ORIGINAL RESEARCH

Arterial Occlusion Effectiveness of Space Blanket–Improvised Tourniquets for the Remote Setting

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Introduction

Control of severe extremity hemorrhage by tourniquet can save lives. In remote areas or in mass casualty incidents with multiple severely bleeding victims, lack of conventional tourniquets may make it necessary to improvise tourniquets.

Methods—Occlusion of the radial artery and delayed onset of capillary refill time resulting from windlass-type tourniquets were experimentally investigated by comparing a commercial tourniquet and a space blanket–improved tourniquet with a carabiner as a rod. This observational study was conducted on healthy volunteers in optimal application circumstances.

Results—Operator-applied Combat Application Tourniquets were deployed more swiftly (27 s, 95% CI: 25.7–30.2 vs 94 s, 95% CI: 81.7–114.4) and achieved 100% complete radial occlusion compared with improvised tourniquets, as assessed by Doppler sonography (P<0.001). When space blanket–improved tourniquets were used, traces of radial perfusion persisted in 48% of the applications. In Combat Application Tourniquets, capillary refill times were significantly delayed (7 s, 95% CI: 6.0-8.2 vs 5 s, 95% CI: 3.9–6.3) compared with those when using improvised tourniquets (P=0.013).

Conclusions—Improvised tourniquets should be considered only in dire circumstances with uncontrollable extremity hemorrhage and when no commercial tourniquets are available. Complete arterial occlusion was achieved in only half of the applications using a space blanket–improved tourniquet when a carabiner was used as a windlass rod. The speed of application was inferior to that for Combat Application Tourniquets. Similar to Combat Action Tourniquets, the correct assembly and application of space blanket–improved tourniquets on upper and lower extremities have to be trained.

Trial registration: ClinicalTrials.gov identifier: BASG No.: 13370800/15451670

Keywords: emergency medical services, hemorrhage control, rescue work, test, Stop the Bleed, tourniquet pain, wilderness medicine
type, elastic-type, ratchet-type, and pneumatic-type TQs. Originally adopted by the military, the windlass-type Combat Application Tourniquet (CAT) is now frequently used by first responders and emergency medical services.

In an emergency setting where commercial devices are not available and prolonged direct pressure is not practicable, an improvised TQ (I-TQ) may be an effective bridge to definitive care. Early hemorrhage control is crucial. This particularly applies to severe hemorrhage in the wilderness setting under extreme environmental conditions when mountaineers have to rigorously stop bleeding until professional rescuers arrive on the scene. For mass casualty incidents with multiple severely bleeding victims, even rescue personnel can quickly run out of commercial TQs. When applied properly, I-TQs were reported to reliably stop severe extremity hemorrhage in prehospital emergency care. Although the cloth and wooden dowel design achieved 42 to 100% success, an effective and safe I-TQ design has not yet been found. To lay rescuers keeping an eye out for materials suitable for building an I-TQ, a space blanket (SB) may appear adequate at first glance. SBs are generally available as common components of the first aid equipment used in Europe in prehospital emergency medicine and outdoor sports as part of hypothermia prevention.

In this experimental study, we aimed to investigate whether rescuers can apply an SB as an I-TQ to provide adequate vascular occlusion of the upper extremity. We compared the quality of radial occlusion achieved with an SB to that of a conventional CAT in a controlled environment.

Methods

An experimental trial concerning rescuer application of an I-TQ compared with a commercial TQ was conducted with uninjured test subjects in the training rooms of Innsbruck Medical University Hospital. The target group of this study focused on mountaineers performing bystander hemorrhage control in the wilderness setting. All voluntary participants were recruited from Mountain Rescue Tyrol (MRT) Group Innsbruck. After announcing the study on social media, 25 eligible volunteers responded, 23 (17 male, 6 female) of whom participated (inclusion rate: 92%). Written informed consent was obtained from all subjects prior to the study investigation. Inclusion criteria were volunteers >18 and <80 y of age, in good general health. Exclusion criteria were missing informed consent, vascular comorbidities, pregnancy, and untimely dropout. Investigations were performed on both upper arms consecutively with the sequence of TQs applied in random order (Figure 1). The study was approved by the institutional ethics committee (EK No.: 1039/2020) and registered (BASG No.: 13370800/15451670) with the Austrian Federal Office for Safety in Public Health Services (https://www.basg.gv.at). After approval and registration, the measurements were made under stationary conditions on a single day in October 2020. Data were collected on a work chart and transferred to electronic files for data processing. Reporting followed the CONSORT 2010 checklist of what information to include when reporting a randomized trial and the extension to randomized pilot and feasibility trials.

Subjects were distributed randomly in a crossover trial to 2 study arms and allocated CAT and SB applications. All participants received the same 2 treatments in alternate order. Random assignment of upper limbs was achieved by rolling 2 dice (simple randomization) and predetermining even numbers for the right and uneven numbers for the left upper limb. Sequence of participation depended on the sequence of arrival of participants.

Focusing on bystander first aid in the out-of-hospital setting, the primary endpoint was assessment of the efficacy of bleeding control by the investigators using 2 assessment devices. The secondary endpoint was the operator’s assessment of practicability, and the tertiary endpoint was his ease of handling. Outcomes were recorded immediately after each application. Data were previously evaluated as part of an academic thesis.

APPLICATION OF TEST DEVICES

This study was conducted by a single operator (M.I.; mountain rescuer) to avoid interoperator bias. The operator was experienced in applying commercial TQs during first aid training but was not familiar with I-TQs. All TQs and I-TQs were applied 2-handed by the operator to the upper extremity of a supine participant on the investigation table. The proximal edge of each device was located within 5 cm of the armpit, a distance that was measured and marked on the skin prior to investigation.

The CAT (Gen 7, Rock Hill, SC) was selected as a commercial TQ as used by MRT and Helicopter Emergency Medical Services (HEMS) in Austria. CAT-7 was one of the nonpneumatic TQs recommended in 2019 for tactical combat casualty care when evaluating the following criteria: arterial occlusion, TQ pressure, simplicity of application, TQ specifications, retention mechanism, complications, safety, usage reports, user preferences, and logistics. The device was applied by inserting the patient’s arm into the prearranged loop and pulling the end of the self-adhering
band tight and securing it back on itself. Then, the operator turned the windlass rod until loss of distal radial pulse was achieved. Finally, the twisted rod was locked in place with the clip and secured with the windlass strap.

One brand of SB (Rescue Blanket; Leina-Werke GmbH, Windeck, Germany)—used by MRT and HEMS in Austria—served as I-TQs. Blankets were selected for their general disposability and their confirmed high tear resistance. The blankets, composed of a polyethylene terephthalate sheet coated with a thin aluminum layer, were 160 × 210 cm in size. In the original packaging, the blankets were laid in 23 layers (22 foldings) of 6.9 cm width; in an unpacked and vertically aligned position, the segment fanned out to 7.8 cm in width.

The SB was routed twice around the upper arm using the single segment longitudinally unfolded. Then, the 2 ends of the SB were joined using a half-square knot (Figure 2a). Another half-square knot was made on top, and a carabiner (passO-SC, Skylotec GmbH, Neuwied, Germany) was inserted between the 2 knots (Figure 2b). This helped protect the skin from direct constriction and doubled the width on the opposite side of the torque. Torque was applied by twisting the carabiner until the radial pulse was eliminated. Then, the twisted carabiner was locked into position with one end of the SB and

Figure 1. Trial design of the arterial occlusion effectiveness of a space blanket (SB)—improvised tourniquet compared with the Combat Application Tourniquet (CAT).
secured to the other end on the opposite side with another 2 to 3 knots (Figure 2c).

INVESTIGATIONS AND MEASUREMENTS

To diminish interobserver bias, measurements were made by Investigator 1 (T.S., cardiac surgeon), assigned to objective assessment using Doppler sonography, and by Investigator 2 (H.S., anesthetist) for assessment of capillary refill times and for recording subjective assessments made by the operator and participants using a questionnaire.

Vascular compression was verified using a portable Doppler sonography device (Huntleigh Dopplex D900, Huntleigh Healthcare Ltd, Diagnostic Products Division, Cardiff, Wales, UK) using a 10-MHz probe. In addition, pressure under the TQs was measured using a slightly inflated neonate blood pressure cuff connected via a rubber tube to a manometer (roid I, boso, CE 0124, Bosch + Sohn GmbH u. Co KG, Jungingen, Germany) for blood pressure measurement. Participants underwent 3 sonographic examinations (the first examination immediately before applying the TQ, the second examination 2 min after obstructing circulation, and the third examination after removing the TQ).

Objective assessment of efficacy was based on results obtained from radial blood flow with Doppler sonography by Investigator 1, 2 min after vascular compression (no flow: missing signal; low flow: trace signal; regular flow: full signal). Capillary refill time was assessed 1 min after vascular compression by Investigator 2. Maintenance of TQ pressure and associated ischemia was restricted to 2 min.

Subjective assessment of efficacy by Investigator 2 was based on results of a capillary refill under the nail of the index finger. Refill time was defined as the time taken for the capillary bed to regain its color after short pressure has been applied to cause blanching. The operator’s subjective assessment of practicability and efficacy and ease of handling were categorized by Investigator 2 on a 5-item Likert-type scale using scores between 0 and 10 (1–2=very good, 3–4=good, 5–6=satisfactory, 7–8=moderate, 9–10=inadequate) and a hardcopy questionnaire. At 1 min after application of either the SB or the CAT, participants were asked to define the maximum intensity of pain using numerical rating scores between 0 and 10 (0=none, 5=medium, 10=most severe). In addition, Investigator 2 recorded participant feedback regarding paresthesia and quality and intensity of pain. Application time defined the interval from the beginning of device application until elimination of palpated pulse after having secured either the windlass rod or the carabiner. Sufficient vascular occlusion pressure was assumed when no radial pulse was detected and confirmed by Doppler sonography. Occluding time, the time taken to stop perfusion, was defined as the interval from beginning of twisting the commercial windlass rod or the carabiner until elimination of the pulse.

STATISTICAL ANALYSIS

In a subjective assessment of efficacy, the estimated sample size was 14 participants to achieve a power of
80% and a level of significance of 5% (2-sided) to detect a true difference in means of 3 points between I-TQ applications and TQ applications. The quotient mean divided by standard deviation equals effect size $= 1.5$. There was no supporting evidence from previous literature for this assumption. Descriptive statistics were applied using the statistical package for the social sciences from International Business Machines Corporation (IBM SPSS Statistics Standard 26, Armonk, NY) to determine measures of central tendency (median) and measures of dispersion (range, SD, variance, minimum and maximum). The null hypothesis to be tested was that there is no difference between SB and TQ regarding the efficacy of bleeding control. The alternative hypotheses were that there are differences between SB and TQ regarding practicability and ease of handling.

A nonparametric test (Wilcoxon Mann-Whitney $U$ test) was used for comparison of ordinal data after Kruskal-Wallis analysis of variance. The association between sonographic findings (objective) and radial pulse taken by the operator (subjective) was expected to be statistically significant when using the $\chi^2$ test of independence.

**Results**

The median age of the 23 participants was 40 (range 20–55) y. There were no losses or exclusions after randomization. A total of 46 applications to the right and the left upper arm were performed with 2 randomly assigned devices. Prior to the investigations, median systolic blood pressure was 133 (range 100–150) mm Hg, median diastolic blood pressure was 72 (range 50–80) mm Hg, and median pulse rate was 68 (range: 50–100) beats·min$^{-1}$. Baseline values and upper arm circumference were comparable between the 2 groups.

Median application time and median choking time were shorter for the CAT (27 s, 95% CI: 25.7–30.2 vs 94 s, 95% CI: 81.7–114.4; $P<0.001$) (Table 1). Most delays in SB application resulted from the time needed to secure the carabiner in position to maintain the constricting force. For the CAT, securing the windlass rod in position took a few seconds. Three windlass rod turns were sufficient in most applications.

Peak pressure under the TQs during adjustment of the SB and the CAT in 8 measurements exceeded 300 mm Hg for both devices. Peak occlusion pressure after 1 min exceeded 300 mm Hg for the CAT and 180 mm Hg for the SB. Complete radial compression 2 min after application of the device was confirmed by the absence of flow in Doppler sonography in 23 (100%) CAT applications and in 12 (52%) SB applications ($P=0.005$). Persistent low flow (traces) was detected in 11 (48%) SB applications. Accordingly, the delay of capillary refill time after 1 min differed between the 2 groups (5 s, 95% CI: 3.9–6.3 vs 7 s, 95% CI: 6.0–8.2; $P=0.013$) (Table 1).

When Investigator 1 performed the second sonographic evaluation 2 min after SB application, he observed that as little as an additional quarter to half turn of the carabiner would have been sufficient to achieve arterial occlusion in 4 of the 11 applications with persistent low flow perfusion.

Subjective assessment of practicability, ease of handling, and efficacy scored better marks for the CAT than for the SB (Table 2). Pain intensity 1 min after

**Table 1.** Survey results regarding application time, occlusion time, pain intensity under the device and paresthesia in the upper arm, and efficacy according to sonographic results from radial Doppler (Investigator 1) and capillary refill time 1 min after vascular compression (Investigator 2) with the Combat Application Tourniquet (CAT) and with space blankets (SBs) serving as improvised tourniquets.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>CAT (n=23)</th>
<th>SB (n=23)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application time (s)</td>
<td>27</td>
<td>4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>95% Confidence interval</td>
<td>25.7–30.2</td>
<td>81.7–114.4</td>
<td></td>
</tr>
<tr>
<td>Occlusion time (s)</td>
<td>15</td>
<td>68</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>95% CI</td>
<td>13.5–17.4</td>
<td>59.5–92.4</td>
<td></td>
</tr>
<tr>
<td>Pain intensity (median; range)</td>
<td>4 (2–6)</td>
<td>2 (1–5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Paresthesia (N; %)</td>
<td>13 (57)</td>
<td>19 (83)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Radial perfusion sonography (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No flow</td>
<td>100</td>
<td>52</td>
<td>0.005</td>
</tr>
<tr>
<td>Low flow</td>
<td>0</td>
<td>48</td>
<td>0.005</td>
</tr>
<tr>
<td>Regular flow</td>
<td>0</td>
<td>0</td>
<td>1.000</td>
</tr>
<tr>
<td>Capillary refill time (s)</td>
<td>7</td>
<td>5</td>
<td>0.013</td>
</tr>
<tr>
<td>95% CI</td>
<td>6.0–8.2</td>
<td>3.9–6.3</td>
<td></td>
</tr>
</tbody>
</table>
application was significantly lower for the SB and was more frequently observed as pinching, whereas pain intensity from CAT application was higher and more frequently defined as having a cutting quality (Table 1). No severe adverse reactions were observed during the study. Scratches, superficial abrasions, and small skin bruises were observed with both devices. All participants regained normal radial artery perfusion at device removal.

Discussion

This experimental study compared differences in arterial occlusion between CAT and SB application. The aluminum-coated SB is used for hypothermia prevention in prehospital emergency medicine. Although the tool cannot actively rewarm a hypothermia victim, it can at least slow down heat loss from thermoradiation and thermoconvection. In this study, an SB applied as an I-TQ proved to be tear resistant and achieved adequate vascular occlusion pressure for hemorrhage control in half of the cases. However, the difficulty, as presumably for most I-TQs, was the provisional windlass rod and its fixation. Rohrich et al reported that a properly constructed I-TQ can be highly effective when 3 components are provided: a strap, a rod, and a securing mechanism. As our study was tailored to mountain rescue missions, a carabiner was used as a provisional windlass rod. It was secured in position, with the 2 ends of the blanket variously arranged and joined with additional knots. A single half-square knot to join the 2 ends of the SB and insertion of the carabiner underneath would have been adequate. We presume that a small stick or a pair of scissors might have provided more efficient torque and could have been more easily secured in position than a carabiner. Kragh et al investigated 3 types of provisional windlass rods and found that a pair of chopsticks worked better than pencils or craft sticks. Cremonini et al observed in an experimental study that a standard leather belt was the fastest to place and was able to effectively stop the bleeding when continuous pressure was maintained. An improvised triangle bandage in windlass design was as effective as the commercial devices and was the easiest to apply.

Wood et al observed in volunteers that loss of distal radial pulse does not indicate a lack of arterial flow distal to upper extremity TQ. On average, an additional one-quarter windlass turn was required to eliminate distal flow. In our study, persistent low flow perfusion was detected in 48% of SB applications. As little as an additional one-quarter to one-half rotation would have been sufficient to completely stop circulation in 4 out of 11 applications. It remains a matter of debate whether the decline in blood pressure can increase the success rate in hypovolemic individuals. Then again, pain may have increased the observed failure rate in normovolemic volunteers. However, neither anticipated pain nor skin lesions from TQ application cast doubt on the importance of hemorrhage control by vascular occlusion.

The Hartford consensus proposed hemorrhage control for approaching mass shooting events, which led to implementation of the nationwide hemorrhage control training course “Stop the Bleed” from the American College of Surgeons Committee on Trauma. This campaign focuses on laypersons to perform hemorrhage control for extremity injuries. However, the principles for correct TQ application are not fully translatable to different commercial or I-TQ types. Laypersons trained on a specific brand may not be prepared to care for bleeding patients with an unfamiliar type of TQ at hand. When an untrained layperson is handed a commonly accepted TQ, failure is unacceptably high. A pilot study by Ross et al on the intuitive nature of applying commercially available TQs found unacceptably high rates of failure. Even TQ training may result in poor skill retention and application of various TQs when inefficiencies arise from limited exposure time. Only 6 of 10 trainees succeeded in placing a TQ 30 days after the course. Similar to commercial TQs, the application of I-TQs has to be trained. McCarty et al reported that even laypersons with training in hemorrhage control achieved 92.2% correct application with the CAT but only 32.4% correct application when applying an I-TQ. Ross et al observed CAT application failure in 82.9% of untrained laypersons, with inadequate tightness (74.1%), improper placement technique (44.4%), and incorrect positioning (16.7%) as the most common causes. Effective use of TQs as first aid needs regular training.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>CAT (n=23)</th>
<th>SB (n=23)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of handling (median)</td>
<td>1</td>
<td>3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Range (1-10)</td>
<td>1–3</td>
<td>2–7</td>
<td></td>
</tr>
<tr>
<td>Practicability (median)</td>
<td>1</td>
<td>3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Range (1-10)</td>
<td>1–2</td>
<td>1–7</td>
<td></td>
</tr>
<tr>
<td>Investigator-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficacy (median)</td>
<td>1</td>
<td>2</td>
<td>0.014</td>
</tr>
<tr>
<td>Range (1-10)</td>
<td>1–2</td>
<td>1–9</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Survey results regarding ease of handling and practicability (operator) and efficacy (Investigator 2) in 23 measurements when using the Combat Application Tourniquet (CAT) and in 23 measurements when using a space blanket (SB) as an improvised tourniquet.
Regarding application time, application of the conventional CAT was performed very fast.\textsuperscript{3,9,24} SB applications required more time than CAT applications but were still within the range of simulation studies using the CAT.\textsuperscript{25,29} This is of particular importance as the time required for a single rescuer to build an I-TQ might interrupt the exertion of direct pressure on the patient’s bleeding site. Compared with the CAT, application of the SB was associated with less pain because of lower tissue compression. We assume that the broader width of the SB compared with that of the CAT allowed lower vascular occlusion pressures.\textsuperscript{7,30} In our study, the peak occlusion pressure after 1 min exceeded 300 mm Hg in the CAT and 180 mm Hg in the SB. This agrees with reported CAT pressures of 250 to 428 mm Hg in normotensive adults.\textsuperscript{30} We are aware that with increasing blood pressure, eg, from pain, TQs might become inadequate. However, hypotension from hypovolemia might increase the quality of vascular compression.

**Limitations**

There are several limitations that might have influenced interpretation of the findings. The members of the study population were all members of a mountain rescue unit. Most of the participants were young males. We did not analyze what made contacts choose not to participate in this clinical trial. In this experimental study, we compared 2 devices applied by a single operator in a homogeneous sample of healthy participants with limited representativeness and generalizability.\textsuperscript{31} It was not our intention to evaluate interuser variability. The operator and investigators in this study were experienced in medical care, teaching, and research but had only limited experience in out-of-hospital hemorrhage control with TQs. We investigated buddy-aid but did not investigate the TQ self-aid that is part of tactical combat casualty care.\textsuperscript{5} We are aware that application of TQs under stress in field conditions may be more frequently unsuccessful.\textsuperscript{24,26,28} Furthermore, the results of our experimental investigation in voluntary participants and our conclusions do not permit generalization to all bleeding emergencies in the prehospital setting. At the end of the investigation, there was a training effect of the single operator that was observed in shorter application times for the CAT and a fatigue effect seen in longer application times for the SB. Preinvestigation training of CAT and SB applications might have diminished the learning effect. We are aware that the order of response options in psychometric tests may influence the preference of items. The descending ordered scales, as used in this study, may be associated with more positive responses.\textsuperscript{32}

While the sonographic investigation may be regarded as an objective measurement, participants’ comments, as well as judgments made by the operator and the investigators, are subjective in nature. This particularly applies to the assessment of practicability and ease of handling. The SB cannot be generalized for all I-TQs, and in this study, the SB was compared with only 1 commercial brand. We cannot tell whether the SB is similarly applicable when used as a lower extremity TQ. Furthermore, the excellent CAT application times in our study are not representative of application times for less experienced rescue personnel working in real emergencies.\textsuperscript{15,30}

**Conclusions**

I-TQs should be considered only in dire circumstances with uncontrolled extremity hemorrhage and when no commercial TQs are available. Complete arterial occlusion was achieved in only half of the applications using an SB-I-TQ when a carabiner was used as a windlass rod. The speed of application was inferior to that for the CAT. Similar to those required for CATs, the correct assembly and application of SB-I-TQs on upper and lower extremities have to be trained.

Acknowledgment: The authors thank Sabine Embacher, M.A., for scientific monitoring and advice.

Author Contributions: study concept (MI, WL); study design, protocol and oversight (MI, WL); acquisition of data (HS, MI, TS, WL); analysis of data (LB, FJW); drafting of the manuscript (HS, LB, MI, TS, WL); critical revision of the manuscript (HS, MI, TS, FJW, WL); approval of the final manuscript (HS, MI, TS, LB, FJW, WL).

Financial/Material Support: No funding is declared for this manuscript except for the purchase of survival blankets and tourniquets, which was covered by institutional funding.

Disclosures: Data were previously evaluated as part of the academic thesis written by Lukas Banyai, published in the German language and kept in 4 copies at the library of the Medical University of Innsbruck.\textsuperscript{16} The other authors report no conflicts.

**References**


