Emergency Tourniquet Effectiveness in Four Positions on the Proximal Thigh

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ABSTRACT

Objective: The purpose of the present study is to determine the performance of tourniquet use by the placement of the tourniquet's windlass on the extremity in four positions—medial, lateral, anterior, and posterior—to inform tourniquet instructors and develop best tourniquet practices. **Methods:** A HapMed™ Leg Tourniquet Trainer was used as a manikin to test the effectiveness of an emergency tourniquet, the Special Operations Forces Tactical Tourniquet. Two users made 10 tests, each in four positions. **Results:** Effectiveness rates of tourniquet use were 100% in all four positions. The two tourniquet users were both right-hand dominant and used their right hand to turn the windlass. One user turned the windlass clockwise, and the other turned it counterclockwise. The association between time to stop bleeding and tourniquet position was statistically significant but associations between time to stop bleeding and the user, user-by-position, and windlass turn number were not statistically significant. The association between tourniquet position and pressure under the tourniquet was statistically significant, and the association between user and pressure under the tourniquet was statistically significant, but the user-by-position and windlass turn number were not statistically significant. The associations between tourniquet position and blood loss volume, user and blood loss volume, and user-by-position and blood loss volume were statistically significant. **Conclusions:** The present study found that tourniquet effectiveness rates were uniformly 100% irrespective of whether the windlass position was medial, lateral, anterior, or posterior. These excellent clinical and statistical results indicate that users may continue to place the tourniquets as they prefer upon the proximal thigh.

KEYWORDS: *first aid, resuscitation, damage control, hemorrhage, trauma, shock*

Introduction

Since 2003, the U.S. Army Institute of Surgical Research has run an Emergency Tourniquet Program that has helped develop best tourniquet practices associated with improved casualty survival.[1-4] However, many questions remain inadequately evidenced as to what the best tourniquet practices should be. For example, in 2012, tourniquet users asked us two questions on how best to position the tourniquet on an extremity that is in need of hemorrhage control. The two questions were similar and regarded the orientation of the tourniquet in its circumferential envelopment of the extremity. The two questions came forward at about the same time from unrelated persons on different continents, but the questions dealt with whether the tourniquet is best used on the anterior thigh as opposed to the lateral, medial, or posterior thigh. One question, from an instructor contracted to train U.S. military personnel, was whether medial or lateral placement was better. Another question was whether the windlass should be medial, lateral, anterior, or posterior. The user, an Australian expert in disaster medicine, wanted this knowledge to be established in order to develop best practices. We found no adequate evidence of superiority of any position reported in clinical experience, both in studies of collapsible tube science and in published research of tourniquet use (either operative or emergency use). Both questioners oriented the tourniquet placement by the windlass position on the thigh, the most common limb segment in need of tourniquet use.

The purpose of the present study was to determine and compare the performance of tourniquet use by the placement of the tourniquet on the extremity in four positions (medial, lateral, anterior, and posterior) in order to inform tourniquet instruction and develop best tourniquet practices.

Methods

The approved laboratory protocol (U.S. Army Institute of Surgical Research Regulatory Office, Practical Biomedical Engineering Research of Tourniquet Application and Use, L-12-009) was executed from March to August 2013. This study was conducted under a protocol reviewed and approved by the regulatory office and in accordance with good laboratory practices. Tourniquet users included a pair of investigators familiar with military tourniquet training and their clinical use. One investigator was an expert in tourniquet use and tourniquet research; the other investigator was trained in tourniquet

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use and was present when the middle third of the Baghdad tourniquet survey was made in 2006, but he did not participate in the Baghdad survey. Both tourniquet users were oriented to the manikin and its use.

The investigators used a HapMed™ Leg Tourniquet Trainer (CHI Systems, Fort Washington, PA), a simulated right-thigh body segment (leg number 000F) with an amputation injury just proximal to the knee; its use in the present study was similar to that described in previous reports.[3,4] The medial hip–pelvic area had an embedded computer interface that included a smartphone-like touchpad. Software (version 1.9) internal to the manikin allowed the leg to stand alone and be operated by user input through finger touch on the pad. The manikin was laid on a desk in the laboratory and was operated in accordance with the manufacturer's instructions. The manikin had no blood-like fluid, but bleeding was represented by red lights that transilluminated the wound. The number of lights illuminated represented the intensity of bleeding—all lights on meant no control of bleeding; no lights on meant bleeding had stopped. Intermediate control was indicated by a few lights twinkling on and off. Arterial pulse was noted when palpable in the popliteal and femoral artery areas.

The system reported the blood loss volume as calculated using a linear equation from the arterial capacity and number of pulses before hemorrhage control. The touchpad readout for each iteration showed the results, which included effectiveness of the bleeding control, time to stop bleeding, pressure exerted under the tourniquet, and blood loss volume. The measurement of the time to stop bleeding started when the iteration began and stopped when the manikin sensed that the thigh was losing no more blood. Effectiveness was defined as the stoppage of blood loss and the termination of distal pulse. Iterations began with a tourniquet device laid out flat undone on the desktop and not yet applied to the thigh and ended when the user pressed the touchpad button, believing that the hemorrhage was stopped. A custom scenario was used; in it, the casualty had a small build and the setting was care under fire, a setting resembling civilian emergency care when there is gunfire or similar danger at the scene of care. The manikin settings also included a constant (635mL/min) hemorrhage rate; the resulting bleed-out time in this scenario was 4 minutes, giving the user 240 seconds to successfully apply the tourniquet. Tourniquet devices, users, test iterations, and outcomes were uniquely identified. The tourniquet was a Special Operations Forces Tactical Tourniquet (SOFTT, Wide version, Tactical Medical Solutions, Anderson, SC). Users tightened the tourniquet until simulated bleeding stopped. The manikin was designed to train users by providing feedback on trainee performance; and we used the manikin in assessing performance of the tourniquet use by its placement on the thigh.

The SOFTT is a strap-and-windlass design. One windlass turn is a 180° excursion arc, which is the limit of wrist supination in turning the windlass. The users by convention regrip the windlass after 180°; this arc is what they deem one turn. The number of turns was recorded. The turn direction (clockwise, counterclockwise) was recorded. Users were categorized individually.

The present study was an experiment of tourniquet performance by placement in four positions on the thigh. The four positions were with the windlass placed anterior, posterior, medial, and lateral on the proximal thigh. Two users made 10 tests, each test in four positions, for a total of 80 tests. Performance criteria included hemorrhage control (yes–no), stopping the palpable pulse distal to the tourniquet (yes–no), time to stop bleeding (seconds), pressure applied to the skin by the tourniquet (mmHg), blood loss volume (mL), and the number of windlass turns executed (whole number). The user tightened the tourniquet until simulated bleeding was believed to have stopped, based on visual inspection of the lights and palpitation for the distal pulse in the device.

Statistical analysis included use of descriptive statistics. We used a least squares analysis of variance (ANOVA) to analyze the effects of tourniquet use on the factors of interest. Analysis allowed for detection of intervariable associations; namely, if there was an association between the user (User 1 versus User 2) and tourniquet position. This user-by-position meant that different users had different results by position overall. Significance level was set at $p = .05$.

Results

Effectiveness rates of tourniquet use were 100% in all four positions (medial, lateral, anterior, and posterior); there was no statistical or clinical difference among the effectiveness rates by position.

The two tourniquet users were both right-hand dominant and used their right hand to turn the windlass. The direction in which the windlass was turned differed between the two users. One user turned the windlass clockwise and the other counterclockwise. These two directions were consistent for both users in all their tests. Therefore, the results by turn direction and user were thus confounded as they essentially collapsed to mean the same thing; user identity and turn direction could not be separated effectively in the model.

When modeling time to stop bleeding, the association between tourniquet position and time to stop bleeding

was statistically significant, but the user, user by position, and windlass turn number were not statistically significant (Table 1).

Table 1 *Results of Time to Stop Bleeding.*

Variable	Degrees of Freedom	Sum of Squares	*F* Ratio	*p* Value
User	1	341.5890	1.3088	.2565
Position	3	2501.8071	3.1953	**.0286**
User by position	3	336.5819	0.4299	.7322
Turn number	1	850.2389	3.2577	.753

When modeling pressure under the tourniquet, the association between tourniquet position and pressure under the tourniquet was statistically significant, and the association between user and pressure under the tourniquet was statistically significant. However, the user-by-position and windlass turn numbers were not statistically significant (Table 2).

Table 2 *Results of Pressure Under the Tourniquet.*

Variable	Degrees of Freedom	Sum of Squares	*F* Ratio	*p* Value
User	1	25,075.764	13.4540	**.0005**
Position	3	22,794.865	4.0767	**.0099**
User by position	3	12,818.854	2.2926	.0854
Turn number	1	3884.272	2.0840	.1532

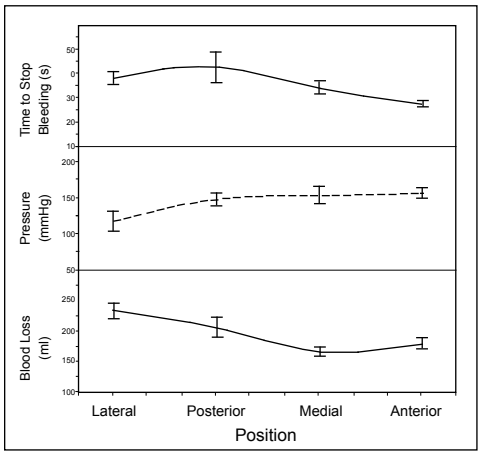
When modeling blood loss volume, the association between tourniquet position and blood loss volume was statistically significant (Table 3), the association between user and blood loss volume was statistically significant, and the association between user-by-position and blood loss volume was statistically significant. However, the windlass turn number was not statistically significant.

Table 3 *Results of Blood Loss Volume.*

Variable	Degrees of Freedom	Sum of Squares	*F* Ratio	*p* Value
User	1	23,474.626	9.9458	**.0024**
Position	3	46,536.196	6.5722	**.0006**
User by position	3	31,399.288	4.4345	**.0065**
Turn number	1	1286.931	0.5453	.4627

Excluding effectiveness, the other results indicated that the position had significant associations with performance for time to stop bleeding, pressure, and blood loss volume. The anterior position had the shortest time to stop bleeding results, and the posterior had the longest. The anterior position had the highest pressures, and the lateral had the lowest pressures. The medial position had the lowest blood loss volume results, and the lateral had the highest. The differences in times, pressures, and volumes were small but clinically significant (Figure 1).

Figure 1 *Tourniquet performance by position. Each error bar is constructed using 1 standard error from the mean.*



Discussion

The main finding of the present study was that tourniquet effectiveness rates were uniformly 100% regardless of whether the position was medial, lateral, anterior, or posterior. These clinical and statistical results are important because they indicate that users may continue to place the tourniquets as they wish on the proximal thigh according to their preference. This finding confirmed the hypothesis that effectiveness and position are not associated. However, effectiveness as a yes-no binary variable is a simple but crude outcome. Other outcomes, such as blood loss volumes, have value also, as discussed in the following minor findings.

The first minor finding was that several of the hypothesis-generating associations yielded interesting results unexpectedly. The experiment was able to detect associations among outcomes like blood loss volume and technique-associated variables like turn direction. However, the design of the experiment was not set up to answer definitively the meaning of such associations.

The second minor finding was that one user turned the windlass in an unexpected direction. Both users were right-hand dominant and preferentially used their right hand to turn the windlass, but one turned the windlass clockwise and the other counterclockwise. Turning the windlass is wrist-based, and turning is either with wrist supination or pronation. Supination turns the palm up, whereas pronation turns the palm down. The two are performed by muscles of substantially different strength as supination is stronger. The power supinator is the biceps

brachii muscle. Over the past decade of seeing hundreds of users in care or training, we have never detected a user who preferred to pronate in turning the windlass. Now that we detected one such user, we relabeled the turn directions as clockwise and counterclockwise (previously we used right and left in assuming all supinated), and we suspect that we may have overlooked infrequent or rare pronators. We also alerted trainers and tourniquet investigators that some users may pronate.

The strength of the present report is its experimental design, which allowed a powerful statistical analysis of several variables of interest. By reporting on a tourniquet experiment, the present report shows investigators a scientific approach to studying emergency healthcare in a way that is understandable and practical. Such an approach is suitable for further experiments in addressing the questions of tourniquet users whether used by the present investigators or any others so interested.

Study Limitations and Future Directions

Limitations of the present report are several. An experiment on a manikin does not model clinical care complexity in its entirety but focuses on the controlled variables of interest. The experiment is mechanical in nature and does not allow easy study of human factors like user knowledge, experience, or skill.

Future directions for research are several. A clinical question remaining unanswered is whether a medial wound is best treated with lateral or medial tourniquet placement as it is not known whether one tourniquet position applies more pressure on an injury on the opposite side of the extremity. To date, evidence in mechanical models indicates that circumferential extremity tourniquets of conventional designs are generally symmetric in their medial-lateral pressure distribution.[5,6]

In summary, the present study reports a manikin experiment that found that medial, lateral, anterior, and posterior positioning of a windlass-and strap emergency tourniquet had 100% effectiveness irrespective of position, but that several associations detected, such as with blood loss volumes by position, are opportunities for further study in order to develop best tourniquet practices.

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Disclaimers

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Department of Defense or United States Government. The authors are employees of the U.S. Government. This work was prepared as part of their official duties and, as such, there is no copyright to be transferred.

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