Tourniquets Revisited

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Background: Controversy swirls about optimal control of life-threatening hemorrhage from an injured extremity whether in combat in the Middle East or in trauma care at home. Left unanswered are four critical questions: (1) What is the simplest tourniquet available? (2) Can it be used below the elbow and the knee? (3) Is pain a factor? (4) What data support so called "Pressure Points?"

Methods: To address these questions, we measured the effects of three common tourniquets on arterial pulses (Doppler signals) at wrist and ankle of 10 healthy adult volunteers of either sex. We recorded ease of application (1–3, with 3 easiest) by the applicant and pain experienced by the subject (none, light, moderate, severe). Tourniquets were applied sequentially to arm, forearm, thigh, and leg. Tourniquet success was defined as sustained elimination of distal pulse. Pressure points were brachial artery in arm and cubital fossa, common femoral artery (groin), and popliteal artery (knee). The same criteria defined success. All numerical data were meaned and standard error (SE) computed. Significance of apparent differences was assessed with Student's *t* test for paired observations.

Results: Mean age was 36.5 ± 6.0 years; blood pressure was 123 ± 6/72 ± 4 mm Hg. All three tourniquets (sphygmomanometer, 1/2 inch rubber tubing, cloth and windlass) were successful in all patients in all four locations with two exceptions. Thighs of two subjects were too large for the sphygmomanometer and one person experienced test terminating pain with the rubber tube on arm and thigh and with the cloth and windlass on the thigh. Manual (digital) occlusion of the brachial artery in the arm was possible in all but one subject; however, the Doppler signal at the wrist returned within 40.6 ± 6.5 seconds in all but one of the other nine subjects. Pressure point control of the common femoral artery resulted in identical findings except that the pulse returned within 20.6 ± 4.7 seconds despite sustained pressure. Attempts at control of the brachial artery at the elbow and the popliteal artery at the knee were less successful.

Conclusions: Our data indicate that all tourniquets can be used successfully below the knee or elbow. The cloth and windlass is the easiest to apply. It is probably the most readily available or simplest to procure/improvise. Pain is irrelevant. "Pressure Point Control" of extremity arterial hemorrhage is a euphemistic misnomer.

Key Word: Tourniquets.

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Much discussion has been generated recently regarding the use of tourniquets by our Armed Forces. The history has been reviewed,[1–11] the various types, old and new, have been described and at least a dozen have been tested.[3,7,8,10] Recommendations for use and caution regarding misuse have ensued. Yet, the debate continues, fostering heated exchanges in our surgical literature. Nations disagree[4,5,10]; armed forces are conflicted and intraservice tempers flare over the same old dilemmas.[11–13] Lost amid the point-counterpoint are several critical questions that cry out for answers. These are four fold: (1) What is the simplest technique for tourniquet control of extremity arterial hemorrhage? (2) Can a tourniquet, placed on the forearm or the leg, arrest distal hemorrhage? (3) Is tourniquet-induced pain an important consideration? (4) Why are we still recommending "Pressure Point Control" of extremity arterial hemorrhage?[14–16]

METHODS

To address these questions, we compared the effectiveness of the three most commonly described and used tourniquets[2–4,6,8,10,11] on the upper and lower extremities of 10 healthy adult volunteers of either sex. We recorded their age, height, weight, systolic and diastolic blood pressures as well as pulse. The three tourniquets studied were the sphygmomanometer (Propper, Rankin Biomedical, Holly, MI), the half inch rubber tubing and the cloth with windlass. Each applicant was asked to grade the ease of tourniquet application on a one to three scale with three being the easiest. Each subject was asked to grade any discomfort experienced with tourniquet use as "None," "Little," "Moderate," or "Severe." The blood pressure cuff was inflated until peripheral pulse, documented by Doppler ultrasound (Koven Technology, St. Louis, MO), was arrested. The systolic pressure required to eliminate the distal pulse was recorded. The radial artery at the wrist and the posterior tibial artery at the ankle were chosen as reference points regarding tourniquet efficacy. Sustained cessation of signal (>60 seconds) was the definition of success. Tourniquets were applied sequentially to arm, forearm, thigh, and leg. Each of the four locations was observed by subject, examiner, Doppler handler, and recorder. Concur-

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rence by all four individuals was required for verification of pulse arrest. All studies were performed with the subject supine.

The half inch rubber tube was wrapped four times around the extremity part, the free ends tucked beneath the first and the last turns. The cloth was a discarded household item, sized to 48 inches × 12 inches and folded on itself to measure 3 inches in width. The associated windlass was a 12-inch stick from a wood pile. The cloth was tied around the limb with a single hitch; the windlass was then tied in place with a square knot, none of which altered the Doppler signal. The windlass, or rubber tube, was then tightened until the pulse was lost to Doppler detection. All data were meaned and standard error (SE) computed. Statistical significance of apparent differences was assessed with Student's *t* test for paired observations and analysis of variance techniques.

Selected studies of alternative techniques addressed the effectiveness of the Combat Application Tourniquet (CAT, North American Rescue Products) with the same methods. We also studied "last resort devices" such as the battle dress uniform belt, the Israeli tourniquet, the quarter inch rubber tube, and extremity ligation. Four "pressure points" (arm/brachial artery, cubital fossa/brachial artery, groin/common femoral artery, and knee/popliteal artery) also were studied in a similar fashion. Success of pressure point control required cessation of distal pulse beyond 1 minute. This study was approved by the Institutional Review Board of the University of Medicine and Dentistry of New Jersey, NJ Medical School.

RESULTS

Mean age of the subjects was 36.5 ± 6.0 (range, 18–72) years. Height and weight were 68.1 ± 1.4 inches and 154 ± 12 pounds, respectively. Systemic arterial pressures were 123 ± 6/72 ± 4 mm Hg. Mean pulse was 70 ± 3 bpm. These data are presented in Table 1. The sphygmomanometer terminated arterial pulses (radial and posterior tibial) when placed in each of the four locations (arm, forearm, thigh, and leg) in all but two subjects whose thighs were too large for the cuff. Mean systolic pressures, at arterial occlusion, were 133 ± 9 mm Hg, 133 ± 8 mm Hg, 163 ± 7 mm Hg and 168 ± 12 mm Hg, respectively. Pressure, required to eliminate the distal pulse, when applied to the thigh (163 mm Hg) was significantly ($p < 0.035$) greater than that required in the arm; pressure applied to the leg (168 mm Hg) to arrest distal pulse was also significantly ($p = 0.035$) greater than that required in the forearm. Ease of application ranged from 3.0 in the upper extremity to 1.9 in the lower extremity. Discomfort was none to light in the upper extremity and none to moderate in the lower extremity.

Table 1 Subject Demographics (Mean ± Standard Error, n = 10)

Age (yrs)	Height (in)	Weight (lbs)	Blood Pressure (mm Hg)	Pulse (beats/min)
36.5 ± 6.0	68.1 ± 1.4	154 ± 12	123 ± 6/72 ± 4	70 ± 3

The half inch rubber tubing successfully eliminated arterial pulses when placed in all four positions with one exception. Because of pain, attempts on the lower extremity (thigh and leg) with one subject were terminated. Ease of application was 2.4 in the upper extremity and 1.9 in the lower extremity. Pain ranged from none to severe and included light and moderate.

The cloth and windlass tourniquet was successful in all subjects in all four anatomic regions with the exception of one subject's thigh, where pain terminated the attempt. Ease of application was 3.0 in the upper extremity and 2.9 in the lower extremity; pain was none to moderate in the upper extremity, none to severe in the lower extremity. These data are presented in Tables 2 and 3.

In selected subjects, the CAT successfully eliminated distal pulses when placed in the four locations. It was easy to apply and caused moderate pain. The uniform belt was similarly effective, when used with a windlass. The Israeli tourniquet, when used with a windlass, simulated the cloth and windlass tourniquet as already described. The rubber tourniquet was not problematic in a bloody field, nor was the cloth with windlass. In selected subjects the cloth when tied, without the windlass, could occlude the brachial artery.

Manual (digital) occlusion, as documented by cessation of distal Doppler signal, of the brachial artery in the arm was possible in all but one subject. However, the Doppler signal from the radial artery at the wrist returned in all but one of the other subjects within 40.6 ± 6.5 seconds. Likewise, manual compression of the common femoral artery in the groin terminated the Doppler signal from the posterior tibial artery at the ankle in all but one subject. Signals returned within

Table 2 Tourniquet Effectiveness

	Location					
	Arm			Thigh		
Tourniquet	EOA*	SEDP	ROP	EOA*	SEDP	ROP
Sphygmomanometer	3.0	Yes	0–L	1.6	Yes	0–M
Half inch rubber tube	2.4	Yes	0–M	1.9	Yes	0–S
Cloth with windlass	3.0	Yes	0–M	2.9	Yes	L–S

* Significantly different, RT vs. CW, $p \leq 0.005$.

EOA, ease of application (1–3, 3 easiest); SEDP, sustained elimination distal pulse (>60 s); ROP, report of pain (none to severe).

Table 3 Tourniquet Effectiveness

	Location					
	Forearm			Leg		
Tourniquet	EOA*	SEDP	ROP	EOA*	SEDP	ROP
Sphygmomanometer	3.0	Yes	0–L	2.9	Yes	0–M
Half inch rubber tube	2.4	Yes	0–M	1.9	Yes	0–S
Cloth with windlass	3.0	Yes	0–M	2.9	Yes	L–S

* Significantly different, RT vs. CW, $p \leq 0.005$.
EOA, ease of application (1–3, 3 easiest); SEDP, sustained elimination distal pulse (>60 s); ROP, report of pain (none to severe).

Table 4 Pressure Point Control

Artery Location	Brachial		Common Femoral Groin	Popliteal Knee
	Arm	Cubital Fossa		
Subjects	10	10	10	10
Loss of pulse	9	6	9	6
Return of pulse	8 (40.6 ± 6.5)*	3 (31.7 ± 6.0)	8 (20.6 ± 4.7)	4 (8.8 ± 1.3)
No. return of pulse	1	3	1	2
No. loss of pulse	1	4	1	4

* Parenthetical figures represent time in seconds (mean ± standard error) for return of distal pulse, despite sustained pressure on “Point” (artery/location).

20.6 ± 4.7 seconds, in response to sustained pressure in all but one other subject. These two times for pulse return were significantly different ($p < 0.02$). Point pressure on the brachial artery in the cubital fossa eliminated the Doppler signal at the wrists of most subjects. Those so responding exhibited restoration of pulse within 31.7 ± 6.0 seconds. Three had no return of pulse during sustained pressure for 60 seconds. In four subjects the pulse could not be eliminated. The popliteal arterial pressure point responded similarly. These data are summarized in Table 4.

DISCUSSION

Our observations support several important conclusions. Tourniquets on arm or thigh that readily eliminate arterial blood flow, based on distal Doppler pulse cessation, accomplish the same objective when placed below the elbow or below the knee. Traditional views contend that the presence of two long bones in forearm and leg, in association with multiple large arteries, two in the forearm and three in the leg, reduce the likelihood of tourniquet compression successfully eliminating blood flow distally. Conversely, the contrasting anatomic features of arm and thigh, a single long bone accompanied by a single, main artery, favor success of tourniquets in those locations. Our data say otherwise and the implication may be the difference between loss and preservation of elbow or knee. Not only the patient, but also the physiatrist would be among the first to applaud.

The second important conclusion is that virtually any tourniquet will work and hence should be part of any first responder's thought process when faced with a patient who has sustained an injury causing life-threatening hemorrhage from an extremity. In all the previously cited material regarding tourniquets, the word pain becomes a criterion for tourniquet use, success, or failure. This is a tragic mistake and pain should be removed from the lexicon of tourniquet use. This symptom should be irrelevant. Consider that the patient is in need of a tourniquet. Blood loss is a likely companion, as is shock. We readily quote, “Better to lose the limb and save the life” (Dominic Jean Larrey, Battle of Borodino, 1812). A corollary is, better to be in pain than interred. Under most circumstances of extremity hemorrhage, hypovolemia, associated injuries, etc. will have blunted pain perception. If not, analgesics can be administered. This is a desperate situation and is likely to require desperate measures to achieve salvation.

Tourniquet availability may be a problem. Improvisation then becomes essential. For this reason, we studied the cloth and windless tourniquet, historically best known as the “Spanish windlass,” and one of the oldest tourniquets in the literature.[9,11] We used household cloth, but any comparable material, including the uniform belt worn by service personnel, will suffice. The windlass can be of any relatively rigid substance, approximately 6 inches to 12 inches long. We used a stick from the yard. Once in place, the windlass must be secured to prevent unwinding. This can be accomplished with a belt or another piece of cloth or rope. Of interest, in subjects with relatively small arms, the cloth could eliminate the radial pulse when simply tied tightly about the arm. In this case, the windlass was not necessary.

The relatively high systolic pressures (163 mm Hg and 168 mm Hg) recorded in lower extremities tourniqueted with the sphygmomanometer reflected the normally higher systolic pressures observed there, especially in older subjects. In addition, these are the sphygmomanometric pressures required to eliminate the distal pulse and, as Shaw and Murray[17] demonstrated in 1982, the percentage of tourniquet pressure delivered to the depths of the thigh (femoral/superficial femoral artery) is inversely proportional to the circumference of the thigh. This proportionality presumably applies to the leg. Circumferences of leg and thigh exceeded those of forearm and arm in all our subjects. One subject required 200 mm Hg pressure to occlude the femoral circulation and another required 240 mm Hg to occlude the tibial circulation. These tourniquet applications were associated with moderate pain in each case.

Environmental conditions, such as mud or water, have been reported to affect adversely some tourniquet applications. A bloody field adversely affected use of the CAT in a recent report[18] and might compromise successful tourniquet application of the half inch rubber tube, although this complication was not mentioned in reports from World War II, where the rubber tube was the most popular tourniquet in use.[2] We compared the half inch rubber tube with the cloth and windless, as tourniquets in a bloody field and found neither to be compromised in such a setting. Of the tourniquets studied, we favor the cloth with windlass as the simplest to improvise and easiest to apply on all four extremity locations.

On a final note, there remains the pressure point that persists in our standard reference texts,[14–16] including the current *Emergency War Surgery*, 2004.[16] Are there data to support the concept that distal hemorrhage can be controlled by manually occluding the brachial artery in the arm or the common femoral artery in the groin? Or are there data to support the reverse, namely that the so-called pressure point concept is an illusion?

In our review of the literature, we find no data to reply affirmatively to the first question. Conversely, the 2005 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations concluded that, "The efficacy, feasibility, and safety of use of pressure points to control bleeding have never been subjected to any reported study . . ."[19] Our own observations indicate that pressure point control is a euphemistic misnomer. The reason the pressure point is useless, in control of extremity hemorrhage, relates to collateral circulation and its extensive network in both upper (elbow) and lower (knee) extremities. In addition, the force necessary to occlude a major artery fatigues the applicant within a minute's time and renders irrelevant possible usefulness of such a technique, especially when the efficacy of tourniquet control is so simple.

In conclusion, the cloth with windlass is the easiest tourniquet to improvise and apply, although any tourniquet will suffice. It can and, where applicable, should be used below the elbow/knee. Pain is irrelevant and pressure points are useless.

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