Stretch and Wrap Style Tourniquet Effectiveness With Minimal Training

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ABSTRACT   The objective was to determine if proper application of the Stretch, Wrap, and Tuck Tourniquet (SWAT-T) would stop arterial flow and would occur with minimal training. Methods: Fifteen undergraduates watched a 19 second video three times, practiced twice, and applied the tourniquet to volunteers at 10 locations: 3 above the elbow or knee and 2 below. Results: Successful occlusion (60 second Doppler signal elimination) was more frequent than proper stretch (96 versus 75), more frequent on arms than legs (59 versus 37), and achieved before completed application (16 ± 8 versus 33 ± 8 seconds; each $p < 0.05$). Proper stretch (correct alteration of shapes printed on the tourniquet) was more frequent on legs than arms (30 versus 45; $p < 0.05$). Applications were rated Easy (101), Challenging (37), Difficult (12) with discomfort None (53), Little (62), Moderate (34), Severe (1). The 8 appliers with <70% proper stretch rates received 10 minutes additional training and then retested at mid upper arm, mid-thigh, and below knee (24 applications) for improved proper stretch and occlusion (5 versus 18 and 10 versus 20; $p < 0.01$). Conclusions: Proper application of the SWAT-T is easy and can stop extremity arterial flow but requires some training for many appliers.

INTRODUCTION

Tourniquets that stop injured extremity arterial flow are life-saving devices in combat-related situations[1] and may be life-saving in some civilian situations.[2–4] Beyond stopping arterial flow, military tourniquets must be small and light enough to carry where they are rapidly accessible on every soldier and must be easy to apply correctly.[1,5,6]

The tourniquets deployed with U.S. servicepersons since late 2004 are a windlass/stick and strap design, the Combat Application Tourniquet (CAT; Composite Resources, Rock Hill, South Carolina).[7] At 3.8-cm wide, this tourniquet may require pressures >300 mmHg to stop thigh arterial flow (tourniquet width/limb circumference 0.048–0.083).[6,8,9] A wider (10.4 cm) stretch and wrap style tourniquet, the Stretch, Wrap, and Tuck Tourniquet (SWAT-T; TEMS Solutions, Abingdon, Virginia) became commercially available in 2008. Published data exist concerning the lab and field effectiveness of the CAT[1,5,6,10–12]; however, such data are currently lacking for the newer SWAT-T.

Like the CAT, the SWAT-T meets military size and cost criteria to be a tourniquet of interest[5,6] and is intended for use in tactical, limited supply scenarios or first responder casualty care by soldiers, military medics, police, etc. Individuals in some of these groups receive limited medical training, and "simple to apply" and "use with little to no training" are listed by the military as ideal emergency tourniquet traits.[6]

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Marketing for the SWAT-T claims effectiveness (rapid control of extremity bleeding) and "Its ease of application is one of its greatest benefits; individuals can effectively apply it in seconds with little to no prior training."[13] (SWAT-Tourniquet, http://swattourniquet.com) We found both claims interesting; so, our hypotheses for this study were that (1) proper application of the SWAT-T would stop arterial flow through each extremity location and (2) college undergraduates would be able to properly apply this tourniquet at each location with very minimal training.

METHODS

This prospective study was approved by the Drake University Institutional Review Board. The purchased SWAT-T tourniquets were 95 g, 10.4 cm wide, 11.7 cm circumference rolled up, 150 cm unrolled, only 1 part, and US $8.50.

Subjects

Fifteen volunteer tourniquet appliers each met the following criteria: undergraduate student taking a course involving physiology-related research with no prior tourniquet-related training. Appliers could be tourniquet recipients, but not before being an applier. Each applier was the same sex as the respective recipient. The 15 volunteer recipients each reported meeting the following criteria: no clotting or circulation abnormalities, no blood pressure problems, and no pain syndromes or peripheral neuropathies.

Protocol

For a very minimal amount of SWAT-T application training, the applier group watched 19 seconds of a thigh application video 3 times[14] (seconds 14–33, Thigh Application of SWAT-T, http://www.youtube.com/v/KypMY7Ng6ak via http://swattourniquet.com/videos.html) with the audio portion

silenced. The first viewing was silent. The second viewing included brief comments to note (1) how the tourniquet secures to itself after the first circumferential wrap, (2) the geometric pattern change from diamonds inside oblongs to squares inside circles when the tourniquet is properly stretched, and (3) the end tucking to secure the tourniquet (these comments were the only auditory instruction given). The third viewing was silent. Appliers were then allowed one application to the training individual's upper arm and one to the training individual's thigh.

Two days later, appliers and recipients (sitting in T-shirts and shorts) completed the study protocol:

(1) Applier and recipient characteristics were collected (Table I). Heart rate and systolic and diastolic pressure were obtained with a wrist automatic blood pressure monitor (Model MF-77, Mark of Fitness, Shrewsbury, New Jersey). Occlusion pressures were the manometer pressures of the pneumatic blood pressure cuffs (arm or thigh) when the distal arterial Doppler pulse signal became inaudible (wrist radial artery or ankle posterior tibial artery).

(2) Tourniquet application order was high upper right arm, mid upper left arm, just above right elbow, just below left elbow, mid right forearm, upper right thigh, mid left thigh, just above right knee, just below left knee, and mid right calf. Upper thigh application was over the shorts; the rest were on skin.

(3) Application time-related data were collected: time to loss of the distal audible Doppler signal (radial artery or posterior tibial artery), time to completed application, and time to return of the audible Doppler signal if it occurred before 60 seconds following application completion (60 second sustained loss of the audible signal was labeled Doppler success and considered successful arterial occlusion).

(4) After each application, a rating was assigned concerning proper tourniquet stretch (proper application). The conversion of diamonds inside oblongs to squares inside circles (shapes printed on tourniquet) was considered proper stretch. The person making the rating had an example picture of properly versus inadequately stretched tourniquet geometric shapes and determined the adequacy of stretch during the process of application.

(5) Before removal, an ease of application rating (Easy, Challenging, Difficult) and a recipient discomfort rating (None, Little, Moderate, Severe) were obtained. Both relate to the scales used by Swan et al.[15]

(6) The tourniquet was removed 60 seconds after application completion.

(7) The tourniquet was applied at the next location 2 minutes later.

Additional work was done to determine whether failures to properly stretch the tourniquet were related predominantly to training and technique or to strength. First, appliers who achieved a <70% proper stretch rate received additional training: 5 additional applications each accompanied by verbal feedback concerning achieving and maintaining adequate stretch while wrapping (approximately 10 minutes additional training time per person). The two expected technique problems were failure to adequately stretch the tourniquet and failure to maintain adequate stretch while passing the tourniquet around the limb. If these were not strength problems, we believed 5 applications with verbal feedback would be sufficient for correction and allowance of a few correct technique practices.

The ability of these volunteers to properly apply the tourniquet was then reassessed. The reassessment was to determine whether these appliers had easily solvable technique issues and was not to check whether the tourniquet could be

TABLE I. Characteristics of Tourniquet Appliers and Recipients

	Male Mean ± SD	Male Range	Female Mean ± SD	Female Range
Appliers				
Age (Year)	21 ± 1	19–21	21 ± 1	19–21
Height (cm)	184 ± 9[a]	175–201	166 ± 6	158–176
Weight (kg)	88 ± 23[a]	58–121	62 ± 12	52–88
Seated Row (kg)	85 ± 35[a]	52–136	41 ± 12	18–59
Overhead Press (kg)	52 ± 23[a]	32–86	23 ± 6	16–32
Recipients				
Age (Year)	20 ± 1	19–22	24 ± 9	19–44
Height (cm)	182 ± 9[a]	171–201	168 ± 6	159–176
Weight (kg)	81 ± 26[a]	50–121	62 ± 13	48–88
Arm Circumference (cm)	30 ± 5[a]	23–36	28 ± 3	24–32
Thigh Circumference (cm)	50 ± 8	40–60	48 ± 4	43–54
Heart Rate (Beats/min)	78 ± 13	60–96	79 ± 15	58–93
Systolic Pressure (mmHg)	135 ± 15[a]	111–152	121 ± 7	112–128
Diastolic Pressure (mmHg)	85 ± 12	66–99	77 ± 9	65–88
Arm Occlusion (mmHg)	132 ± 22	86–162	124 ± 17	110–156
Thigh Occlusion (mmHg)	155 ± 23[b]	120–>250[b]	155 ± 27	126–194

[a]$p < 0.05$ male versus female. [b]1 male not included in mean; pulse still faintly audible at upper limit of 250 mmHg.

effective; therefore, only 3 sites were used: mid right upper arm, mid left thigh, and below the right knee. An arm location was chosen because arms tended to be more mobile during application than legs and therefore potentially more difficult for maintaining proper stretch. The upper arm was chosen because upper arm locations were reported as more common use than forearm locations (162 arm versus 13 forearm of 862 tourniquets on 499 patients reported by Kragh et al[1]) and, based on circumference, are more likely to require proper stretch to achieve cessation of blood flow than forearm locations. The thigh was chosen because it is the location with a U.S. military specified minimum desirable success rate. The thigh is potentially the hardest site at which to achieve occlusion because of circumference,[8,12] but it may have been one of the easier locations at which to achieve proper stretch because of less limb mobility during application than encountered at other locations. Thigh locations were reported as the most common use location by Kragh et al[1] (436 thighs of 862 tourniquets). The below knee location was chosen because lower leg locations were the third most common site reported by Kragh et al[1] (46 reported).

The tourniquet reassessment recipients were from the original recipient group. Reassessment recipients were restricted to those with initially measured systolic pressures <140 mmHg.

The second method used to determine whether proper stretch failures were predominantly technique or strength issues was an assessment of each applier's pulling and pushing strength. Using weight machines, each applier's strength was assessed on a seated row and an overhead press.

Statistical Analysis

Parametric data (pressures, times, etc.) were compared using unpaired t-tests, paired t-tests, or two-way repeated measures analysis of variance. Contingency tables (Doppler success, proper stretch, etc.) were analyzed using χ^2 or Fisher's exact test. Graphing and statistical analyses were done using Microsoft Office Excel 2003 (Microsoft, Redmond, Washington) and GraphPad Prism version 5.02 for Windows (GraphPad Software, San Diego, California). Means ± SD are shown.

RESULTS

There were 150 tourniquet applications. Seven appliers were recipients. Characteristics of appliers and recipients are listed in Table I.

Minimal Training Only

Tourniquet application was generally rated "Easy" (101 Easy, 37 Challenging, 12 Difficult). Doppler successes were more frequently associated with application ratings of "Easy," and Doppler failures were more frequently associated with ratings of "Challenging" or "Difficult" (96 Doppler successes: 85% Easy, 13% Challenging, 2% Difficult versus 54 Doppler failures: 35% Easy, 46% Challenging, 19% Dif-

ficult; $p < 0.0001$). Proper or inadequate application stretch was not as associated with specific application ratings (75 properly stretched applications: 73% Easy, 20% Challenging, 7% Difficult versus 75 inadequately stretched applications: 61% Easy, 29% Challenging, 9% Difficult; $p = 0.29$).

Tourniquet application generally involved minimal recipient discomfort (53 None, 62 Little, 34 Moderate, 1 Severe). Doppler successes were more frequently associated with discomfort ratings of "Little" to "Moderate," and Doppler failures were more frequently associated with ratings of "None" (Doppler successes: 24% None, 44% Little, 31% Moderate, 1% Severe versus Doppler failures: 56% None, 37% Little, 7% Moderate, 0% Severe; $p < 0.0001$). Properly stretched applications were more frequently associated with discomfort ratings of "Little" to "Moderate," and inadequately stretched applications were more frequently associated with ratings of "None" (properly stretched applications: 20% None, 47% Little, 33% Moderate, 0% Severe versus inadequately stretched applications: 51% None, 36% Little, 12% Moderate, 1% Severe; $p = 0.0002$).

Average application times were <40 seconds for all locations (31 ± 6 seconds male, 34 ± 13 seconds female; $p = 0.02$). When it occurred, audible Doppler signal loss happened before completed application (16 ± 8 versus 33 ± 8 seconds; $p < 0.0001$). The time to completion of applications without audible Doppler signal loss was not significantly different from the time to completion of applications with audible Doppler signal loss (32 ± 14 seconds for completion without audible Doppler signal loss). The times to apply did not decrease as the number of applications increased (leg application times were not shorter than arm application times). There also did not appear to be any time effects related to tourniquet application to the left or right side of the body.

Appliers dropped the tourniquet 14 times. The dropped portion unrolled partially to completely. Completing the application with an unrolled tourniquet did not appear to add to the completion time or the difficulty (35 ± 11 seconds; 7 Easy, 6 Challenging, 1 Difficult).

Doppler success was more frequent than proper stretch, and both were more frequent for males ($p < 0.05$ for each; Fig. 1). Thirteen of the Doppler failures involved resumption of an audible pulse before 60 seconds; the remaining 41 Doppler failures had no loss of the audible pulse.

Doppler success was more frequent on arms than legs ($p = 0.0003$; Fig. 2). Proper stretch was more frequent on legs than arms ($p = 0.02$; Fig. 2). Only once was proper stretch achieved on the arm without Doppler success (mid upper arm, male subject). Tourniquet placement high on the thigh had the lowest Doppler success rate (2 of 8 males, 1 of 7 females), and, when Doppler successful, the longest times to loss of the Doppler signal (28 ± 3 seconds males, 34 seconds female). Doppler success was not achieved high on the thigh without proper stretch, but proper stretch was achieved high on the thigh without Doppler success 5 times
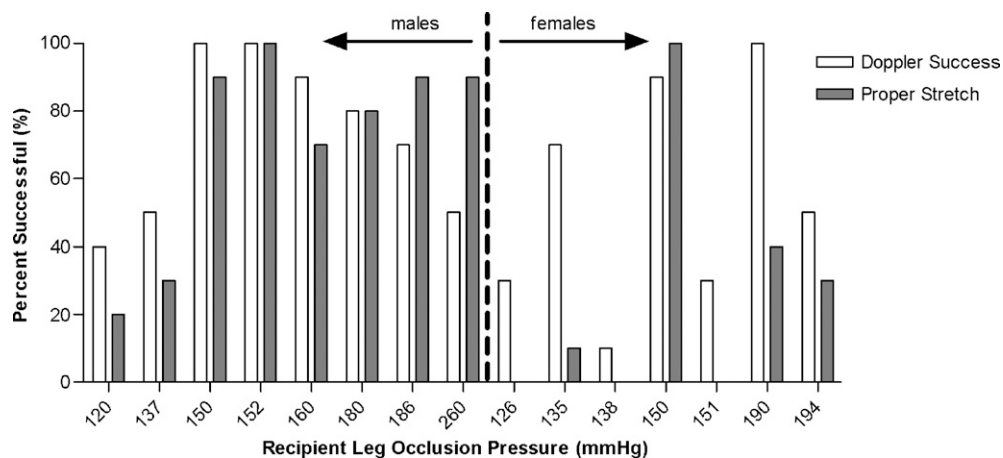
FIGURE 1. Initial tourniquet applier success. Doppler success (white) and proper stretch (gray) are ordered by gender (8 males, 7 females) then mid thigh occlusion pressure.
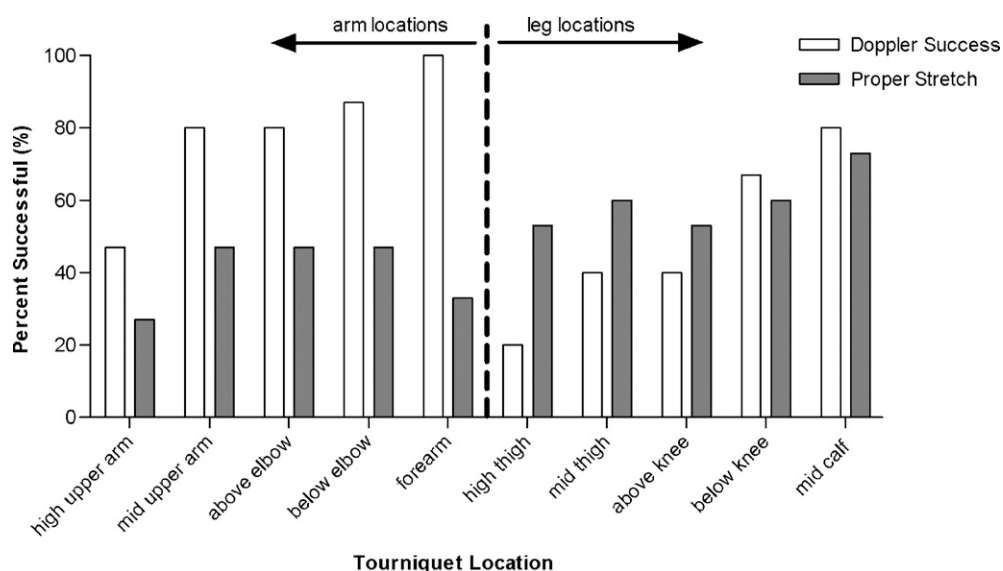

FIGURE 2. Initial tourniquet location success. Doppler success (white) and proper stretch (gray) are ordered by location.

(2 involved resumption of an audible pulse before 60 seconds). Doppler success was also not achieved at mid thigh without proper stretch, but proper stretch was achieved at mid thigh without Doppler success 3 times (1 involved resumption of an audible pulse before 60 seconds). The relationships between limb occlusion pressures and limb circumferences were that, in general, the larger circumference limbs had higher occlusion pressures. Circumference, however, was not the sole determinant of occlusion pressure; the recipient's systolic blood pressure also played a role.

Additional Training

Two males and 6 females had initial proper stretch rates <70% and received additional training. One male completed his reassessment applications on a different recipient than his first applications (original recipient systolic pressure >140 mmHg). The remainder completed their reassessments on the same recipients as on their first assessments.

The remeasured systolic pressures of the reapplication recipients were not significantly different from their previous values (118 ± 11 versus 119 ± 7 mmHg). The remeasured mid upper arm occlusion pressures were not significantly different from their previous values (114 ± 17 versus 121 ± 21 mmHg). Leg occlusion pressures were not remeasured.

Reassessments occurred at mid right upper arm, mid left thigh, and below right knee. During the 24 reassessment applications, proper stretch and Doppler success rates improved (Fig. 3). Mid thigh was the only location with reassessment failures to achieve Doppler success (Fig. 4; one audible pulse return before 60 seconds and three failures to lose the audible pulse). Every properly stretched reassessment application was Doppler successful. Following the additional training, the times to apply were slightly longer
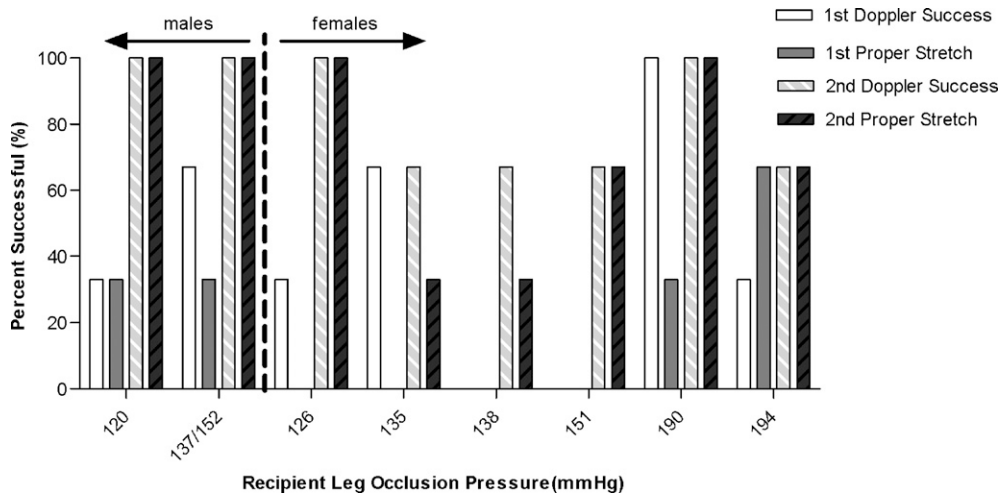
FIGURE 3. Additional training tourniquet applier success. Reassessments by gender then thigh occlusion pressure, first indicates after minimal training (Doppler white, proper stretch gray), second after additional training (Doppler light gray diagonal white, proper stretch dark gray diagonal black). Improvement: Doppler success $p = 0.007$, proper stretch $p = 0.004$.
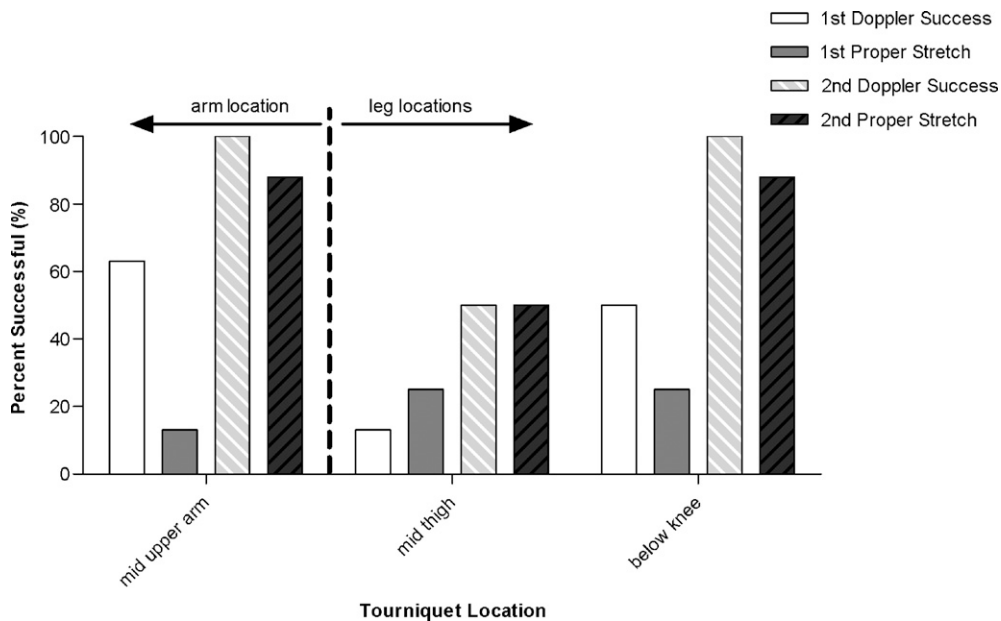

FIGURE 4. Additional training tourniquet location success. Reassessment locations, first indicates after minimal training (Doppler white, proper stretch gray), second after additional training (Doppler light gray diagonal white, proper stretch dark gray diagonal black).

but were all <60 seconds (38 ± 11 versus 33 ± 13 seconds; $p = 0.08$). The average times to loss of the Doppler signal when it occurred were the same on reassessment as obtained previously (18 ± 8 versus 18 ± 9 seconds). Recipient discomfort increased (11 None, 9 Little, 4 Moderate, 0 Severe to 2 None, 7 Little, 8 Moderate, 7 Severe; $p = 0.002$), but application was still generally considered easy (17 Easy, 7 Challenging, 0 Difficult). No tourniquet drops occurred during reassessments.

Strength
Applier seated row and overhead press weights moved are shown in Table I. The weakest applier to achieve a >70%

proper stretch rate with no additional training was a female with a 100% proper stretch rate and a combined weight moved of 64 kg (row + press). Only 2 appliers, both females, moved less combined weight than 64 kg. The weakest applier overall had an initial 0% proper stretch rate and a combined weight moved of 34 kg. She achieved a 100% proper stretch rate after additional training.

DISCUSSION
Properly applied, the SWAT-T stretch and wrap style tourniquet can stop arterial flow through each extremity; however, despite its apparent ease of use, to achieve proper application

stretch many appliers will need some technique training. Arterial occlusion is less likely at larger circumference locations such as the thigh without proper application stretch. Fortunately, trainable technique rather than great strength is the key to achieving proper application.

The tested tourniquet has characteristics desired for military use: <230g, >2 inches wide, easy to apply in <60 seconds, easy to remove and reapply, rugged, <$25/unit, and, most importantly, it can stop extremity arterial flow.[5,6,16] The critical location specified by the military is the thigh with an 80% success rate desired.[5] Data from the 10th, 28th, and 31st Combat Support Hospitals in Iraq support the importance of this location,[1,12,17] and knowledge of limb circumferences and under-tourniquet pressure distributions supports use of the thigh as the hardest limb location at which to achieve success.[8,18] Combining the minimal training and postadditional training results, we observed a 77% mid-thigh Doppler success rate when the SWAT-T was properly stretched. Comparing this to lab data with the CAT, this is lower than the CAT 100% (18 applications) and >95% (20 applications) thigh Doppler success rates reported by Walters et al[5] and Ruterbusch et al[11] but much higher than the CAT 12.5% (6 of 48) thigh Doppler success rate reported by Taylor et al.[10]

Blood pressure and location circumference play major roles in tourniquet success. The 3 mid-thigh Doppler failures despite proper stretch in this study occurred in subjects with elevated systolic pressures (148, 128, and 152 mmHg), larger thigh circumferences (53, 53, and 55 cm), and high pneumatic cuff thigh occlusion pressures (186, 194, and >250 mmHg). Systolic pressures in some of this study's subjects were higher than in reports concerning the CAT and other tourniquets (range 100–130 mmHg,[5] range 103–140 mmHg[10]). Thigh circumferences in this study (40–60 cm) did not reach the top end for U.S. male soldiers (46–79 cm)[9] or for the subjects in the Walters et al[5] study (52–68 cm). (Circumferences were not reported for the Ruterbusch et al[11] or the Taylor et al[10] studies.)

This study had several limitations. First, there was an attempt to have conditions favoring Doppler success: low stress, well-lit indoor environment with no blood, dirt, or sand on the tourniquet and no thick, full length pants or long-sleeved shirts on recipients. This was done to determine if proper application could result in arterial occlusion and if a high rate of proper application could be achieved with very minimal training. Second, there was no visual bleeding feedback, but there was audible Doppler feedback. Although audible Doppler signal loss is a commonly used method for assessing tourniquet-related cessation of blood flow, it is not always an accurate indicator of the absence of blood flow.[11,19] Third, the rating of proper stretch was subjective and made during the timed application. Fourth, as already mentioned, the range of subject thigh sizes did not include the top end for U.S. soldiers.

On the other hand, the study had several strengths. First, appliers had no previous tourniquet experience and very min-

imal training before the first applications. These were desirable characteristics because of interest in the militarily desired traits of "simple to apply" and "use with little to no training."[6] The military desirability of these traits reflects the ideals of emergency tourniquet use: immediate, on-scene application before sufficient blood loss has occurred to result in shock,[1] and the consequent realities of who is applying most of the tourniquets (when recruited, U.S. Army soldiers average 21 to 22 years of age and have an educational background of a high school diploma and sometimes some college credits[20] [Support Army Recruiting http://www.2k.army.mil/faqs.htm#age]; they do not generally have tourniquet training before what they receive in the military). In their study of military tourniquet use, Kragh et al[1] found that "persons with limited training most frequently made the decision to use tourniquets." Those "persons with limited training" would be the "casualties themselves, lay bystanders," and "soldiers" who applied an unspecified number of the prehospital tourniquets to 422 of the 499 patients who received tourniquets.[1]

A second strength is that this study clearly delineated between height, gender, and strength versus trainable technique as factors for achieving success. The key difference between the initial assessment and the reassessments was approximately 10 minutes of additional training with feedback.

A third strength is that this study had both male and female appliers with no requirement for applier strength or fitness. Although strong, fit, male appliers are more likely in military settings, the possibility of variable strength, fitness, and gender appliers clearly exists in nonmilitary settings (wilderness first aid, farm implement-related accidents, etc.).

A fourth strength is that this study looked at a variety of locations. The thigh is the most difficult location to occlude blood flow based on circumference, but factors other than circumference can play a role in tourniquet success. One such factor might be the presence of a single long bone with a single major artery (upper arm and thigh) versus two long bones with more major arterial branches (lower arm and lower leg). As in our study, Swan et al[15] found this anatomic difference between upper and lower arm and leg locations not of importance in achieving tourniquet success. In casualty use, Kragh et al[12] also did not observe high tourniquet ineffectiveness on the forearm and lower leg. Another location-related factor is Hunter's canal in the distal thigh with its suggested medial condyle of the femur protection of the superficial femoral artery from compression.[12] Our study showed that Doppler success could be achieved with this tourniquet at the distal thigh location.

Two additional location-related factors come into play because the tested tourniquet needs to be stretched and wrapped: the limb mobility encountered during application and the ability to pass the wrap around the limb without losing tension. The more frequent achievement of proper stretch on the legs than the arms may have been caused by greater recipient arm movements during the tourniquet applications. The maintenance of tension during the wrapping

process may have been an issue contributing to inadequate stretch by some of the appliers after only the initial training and was an area addressed during the additional training. In summary, the strengths of this study were the lack of applier experience, the clear delineation of trainable technique as a key to success, the use of appliers of both genders, and the evaluation at a variety of locations.

At all locations, regardless of proper stretch or Doppler success and both before and after the additional training, appliers considered the tested tourniquet easy to apply. Easy application is a claim with most tourniquets that are currently marketed toward military use, and user comments indicating easy to use are common among tourniquets with lab evaluations.[11,16,21] Our findings confirm that appliers found the tested stretch and wrap style tourniquet easy to apply, but they also show that an applier's rating of ease of application does not indicate visually correct application or cessation of distal blood flow. A failure of appliers, even with training, to achieve proper application has been noted with both of the two most commonly used military tourniquets (stick and strap CAT and pneumatic Emergency Medical Tourniquet (EMT): incorrect band routing with the CAT and failure to remove slack with both the CAT and EMT). Similar to the need for training to properly apply other styles of emergency tourniquets, our findings also suggest that a significant percentage of adults without prior tourniquet knowledge would not achieve proper application with the tested stretch and wrap style tourniquet without some technique-related training.

Applications with proper stretch tended to be less comfortable than applications with inadequate stretch. However, none of the properly stretched and Doppler successful applications were uncomfortable enough to result in immediate removal. Although we would agree with Swan et al[15] that "pain is irrelevant" with regards to tourniquet discomfort in the face of life threatening hemorrhage, it may not be irrelevant with regards to training with a particular tourniquet. Since this tourniquet is wider than most other field targeted and used designs (CAT, M2, Self-Applied Tourniquet System [SATS] 3.8 cm, Special Operations Forces Tactical Tourniquet [SOFTT] 2.5 cm, London Bridge tourniquet 2.4 cm—all used in Iraq[6,12]), it might stop limb arterial flows at lower pressures, and it might well be a more comfortable design with which to practice.[6,8,18,22] What pressures are actually exerted when the SWAT-T and other commercial designs are used should be examined.

CONCLUSIONS

The SWAT-T stretch and wrap style tourniquet can easily be properly applied and can stop arterial flow at a variety of extremity locations. Proper application is associated with cessation of arterial flow. Cessation of arterial flow can occur without proper stretch at smaller circumference locations. Proper stretch can occur without cessation of arterial flow at larger circumference locations with higher occlu-

sion pressures. Despite the ease of application, specific training on stretch and wrap techniques is desirable to achieve high rates of proper application stretch. Considering its effectiveness when properly applied, ease of use, small size, light weight, and low cost, this tourniquet might prove useful in its intended arenas of care (tactical, limited supplies, or possibly first responder casualty care) with adequate user training.

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