	2	20	12	12	60% (40)
	3	20	20	18	95% (40)
	4	20	NA	20	100% (20)

NA, not applicable.

Table 4. Results of windlass breakage by windlass type

	Breakage		
Windlass type	*No*	*Yes*	*Total*
Chopstick	57	23	80
Pencil	111	29	140
Craft stick	81	59	140
Total	249	111	360

Data represent sum of all iterations, users, and windlasses.

Table 3. Results of windlass breakage by windlass turn number

	Breakage		
Turn number	*No*	*Yes*	*Total*
1	40	61	101
2	143	34	177
3	52	13	65
4	14	3	17
Total	249	111	360

Data represent sum of all iterations, users, and windlasses.

Table 5. Results of windlass breakage by windlass number

	Breakage		
Windlass number	*No*	*Yes*	*Total*
1	38	82	120
2	102	18	120
3	69	11	80
4	40	0	4
Total	249	111	360

Data represent sum of all iterations, users, and windlasses.

There is very limited data regarding the use of improvised tourniquets for the treatment of life-threatening hemorrhage, comparative studies as comprised of 22 individuals. In contrast, the vast majority of data for human tourniquet use comes from military and now emerging civilian use of manufactured tourniquets. Based on this data, the use of a manufactured tourniquet is recommended over the use of an improvised tourniquet. However, there is some limited evidence that trained providers can use improvised tourniquets to eliminate distal pulses in volunteer and simulation studies. Additional research is needed to determine if the lay responder can effectively use an improvised tourniquet and if so which types of improvised tourniquet should be used. As all tourniquets, both manufactured and improvised, rely on the principal of a circumferential wrap and mechanism of tightening to occlude distal pulses, instructors must be familiar with the concept of tourniquet function and application as a method of applying indirect pressure.

<u>2022 Updated Scientific Foundation:</u>

In this update to the initial 2019 Scientific Review, a literature search was conducted in PubMed from January 1, 2018, to July 12, 2021. An additional 7 articles were identified in this triennial review; 6 were simulation studies and 1 was a systematic review. Studies continue to be conducted with participants who generally have either some medical knowledge or received some training on applying a commercial and improvised tourniquet. One study demonstrated some success in application of an improvised strap (such as a shirt or strip of fabric) and windlass tourniquet on a tourniquet training manikin through just in time emergency dispatcher instructions (Scott 2020). The success rate for stopping simulating bleeding was inferior to the CAT tourniquet but superior to the SAM XT tourniquet. Studies continue to demonstrate that manufactured tourniquet are more reliable at being applied appropriately and stopping simulated bleeding or distal blood flow, particularly for windlass style tourniquets (Scott 2020, McCarty 2019, Ellis 2020, Hay-David 2021). However, in one study (McCarty 2019) a strap (6 ft piece of gauze or belt) and windlass (heavy wooden rod) improvised tourniquet had better success in stopping simulated blood flow than the SWAT-T or RATS tourniquets.

A systematic review evaluating the literature on improvised tourniquets reported that in the retrieved studies, improvised tourniquets seem unable to reliably achieve the marker of success. Of the various improvised designs in the reviewed studies, the band and windlass, was most successful in achieving the outcome of success. Designs without a windlass, including rope and belts generally demonstrated a lower success rate. However, one study published subsequent to this systematic review suggests that an improvised tourniquet using a leather belt can be applied more quickly with an equal time to hemostasis as both improvised windlass tourniquets and manufactured tourniquets (Cremonini 2020). Several studies in this and prior reviews that indicate the windlass mechanism may break if not robust enough. In a current study a wooden rod was superior to PVC pipe and in the original 2019 Red Cross review 2 chopsticks were superior to up to three pencils or craft sticks in preventing windlass breakage (Kragh 2015).

Studies were conducted in adults 18 years of age or older, who were medical personnel and who appeared to have a higher level of education. Studies had 50-60% male participates. There is a lack of data in those with lower education or socioeconomic status. These individuals may benefit most from improvised tourniquets due to the cost of manufactured tourniquets and the epidemiology of certain types of trauma.

Overview of Recommendation:

The majority of evidence demonstrates that manufactured tourniquets achieve markers of success in simulation studies more commonly than improvised tourniquets. Therefore, manufactured tourniquets continue to be recommended over improvised tourniquets. However, very little data is available in real world studies, and some simulation studies demonstrate that improvised tourniquets can stop distal blood flow if applied appropriately, often by trained personnel. If a manufactured tourniquet is not available a provider should consider other options, including an improvised tourniquet per SAC guidelines, if they are trained to do so. Improvised tourniquets using a rod and windless have the most data supporting their use. If an improvised tourniquet is attempted, a band and windlass design is preferred. The windless system used should be sturdy enough to avoid breakage during tightening.

PROGRESS-Plus Statement

Studies were primarily conducted in military or medical personnel. Only one study enrolled participants from the general employees of a football stadium. Therefore, socioeconomic status and education of the majority of participants was likely to be at or above the general population. Participants in studies were roughly of equal gender and were all greater than or equal to 18 years of age. Trauma is the leading cause of death for young people aged 1-45 years-old. (CDC 2021) Mortality from trauma disproportionally affects those of lower socioeconomic status and Black race (Ali 2013, Haider 2013, Loberg 2018, Popal 2021). In addition, penetrating trauma is more prevalent in these populations and may contribute to the risk of mortality. (Loberg 2018) Data on these populations are lacking in the current studies published on improvised tourniquets. As improvised tourniquets present a lower cost option to those of lower socioeconomic status, research is needed to determine the cost benefit ratio of improvised tourniquets in these populations.

2022 Updated Specific Recommendations and Strength

Standards:
A manufactured tourniquet is preferred over an improvised tourniquet for the treatment of life-threatening extremity bleeding. (See American Red Cross Scientific Advisory Council, Scientific Review, Tourniquets for Life-Threatening Bleeding, rev. June 2021)

Guidelines:
If a manufactured tourniquet is not immediately available for life-threatening extremity bleeding, the provider should consider other options including direct pressure (with a hemostatic dressing, if available) or improvised tourniquet, if trained to do so, per SAC guidelines (see SAC Answers Science Summary for the Control of Life-Threatening Bleeding Jan 2021).

Options: Using a manufactured tourniquet approved by the Committee on Tactical Combat Casualty Care is preferred over other types of tourniquets. (see https://deployedmedicine.com/market/31/content/100?fbclid=IwAR23_DajEqhXIvTBozbDK8CSl_7PQugzEv1Q14yr3Bj9Jf2srZeNdvKqJ_E for list of currently approved CoTCCC tourniquets.)

- If an improvised tourniquet is used, a strap and windlass style tourniquet has the most evidence for the ability to occlude distal pulses. The windlass device (see Figure 1 below) should be sturdy enough to prevent breaking during tightening of the band.

    Note: Windlass examples used in studies include a 5/8” diameter wooden rod, wooden cooking spoon, and two chopsticks. (Figure 1 for examples)

Knowledge Gaps and Future Research:

As improvised tourniquets present a lower cost option to those of lower socioeconomic status, research is needed to determine the cost benefit ratio of improvised tourniquets in these populations.

Implications for American Red Cross Programs:

First aid instructors must be familiar with the concept of tourniquet function and application as a method of applying indirect pressure.

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	Key results and magnitude of results	Support, Neutral or Oppose Question	Level of Evidence (Using table below)	Quality of study (excellent, good, fair or poor) and why
Altamirano MP, Kragh JF, Aden JK, Dubick MA	Role of the Windlass in Improvised Tourniquet Use on a Mannequin Hemorrhage Model. J Spec Oper	Simulation study that compared improvised tourniquets with a windlass to improvised tourniquets without a windlass in which 2 researchers applied the tourniquets to a mannequin. The strap used was a T-shirt and	Simulation	Serious	Serious/Serious/Serious	Tourniquets without a windlass failed to stop stimulated bleeding 79/80 (99%; 95% CI: 93-100%) compared to with a windlass 26/80 (32%;95% CI, 23-43%), p<0.0001.	Neutral	4	Poor, simulation study that involved only 2 participants

	Med. 2015;15(2):42-6	windlass was chopsticks. Forty tests were performed per group per user for a total of 160 tests.				Mean pressure applied with a windlass tourniquet was 114 mmHg (95% CI 92-136 mmHg).			
Guo JY, Liu Y, Ma YL, Pi HY, Wang JR	Evaluation of emergency tourniquets for prehospital use in China. Chin J Traumatol. 2011;14(3):151-5	Simulation study enrolling 20 healthy military personnel testing 5 types of tourniquets: tested including pneumatic, commercial windlass, commercial "cargo strap", rubber tubing, and improvised canvas belt. Participants were given 15 minutes of training on tourniquet use as well as practice. Doppler signal was used to assess successful application.	Simulation	Serious	Serious/Serious/Not serious	RR for unsuccessful application of an improvised tourniquet compared with commercial windlass was 4.75 (95% CI 1.77-12.72). Relative risk for unsuccessful application of surgical tubing compared with commercial windlass was 4.33 (95% CI 1.57-11.97).	Oppose	4	Poor, simulation study in healthy volunteers.

		Participants were also asked to rate their experience on 0-3 scale.							
Heldenberg E, Aharony S, Wolf T, Vishne T.	Evaluating new types of tourniquets by the Israeli Naval special warfare unit. Disaster Mil Med. 2015;1(1)	Simulation study enrolling 23 health military volunteers who performed application of two manufactured tourniquets 1 improvised strap and windlass tourniquet. Training was given. 828 total applications occurred during the study, although it is unclear on how this allocation occurred. Failure was defined as palpable pulse, present Doppler signal or mechanical failure of the tourniquet.	Simulation	Serious	Serious/Serious/Not Serious	Assessment scores on a 1-5 scale for overall ease of use were as follows: CAT 4.6±10.6, SOFTT 4.0±11.0, IRT 2.1±1.0; p=<0.0001. CAT and SOFTT thigh application occurred more quickly than IRT (19±7 sec and 24± 7 sec compared with 53±23 sec). Failure rates for IRT were higher compared with both CAT and SOFTT (35%	Oppose	4	Poor, simulation study using healthy volunteers

						compared with 23% and 21%) although these results were not statistically significant. For application on the thigh, the CAT had less failure than IRT (21% compared with 40%, p=0.019).			
King RB, Filips D, Blitz S, Logsetty S	Evaluation of possible tourniquet systems for use in the Canadian Forces. J Trauma.	Simulation study testing 5 different tourniquet systems with 10 healthy volunteers. Tourniquets tested were: improvised cloth and windlass (IT), self-applied tourniquet system (SATS) (ratcheting	Simulation	Serious	Serious/Serious/Not serious	Elimination of a pulse for summer and winter uniforms, occurred 70%/30% for Improvised tourniquet, 100%/90% for surgical tubing, and 60%/50% for the manufacture	Oppose	4	Poor, simulation study using healthy volunteers.

	2006;60(5):1061-71	system), one-hand tourniquet (OHT) (belt type), pneumatic emergency medical tourniquet (EMT), latex surgical tubing (ST). All participants reported understanding of each tourniquet system prior to beginning the study. Five two person teams applied each tourniquet system; team members applied each tourniquet to each other then rotated, teams rotated through twice, once with summer uniform and once with winter uniform (applied over uniform)				d tourniquet. RR for failure to eliminate of Dopplerable pulse was 1.40 (95% CI 1.11-1.77) for the improvised tourniquet compared with self-applied tourniquet system. RR for elimination of Dopplerable pulse was 0.0099 (95% CI 0.0006-0.16) for the surgical tubing compared with self-applied tourniquet system. There was a significant			

		resulting in 100 different applications. Applications only occurred on the lower extremities. Successful application was noted by lack of palpable pulse with subsequent measurement of pulse by Doppler.				difference between pain scores for the different types of tourniquets ($p < 0.001$). Of note, the ST was noted to be the second most painful after the IT by a small margin.			
King DR, Larentzakis A, Ramly EP.	Tourniquet use at the Boston Marathon bombing: Lost in translation. J Trauma Acute Care Surg. 2015;78(3):594-9	Case series evaluating 35 patients with recognized life-threatening extremity injury after explosion at Boston marathon. Twenty-seven had tourniquets applied to the wound pre-hospital, all were improvised.	Case series	Serious	Not serious/ Serious/ Not serious	Eight patients with life-threatening extremity wounds presented to the ED without a tourniquet. No deaths occurred in either group. A subset of 10 patients with major vascular injury, 5 with	Neutral	3b	Poor, case series with no comparative data

						pre-hospital tourniquet and 5 without a tourniquet were analyzed. No deaths occurred in either group. All patients had a similar injury severity score with no significant difference in SBP, HR or GCS.			
Kue RC, Temin ES, Weiner SG, et. al.	Tourniquet Use in a Civilian Emergency Medical Services Setting: A Descriptive	Case series of 98 cases of prehospital tourniquet use in the pre-hospital setting from 2005-2012. The majority were placed by emergency medical services. Sixty-sixty of the 98 were placed for penetrating	Case series	Serious	Not serious/ Serious/ Not serious	Eighty-seven of 95 (91.6%, 95% CI 85.9-97.3%) with available data resulted in successful hemorrhage control.	Neutral	3b	Poor, case series with no comparative data

	Analysis of the Boston EMS Experience. Prehosp Emerg Care. 2015 Jul-Sep;19(3):399-404. doi: 10.3109/10903127.2014.995842. Epub 2015 Feb 9.	trauma and 15 were place for a bleeding hemodialysis shunt. A flexible rubber surgical tubing was used 94/98 cases. One BP cuff was used, which was successful in hemorrhage control. In three cases of bystander-placed tourniquets the type was not recorded.							
Kragh JF, Wallum TE, Aden JK, Dubick MA, Baer DG.	Which Improvised Tourniquet Windlasses Work Well and	Simulation study involving two participants testing multiple windlass types with a triangular bandage with windlass improvised tourniquet on	Simulation	Serious	Serious/ Serious/ Serious	When only two chopsticks were used as a windlass the tourniquet was 100% effective for both users.	Neutral	4	Poor, simulation study that involved only 2 participants

	Which Ones Won't? Wilderness Environ Med. 2015;26(3):401-5	mannequin simulator (HapMed tourniquet trainer). Effectiveness was determined by cessation of simulated blood loss and absence of simulated distal pulse. Windlass types including chopsticks, pencils and craft sticks, with increasing numbers of each item taped together.				The number of items taped together was associated inversely with breakage percentage (p<0.0001). Craft sticks had the highest percentage of breakage followed by pencils and chopsticks (53.2%, 26.1% and 20.7%; p<0.005).			
Lakstein D, Blumenfeld A, Sokolov T, et. al.	Tourniquets for hemorrhage control on the battlefield: a 4-year accumulated	Observational study retrospectively evaluating charts for all cases of tourniquet use in the military prehospital setting. One-hundred-ten tourniquets were	Observational	Not serious	Not serious/ Serious/ Not serious	Of data reported, 13/18 (72%) improvised cloth and windlass tourniquets were effective compared with 20/30	Support	2b	Poor, subset of main population, low numbers, only comparative data on one body part.

	experience. J Trauma. 2003;54(5):Suppl S221-5	applied to 91 patients during this time period.				(66%) silicon band tourniquets when applied to the thigh (RR 0.83; 95% CI 0.34-2.05). The overall complication rate was 5.5%, although no other data is reported comparing improvised with manufactured.			
Lyles WE, Kragh JF, Aden JK, M. A. Dubick MA.	Testing Tourniquet Use in a Mannequin Model: Two Improvised Techniques. J Spec	Simulation study involving 2 participants testing one commercial windlass tourniquet (CAT) and 2 improvised windlass tourniquets: one triangular bandage and one bandana, both	Simulation	Serious	Serious/ Serious/ Serious	CAT effectiveness, as measured by cessation of simulated blood loss, was 100% (20/20) compared with 40% (8/20) for the triangle bandage RR	Oppose	4	Poor, simulation study that involved only 2 participants

	Oper Med. 2015;15(4):21-6	with 8 chopsticks used as windlass. Participants performed 10 tests with each type of tourniquet on a mannequin (HapMed tourniquet trained) for a total of 60 tests.				25.00 (95% CI 1.58-395.50) and 10% (2/20) RR 37.00 (95% CI 2.38-574.84) for the bandana. Pooled RR 31.24; 95% CI 2.01-486.08. CAT effectiveness as measured by cessation of simulated pulses was 100% (20/20) compared with 45% (9/20) (RR 23.00 95% CI 1.45-365.62) for the triangle bandage and 10% (2/20) for the bandana (RR 37.00 (95% CI 2.38-			

						574.83). Pooled RR 30.22; 95% CI 1.94-470.51. CAT was applied faster (25 secs) compared with either the triangle bandages (196 secs or bandana 178 secs; p <0.0001). Simulated blood loss was less for the CAT (159mL) compared with the triangle bandage or bandana (548ml and 567 mL, respectively; p<0.0001).			
Passos E, Dingley	Tourniquet use for	Observational trial with very low certainty	Observational	Serious	Serious/ Serious/ Not serious	No deaths occurred in either group	Support	2b	Poor, subset of main

B, Smith A, et. al.	peripheral vascular injuries in the civilian setting. 7 Injury. 2014;45(3):573-7	evidence (downgraded for risk of bias, indirectness and imprecision) that in a subgroup analysis evaluated 8 patients at two level one trauma centers that had arterial injuries after extremity trauma. Four patients had an improvised pre-hospital tourniquet and 4 had manufactured tourniquet placed in early after hospital arrival (pneumatic BP cuff).				(RR 1.00; 95% CI 0.02-41.22).			population, very small number.
Swan KG Jr, Wright DS, Barbagiovanni SS, Swan BC,	Tourniquets revisited. J Trauma. 2009 Mar;66(3):672	Simulation study enrolling 10 volunteers that tested three improvised tourniquets: a sphygmomanometer, half inch	Simulation	Serious	Serious/ Serious/ Not serious	RR for unsuccessful application of RR 1.00 (95% CI 0.15-6.76) for rubber tubing and	Support	4	Poor, simulation study, no comparison with manufactured tourniquet

Swan KG.	-5. doi: 10.1097/TA.0b013e3181986959.C299	rubber tubing, and a cloth strap with a windlass. The tourniquets were applied sequentially to the arm, forearm, thigh and leg for a total of 120 iterations.				RR 0.50 (95% CI 0.05-5.30) for cloth and windlass when compared with a sphygmomanometer, respectively. Ease of application on a 0-3 scale (3 = easiest) was significantly different in the cloth with windlass compared with rubber tubing p<0.005. However, no other significant differences were present for ease of application or pain.			

2022 Updated Summary of Key Articles/Literature Found and Level of Evidence/Bibliography:

Author(s)	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	Key results and magnitude of results	Support, Neutral or Oppose Question	Level of Evidence (Using table below)	Quality of study (excellent, good, fair or poor) and why
Scott 2020	Commercial and improvised tourniquets were applied in a simulated setting with emergency dispatcher instructions.	Prospective randomized trial with lay person volunteers. Study done on a bleeding control model.	Serious, researchers appear to be unblended.	Serious	82% of the improvised tourniquet applications, the "patient" was deemed to be stable after tourniquet application. This was 89% for the CAT tourniquet and 70% for the SAM XT tourniquet (p = 0.003).	Neutral	4	Fair, study done in a model, no apparent blinding.
McCarty 2019	Commercial and improvised tourniquets were applied in a simulated setting after enrollees participated in a B-Con course.	An unblinded, crossover, sequential randomized clinical trial	Serious	Serious	The CAT was correctly applied at a significantly higher rate (94 [92.2%];	Neutral	4	Fair, Fair, study done in a model, no blinding.

					95% CI, 85.1%-96.6%) than all other tourniquet types (P < .001 for each pairwise comparison). The windlass-based SOFT-T had the second highest rate of correct application (70 [68.6%]; 95% CI, 58.7%-77.5%) followed by the improvised tourniquet (33 [32.4%]; 95% CI, 23.4%-42.3%), the SWAT-T (12 [11.8%]; 95% CI, 6.2%-			

					19.6%), and the RATS (12 [11.8%]; 95% CI, 6.2%-19.6%).The CAT exerted the most pressure of all tourniquet types (mean [SD], 390.0 [108.1] mm Hg) followed by the SOFT-T (mean [SD], 309.6 [158.2] mm Hg), improvised tourniquet (mean [SD], 160.9 [166.8]mmHg), SWAT-T (mean [SD], 109.7 [130.1] mm Hg), and RATS (mean [SD], 92.4 [113.9] mm Hg).			

Hay-David 2020	Commercial and improvised tourniquets were applied in a simulated setting by one of the authors.	Prospective study with only one participant who applied all the tourniquets. No apparent randomization/	Serious	Serious	Time to occlusion/application: SOFTT-W 25/32; C-A-T 27/32 secs; SWAT-T 3360 secs; Tourni-key Plus 40/58; tie and wooden spoon 26/42 secs	Neutral	4	Poor, single person study with experience applying tourniquets and done on a model.
Ellis 2020	Commercial and improvised tourniquets were applied on a single human model by emergency medicine residents	Prospective study, no apparent randomization, no blinding	Serious	Serious	Success rates for distal arterial flow cessation were 89% CAT7; 67% SWAT-T; 89% RATS; and 78% TK (H 0.89; P = .83). Mean (SD) application times were 10.4 (SD = 1.7) seconds CAT7; 23.1 (SD = 9.0)	Neutral	4	Fair, conducted with medical personnel, no blinding or apparent randomization.

					seconds SWAT-T; 11.1 (SD = 3.8) seconds RATS; and 20.0 (SD = 7.1) seconds TK (F 9.71; P <.001).			
Cremoni ni 2020	Commercial and improvised tourniquets were applied on a perfused cadaver model by 48 medical student volunteers	Randomized, unblinded study in a perfused cadaver model	Serious	Serious	Success rate, time to application, time to hemostasis: CAT 100%, 37.0, 37.3; RATS 95.8, 34.0, 33.0; SWAT-T 100, 47.8, 39.0; Windlass 100, 32.0, 34.0; belts 100, 15.2, 38.6. p values 0.20, <0.05, 0.24, respectively.	Neutral	4	Fair, conducted with medical personnel, no blinding
Taylor 2021	Inguinal compression or a roper tourniquet was applied to study participants	Prospective trial, unblended, no	Serious	Serious	Pooled data from each intervention showed that	Oppose	4	Poor, conducted with medical

		apparent randomization,			inguinal compression resulted in a mean reduction of popliteal artery peak systolic velocity of 89.7% (95% CI 83.9%, 95.5%) compared to leg rope application 43.8% (95% CI 34.5%, 53.1%; P ≤ 0.001).			personnel, no blinding, rope tourniquet design may have been inadequate.
Cornelissen 2021	Systematic review of improvised tourniquets for life-threatening hemorrhage	Systematic review of the literature. PubMed, EMBASE.com and Cochrane Library were searched.			Twenty studies were included. In both simulated experiments and real-life situations, manufactured TQs outperformed improvised TQs regarding	Oppose	1a (no metanalysis)	Good, high quality systematic review, although with heterogeneity between studies, comparisons are difficult and no metanalysis

					success rate. Of the I-TQs, the band and windlass design performed most consistently. Although lacking any statistical analysis, there was no reported difference in adverse events between I-TQs and C-TQs.				was able to be performed.

2022 Articles Summaries

Scott G, Olola C, Gardett MI, Ashwood D, Broadbent M, Sangaraju S, Stiegler P, Fivaz MC, Clawson JJ. Ability of Layperson Callers to Apply a Tourniquet Following Protocol-Based Instructions From an Emergency Medical Dispatcher. Prehosp Emerg Care. 2020 Nov-Dec;24(6):831-838. doi: 10.1080/10903127.2020.1718259. Epub 2020 Mar 3. PMID: 31961756.

This was a prospective, randomized trial involving layperson volunteers to determine whether layperson callers can effectively stop simulated bleeding using an improvised or a commercial tourniquet, when provided with scripted instructions via phone from a trained protocol-aided emergency dispatcher. Volunteers were assigned randomly to three groups: one for each of two commonly available commercial tourniquets and one for an improvised tourniquet. For the improvised tourniquet the caller was instructed to fashion a strap-and-windlass type of tourniquet with commonly available materials, such as a shirt or strip of fabric. Following the emergency dispatcher's instructions, each participant attempted to place the tourniquet onto a HapMed Leg Tourniquet Trainer. A total of 246 subjects participated in the study. The overall median time for all trials (i.e., elapsed time from the start to the end of the simulation) was 3 minutes and 19 seconds. Median time to stop the bleeding (i.e., elapsed time from the start of the simulation to the time the participant was able to successfully stop the bleeding) was 2 minutes and 57 seconds. Median tourniquet pressure was 256 mmHg and median-end blood loss was 1,365 mL. A total of 198 participants (80.49%) were able to completely stop the bleeding while 16 participants (6.5%) had the tourniquet applied with some bleeding still occurring, and 32 participants (13.01%) exceeded the threshold of 2,500mL of blood loss, resulting in the "patient" not surviving. In 82% of the improvised tourniquet applications, the "patient" was deemed to be stable after tourniquet application. This was 89% for the CAT tourniquet and 70% for the SAM XT tourniquet (p = 0.003).

TABLE 3. Overall survival statuses of patients

Measure	Not stable[a] n (%)	Stable n (%)	*p*-value
Gender			
Female	31 (23%)	104 (77%)	0.1788
Male	17 (15%)	94 (85%)	
Tourniquet type			
CAT	10 (11%)	85 (89%)	0.003
SAM XT	26 (30%)	60 (70%)	
Improvised	12 (18%)	53 (82%)	
Pressure status[b]			
Good	3 (2%)	182 (98%)	<0.001
Loose	45 (75%)	15 (25%)	
Tight	0 (0%)	1 (100%)	

[a]Bleeding or dead.
[b]Variable taken from exit survey. Tourniquet pressure status was defined as 'loose' if it was below 200 mmHg, although it was still possible to stop or slow the simulated bleeding with a high-end 'loose' reading.

McCarty JC, Hashmi ZG, Herrera-Escobar JP, et al. Effectiveness of the American College of Surgeons Bleeding Control Basic Training Among Laypeople Applying Different Tourniquet Types: A Randomized Clinical Trial. *JAMA Surg.* 2019;154(10):923–929. doi:10.1001/jamasurg.2019.2275

This nonblinded, crossover, sequential randomized clinical trial with internal control assessed a volunteer sample of laypeople who attended a B-Con course at Gillette Stadium and the Longwood Medical Area in Boston, Massachusetts, for correct application of each of 5 different tourniquet types immediately after B-Con training. Full B-Con course, including cognitive and skill sessions that taught bleeding care, wound pressure and packing, and CAT application. Tourniquets tested included the Special Operation Forces Tactical Tourniquet, Stretch-Wrap-and-Tuck Tourniquet, Rapid Application Tourniquet System, CAT and improvised tourniquet. The order of application varied for each participant using randomly generated permutated blocks. For the improvised tourniquet, participants were given an assortment of materials and told that they could use any of or all the available components. Components included a 6-ft length of gauze, a shoestring, a leather belt, and a 12-in polyvinyl chloride plastic or heavy wooden rod. Participants were blinded to what tourniquets they would be applying other than the CAT until the moment of each test. Correct tourniquet application included an applied pressure of > 250 mmHg with a 2-minute time cap. A total of 102 participants (50 [49.0%] male; median [interquartile range] age, 37.5 [27.0-53.0] years) were included in the study. The CAT was correctly applied at a significantly higher rate (94 [92.2%]; 95% CI, 85.1%-96.6%) than all other tourniquet types (P < .001 for each pairwise comparison). The windlass-based SOFT-T had the second highest rate of correct application (70 [68.6%]; 95% CI, 58.7%-77.5%) followed by the improvised tourniquet (33 [32.4%]; 95% CI, 23.4%-42.3%), the SWAT-T (12 [11.8%]; 95% CI, 6.2%-19.6%), and the RATS (12 [11.8%]; 95% CI, 6.2%-19.6%).The CAT exerted the most pressure of all tourniquet types (mean [SD], 390.0 [108.1] mm Hg) followed by the SOFT-T (mean [SD], 309.6 [158.2] mm Hg), improvised tourniquet (mean [SD], 160.9 [166.8]mmHg), SWAT-T (mean [SD], 109.7 [130.1] mm Hg), and RATS (mean [SD], 92.4 [113.9] mm Hg). For fashioning an improvised tourniquet, participants used 1 or more of the following available materials: leather belt, 37 (36.3%); gauze, 49 (48.0%); shoelace, 60 (58.8%); and a windlass, 80 (78.4%). During the first session of 10 participants, a 12-in-long heavy-duty polyvinyl chloride pipe was available as the windlass. This device broke in 7 instances secondary to the torque applied when used as a windlass. In all subsequent sessions, a 12-in heavy wooden rod was used. A windlass was used with the belt in 24 cases, and in 11 (45.8%) of these cases, the tension from the windlass caused the belt to break at the buckle or the strap. Among the 22 participants who did not use a windlass, 1 (4.6%) was able to correctly apply an improvised tourniquet.

Ellis, J., Morrow, M., Belau, A., Sztajnkrycer, L., Wood, J., Kummer, T., & Sztajnkrycer, M. (2020). The Efficacy of Novel Commercial Tourniquet Designs for Extremity Hemorrhage Control: Implications for Spontaneous Responder Every Day Carry. Prehospital and Disaster Medicine, 35(3), 276-280. doi:10.1017/S1049023X2000045X

The purpose of the current study was to compare the efficacy of three novel commercial TQ designs to a military-approved TQ. Nine Emergency Medicine residents evaluated four different TQ designs: Gen 7 Combat Application Tourniquet (CAT7; control), Stretch Wrap and Tuck Tourniquet (SWAT-T), Gen 2 Rapid Application Tourniquet System (RATS), and Tourni-Key (TK)(combined with a Men’s necktie). Success rates for distal arterial flow cessation were 89% CAT7; 67% SWAT-T; 89% RATS; and 78% TK (H 0.89; P = .83). Mean (SD) application times were 10.4 (SD = 1.7) seconds CAT7; 23.1 (SD = 9.0) seconds SWAT-T; 11.1 (SD = 3.8) seconds RATS; and 20.0 (SD = 7.1) seconds TK (F 9.71; P <.001). Steady state maximal forces were 29.9 (SD = 1.2) N CAT7; 23.4 (SD = 0.8) N SWAT-T; 33.0 (SD = 1.3) N RATS; and 41.9 (SD = 1.3) N TK. All novel TQ systems were non-inferior to the military-approved CAT7. Mean application times were less than 30 seconds for all four designs.

Cremonini C, Nee N, Demarest M, Piccinini A, Minneti M, Canamar CP, Benjami ER, Demetriades D, Inaba K. Evaluation of the efficacy of commercial and noncommercial tourniquets for extremity hemorrhage control in a perfused cadaver model. J Trauma Acute Care Surg. 2021 Mar 1;90(3):522-526. doi: 10.1097/TA.0000000000003033. PMID: 33230091.

This prospective randomized study used a perfused-cadaver model with standardized superficial femoral artery injury bleeding at 700 mL/min. Five tourniquets were tested: combat application tourniquet; rapid application tourniquet system; Stretch, Wrap, And Tuck Tourniquet; an improvised triangle bandage windlass; and a leather belt. For the windlass tourniquet, a cloth triangle bandage measuring 40x40x50 inches and a wooden dowel measuring 12x5/8 inches were used. The cloth was folded into a 1- to 2-in strip and tied into a fixed loop around the limb. The dowel was placed inside the loop. The dowel was then turned clockwise or counterclockwise to tighten the windlass around the limb. For the leather belt tourniquet, a standard leather belt, 1.5-in thick, size 32 with a metal buckle was wrapped around the limb above the injury, threading the free end through the metallic cleat of the belt. The belt was then tightened, pulling the free end in the opposite direction of the first wrap until the bleeding was stopped. Forty-eight medical students underwent a practical hands-on demonstration of each tourniquet. Time to hemostasis, time to secure devices, estimated blood loss, and difficulty rating were assessed. The mean ± SD participant age was 25 ± 2.6 years, and 29 (60%) were male. All but one tourniquet was able to stop bleeding, but the rapid application tourniquet system had a 4% failure rate. Time to hemostasis and estimated blood loss did not differ significantly ($p > 0.05$). Stretch, Wrap, And Tuck Tourniquet required the longest time to be secured (47.8 ± 17.0 seconds), whereas the belt was the fastest (15.2 ± 6.5 seconds; $p < 0.001$). The improvised windlass was rated easiest to learn and apply, with 22 participants (46%) assigning a score of 1. Four of the tourniquets (CAT, SWAT-T, the windlass, and the belt) successfully stopped the bleeding in all attempts. Two participants (4.2%) were unable to achieve hemostasis with the RATS tourniquet within the allotted 4 minutes. In regard to time required to apply the tourniquet, the SWAT-T took the longest time to be placed (47.8 ± 17.0 seconds), while the belt was the fastest (15.2 ± 6.5 seconds; $p < 0.001$). With respect to time to achieve hemostasis, there was no statistically significant difference in the time to hemostasis between the five tourniquets. For estimated blood loss, the CAT had the highest estimated blood loss (240.7 ± 125.7 mL), and the belt had the lowest (190.3 ± 119.8 mL), although the difference between the five tourniquets was not statistically significant.

TABLE 2. Tourniquet Efficacy

	CAT	RATS	SWAT-T	Windlass	Belt	*p*
Success, n (%)	48 (100)	46 (95.8)	48 (100)	48 (100)	48 (100)	0.20
Time to application, mean ± SD, s	37.0 ± 16.5	34.0 ± 11.0	47.8 ± 17.0	32.0 ± 12.8	15.2 ± 6.5	<0.05
Time to hemostasis, mean ± SD, s	37.7 ± 16.2	33.0 ± 10.3	39.0 ± 17.0	34.0 ± 12.7	38.6 ± 28.8	0.24
Blood loss, mean ± SD, mL	240.7 ± 125.7	236.7 ± 195.6	214.0 ± 138.3	205.7 ± 97.0	190.3 ± 119.8	0.07

Taylor NB, Lamond DW. Stopping Haemorrhage by Application of Rope tourniquet or inguinal Compression (SHARC study). Emerg Med Australas. 2021 Feb 7. doi: 10.1111/1742-6723.13736. Epub ahead of print. PMID: 33554450.

This study evaluated the used of inguinal compression compared with an improvised tourniquet made from a surfboard leash for control of lower limb hemorrhage. A Doppler ultrasound to record the reduction in popliteal artery peak systolic velocity created by surfboard leg rope tourniquet and by inguinal region external compression in healthy volunteer subjects with and without a wetsuit. A standard, commercially available surfboard leg rope was wrapped twice around the proximal thigh and then a double hitch was tied. Maximal tension was then applied and maintained by the volunteer pulling on each end of the leg rope. Popliteal artery peak systolic velocity was measured at 30 s post-tension application. Pooled data from each intervention without and with a wetsuit showed that inguinal compression resulted in a mean reduction of popliteal artery peak systolic velocity of 89.7% (95% CI 83.9%, 95.5%) compared to leg rope application 43.8% (95% CI 34.5%, 53.1%; $P \leq 0.001$). There was no significant influence by the wetsuit on effectiveness of either intervention technique.

Hay-David AGC, Herron JBT, Thurgood A, Whittle C, Mahmood A, Bodger O, Hodgetts TJ, Pallister I. A Comparison of Improvised and Commercially Available Point-of-Wounding Tourniquets in Simulated Traumatic Amputation with Catastrophic Hemorrhage. Mil Med. 2020 Sep 18;185(9-10):e1536-e1541. doi: 10.1093/milmed/usaa085. Erratum in: Mil Med. 2021 Feb 26;186(3-4):e463. PMID: 32426823.

This study evaluated the use of improvised and 4 commercially available tourniquets to investigate the time taken to stop simulated bleeding and to secure the device; evidence of rebleeding when the “blood pressure” was restored and to gain qualitative feedback on their application. Four commercially available tourniquets (Combat Application Tourniquet [CAT], Special Operations Forces Tactical Tourniquet - Wide (SOFTT-W), stretch, wrap, and tuck tourniquet [SWAT-T], and the Tourni-key) and an improvised tourniquet (tie & wooden spoon) were tested on a complex silicone simulation model used to replicate catastrophic hemorrhage from a blast injury with above traumatic knee amputation. The same investigator applied each tourniquet and each was tested 3 times. None of the devices took longer than 1 minute to secure. The SOFTT-W was the fastest to achieve occlusion in 25 seconds and was joint fastest (with the CAT) to apply in 32 seconds. In spite of this, it performed the worst on secondary hemorrhage—this being a problem on 2 out of the 3 attempts. The CAT took an average of 27 seconds to stop the bleeding, and tied with second with an average time to apply of 32 seconds. There was no secondary hemorrhage. The SWAT-T took an average time of 33 seconds to stop the bleeding, taking the longest to apply in 60 seconds on average. There was no secondary hemorrhage. It was found to have the least obvious ligature effect. The Tourni-key Plus includes a triangular bandage and an antipinch card. It took an average of 40 seconds to stop bleeding. Total application time took on average 58 seconds. It was found to be secure and there was no secondary hemorrhage. A tie and wooden spoon was the second fastest to stop bleeding (average 26 seconds) and apply in an average of 42 seconds, there was no secondary hemorrhage. This had a very clear ligature effect. Statistical analysis demonstrated that the

Tourni-key is slowest until occlusion and joint slowest with SWAT-T to complete application ($p < 0.05$); however, this difference in occlusion and application time is unlikely to be clinically important.

Cornelissen MP, Brandwijk A, Schoonmade L, Giannakopoulos G, van Oostendorp S, Geeraedts L Jr. The safety and efficacy of improvised tourniquets in life-threatening hemorrhage: a systematic review. Eur J Trauma Emerg Surg. 2020 Jun;46(3):531-538. doi: 10.1007/s00068-019-01202-5. Epub 2019 Aug 20. PMID: 31432195.

This study is systematic review of literature summarize the existing literature on designs, efficacy and safety of I-TQs. Bibliographic databases PubMed, EMBASE.com and Cochrane Library were searched. All types of original studies about I-TQ's were included. Review studies, exempts from textbooks or studies with TQs applied during elective surgeries were excluded. The search of the online databases yielded 3331 unique studies; 3177 studies were excluded by title and abstract screening;154 studies were assessed by full-text analysis; 20 studies were included. I-TQs reported in the retrieved studies seem unable to reliably achieve hemorrhage control as all studies comparing commercial devices to improvised designs showed the improvised design to be inferior regarding efficacy. Of the I-TQs, the band and windlass design performed most consistently. Although lacking any statistical analysis, there was no reported difference in adverse events between I-TQs and C-TQs. The use of- and training in I-TQ by civilian immediate responders is not recommended because of limited efficacy and safety concerns; direct pressure is a viable alternative. However, I-TQs may save lives when applied correctly with proper objects; therefore, future studies regarding the best design and training in application of effective and safe I-TQs should be encouraged. In order to occlude arterial blood flow, it is essential that the applied pressure of the TQ is sufficient. Of the various improvised designs in the reviewed studies, one design achieved the most consistent occlusion of arterial flow success rates across all studies, which came close the success rates of C-TQ's. That design consistently included a band and windlass [19–22, 30]. When directly compared to similar designs without a windlass, I-TQ consistently showed very low success rates [8, 20, 24]. Therefore, it appears that the windlass could be a key-element to reach sufficient pressure to occlude arterial flow.

Table 3 Simulated environment studies on improvised tourniquets

Author, Year of publication	Experimental design	Number of applications	Design, succes rate.					Reported complication rate	Type of complication
King, R.B. 2006	Volunteers	160	Cloth with wooden dowel	Pulse palpation success: Ideal 14/20 (70%)	TQ over winter clothing 16/20 (80%)			Unknown	Highest subjective pain score, skin pinching observed
				Echo Doppler success: Ideal 6/20 (30%)	TQ over winter clothing 10/20 (50%)				
			Surgical tubing	Pulse palpation success: Ideal 20/20 (100%),	TQ over winter clothing 18/20 (90%)			Unknown	Second highest subjective pain score
				Echo Doppler success: Ideal 20/20 (100%)	TQ over winter clothing 18/20 (90%)				
Swan, K.G. 2008	Volunteers	80		Upper Arm	Upper Leg	Lower Arm	Lower Leg	1/80 (0.01%)	Pain
			Rubber tubing	10/10(100%)	10/10 (100%)	10/10 (100%)	10/10 (100%)		
			Cloth with wooden stick	10/10 (100%)	10/10 (100%)	10/10 (100%)	10/10 (100%)		
Guo, J.Y. 2011	Volunteers	80	Surgical tubing wrapped around extremity tightly		Canvas belt			Unknown	Highest subjective pain score
			Upper extremity 12/20 (60%) Lower extremity15/20 (75%)		Upper extremity 9/20 (45%) Lower extremity 12/20 (60%)			Unknown	Highest subjective numbness score
Heldenberg, E. 2015	Volunteers	46	Improvised Russian tourniquet; triangular bandage, wooden dowel. Lower extremity = 62%					Unknown	Unknown
Altamirano, M.P. 2015	Mannequin with simulated blood loss	160	T-Shirt with 6 chopsticks taped together turned 180 degrees		No windlass			Unknown	Swirling of mannequin skin indicating shearing stress
			54/80 (68%)		1/80(1%)				
Kragh, J.F. jr. 2015	Mannequin with simulated blood loss	360		1 Stick	2 Sticks	3 Sticks	4 Sticks	111/249 (45%)	Breakage of windlass (most contributed by single craft stick)
			Chop stick	17/40 42%	40/40 (100%)	-	-		
			Pencil	21/40 (52%)	37/40 (92%)	33/40(82%)	20/20(100%)		
			Craft stick	0/40 (0%)	24/40 (60%)	38/40 (95%)	20/20 (100%)		
Lyles, W.I. III 2015	Mannequin with simulated blood	40	Triangular bandage		Bandana			0/60 (0%)	Usual wear and tear on silicone skin observed
	loss		8/20 (40%)		2/20 (10%)				

Table 4 Real-life studies on improvised tourniquets

Author name.pub year	Type of study	Trauma mechanism	Number of applications	Design, success rate		Reported Complication rate	Complications
Kragh, J.F. 2008	PA	Explosive device, gun, burn, motor vehicle crash,	16	Cloth and wooden dowel 3/7(42%) of limbs	String, iv tube 2/8 (25%) of limbs	12/16 (80%)	Amputation and fasciotomy most common
Inaba, K. 2015	RA	Stab wound 51.7%, Industrial accident	7	No design mentioned 7/7 (100%)		0/7 (0%)	None
Lakstein, D. 2002	RA	Penetrating trauma, mainly caused by explosions	21	Wide rubber band wrapped around limb 13/18 (72%)	Improvised tourniquet, (2 belts, 1 wire) 2/3 (66%)	7/110 (6%)	Nerve palsy
Larsen, J.2004	RA	Mine explosions	18	String, belts and cloths 0/18 (0%)		3/18 (17%)	Death
Zietlow, J.M. 2011	RA	Blunt (37%) Laceration (29%) Stab wound (10%) Hemodialysis (7%) Fall 4% Gunshot (4%) Other (10%)	3	Belt 0/3 (0%)		0/3 (0%)	None
King D.R. 2012	RA	Explosive device, gunshot, crush	2	Cloth and wooden dowel. 0/2 (0%)		Not mentioned	Not mentioned
King, D.R. 2015	RA	Improvised explosive device	27	27 improvised tourniquets. Most encountered was surgical tubing wrapped tightly and then twisted with a clamp. Although no numbers mentioned; most were ineffective (venous) tourniquets		Not mentioned	Not mentioned
Kue, R.C. 2015	RA	Penetrating 67%, Non traumatic bleeding 23.5% blunt 9.2%	98	Surgical tubing wrapped around limb, twisted with a clamp 87/95 (91%)	Belts 0/3 (0%)	0/98 (0%)	None
Passos, E. 2014	RA	2 penetrating trauma 2 blunt trauma	4	Neck tie, belt, handkerchief. No effectiveness described		0/4 (0%)	None
Schroll, R. 2015	RA	Gunshot (14,7%), Stab (41,6%), Blunt (36%), Unknown (7.5%)	40	40/197 improvised. Design not described. Hemorrhage control percentage not described.		Damage all similar to commercial devices	Amputation, nerve palsy, ischemia/reperfusion
Malo, C 2015	CR	Penetrating trauma by gunshot wound	2	Belt and Seatbelt combined 1/1 (100%)		1/1 (100%)	Tourniquets in place for 17 hours, above the knee amputation.
Dayan, L. 2017	CR	Improvised explosive device creating a traumatic amputation below the knee	1	Cloth with wooden dowel. In place for 11 hours 1/1 (100%)		1/1 (100%)	Above the knee amputation, skin below tourniquet not viable to serve as a flap.
Kragh, J.F. 2007	CR	Gunshot, shrapnel.	2	Wide strap with spring clip. 0/1 (0%)	Cloth with wooden dowel 1/1 (100%)	0/1 (0%)	none

Figure 1a. Examples of windlasses

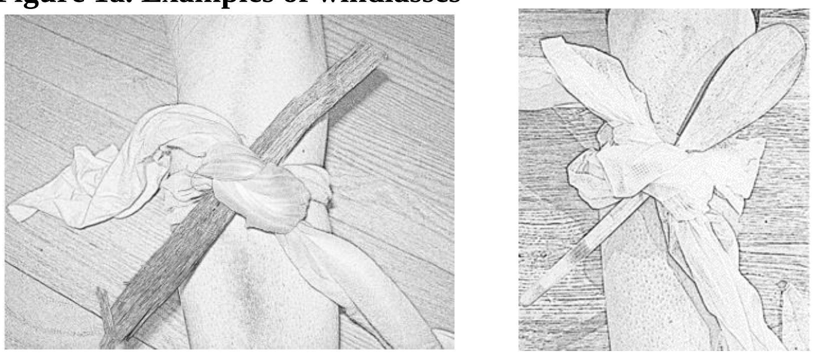
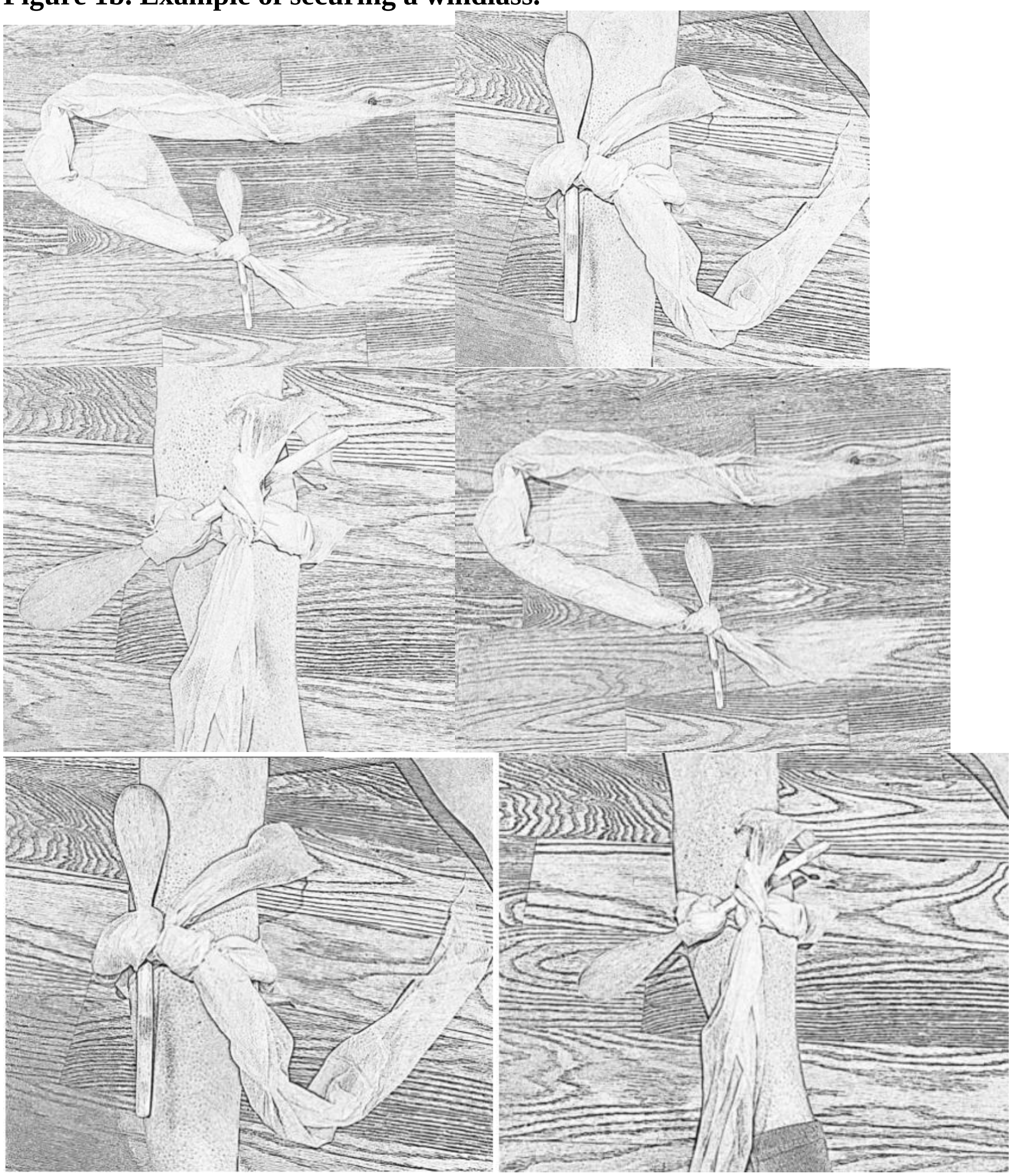


Figure 1b. Example of securing a windlass.



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.

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