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Issues Related to the Use of Tourniquets on the Battlefield

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Abstract

On the battlefield, a properly applied tourniquet can be an extremely effective means of controlling severe extremity wound hemorrhage. However, a great deal of confusion exists among soldiers, medics, and military medical officers on a number of tourniquet-related issues. What is an appropriate combat tourniquet? When is it appropriate to use a tourniquet? When and by whom should a tourniquet be removed? Under what conditions a tourniquet should not be released or removed? What are the most effective ways to increase limb salvage while using a tourniquet? These and additional issues were addressed by a panel of experts at the 2003 Advanced Technology Applications for Combat Casualty Care Conference on August 21 and 23 at St. Pete's Beach, FL. Here we review those issues and present a summary of the panel's recommendations.

Introduction

A properly applied tourniquet can be an extremely effective means of controlling extremity wound hemorrhage and could prevent 7 out of 100 combat deaths [1, 2]. However, tourniquet use remains controversial and is the source of a good deal of confusion [3]. In civilian emergency medicine, the fear of tourniquet-related complications has all but eliminated their use [3]. Yet, the Israeli Defense Force (IDF) advocates the liberal use of tourniquets [4], as do members of the Special Operations Forces community [5, 6]. These divergent views have led to considerable confusion on the part of soldiers, combat life savers (CLS), medics, and other military medical personnel.

A panel of physicians, medics, scientists, and biomedical engineers convened as part of the 2003 Advanced Technology Applications for Combat Casualty Care Conference on August 21 and 23 in St. Pete's Beach, FL to address some of the major issues regarding tourniquets in combat. Care was taken to include individuals possessing combat, clinical and/or scientific experience and knowledge of tourniquet use. We present a brief review of each issue followed by a distillation of the panel's discussion and major recommendations, which appear in Table 1.

Major Issues

What Is an Appropriate Combat Tourniquet?

Panel participants emphasized that first, and foremost, an adequate tourniquet must stop arterial bleeding; anything short of this is unacceptable. A tourniquet tight enough to

occlude venous return but not arterial flow can exacerbate bleeding. An inadequate tourniquet can also cause significant bleeding if extensive laceration of the soft tissues is present distal to the device. This is a critical point, as many soldiers, including CLSs and medics, erroneously believe that partial arterial occlusion actually is preferred and will prevent limb loss from ischemia. A properly functioning tourniquet should be tightened until blood flow stops. Some oozing will continue to occur following a sufficiently tightened tourniquet due to medullary (bone) blood flow.

Tourniquet tightness must increase considerably as limb size increases. This is due to the inverse relationship between the tourniquet pressure required to occlude arterial flow and the circumference of the limb[7-10]. Additionally, there is also an inverse relationship between tourniquet width and the pressure required to occlude arterial flow [8-10] (Fig. 1). Given that the range of limb circumferences for male soldiers are; 11.5 to 15.0 inches and 20.3 to 26.7 inches for the arm and leg, respectively[11], two key concepts become clear. First, complete occlusion of the leg is extremely difficult, if not impossible, with a one-inch tourniquet, especially without mechanical augmentation (windlass, ratchet, cams, or elastic components). This is exemplified by the inability of the strap and buckle tourniquet (NSN 6515-00-383-0565) and one-handed tourniquet (OHT) (NSN 6515-01-504-0827), both one inch wide, to effectively occlude arterial flow in the leg [12]. The second concept is that small changes in width have a large impact on reducing occlusion pressure. Thus, wider tourniquets are much more effective. However, simply increasing the width of the tourniquet strap does not eliminate the need for mechanical augmentation because, as width increases, so does the amount of tissue that must be compressed,

greatly increasing the effort required to produce tension. Additionally, as the width of a strap increases it tends to bow, thus transmitting relatively more pressure to the center than to the edges, and effectively reducing the functional width [13].

Caulkins et al. field-tested eight potential battlefield tourniquets [14]. Of these, only three were capable of reliably occluding arterial flow in the lower limbs, and none of these favored one-handed operations. These included two strap/ratchet and one pneumatic design. These three systems were the only tourniquets tested that could augment the user's ability to tighten them by mechanical means. All others tested depended on elastic components or some form of a strap and buckle design. This critical observation emphasizes the fact that simple strap and buckle type tourniquet systems can not reliably occlude arterial flow in the lower limbs.

In contrast to straps, which compress limb tissue via circumferential tension, pneumatic tourniquets use inflation pressure, which is controlled more easily and more evenly applied around the circumference of the limb. Compared with the strap tourniquet the contoured pressure profile of a pneumatic tourniquet also reduces high shear stresses at the tourniquet edge that can result in nerve damage [15, 16]. The greater width of the pneumatic tourniquet, combined with the greater effectiveness of tissue compression, also allows it to be much more effective at lower pressures, thereby reducing the likelihood of tissue damage [15, 17]. These desirable properties have nearly eliminated tourniquet-related complications following orthopedic surgery where pneumatic tourniquets have become the standard[18]. The potential advantages of a pneumatic tourniquet on the battlefield

were recognized before WWII [19, 20]. However, concerns about size and weight, leaking, and ruggedness have kept them off the battlefield. These technical concerns have been largely overcome by in at least one commercially available pneumatic trauma tourniquet (Delfi EMT tourniquet). The panel recognized that equipping all soldiers with pneumatic battlefield tourniquets may not be practical, but recommended that it be considered for medics and issued to all casualty evacuation vehicles.

The panel recognized the potential for the all-but-forgotten rubber-tubing tourniquet, a very popular tourniquet used during WWII and first used in the 1870's. A six-foot piece of ½ inch (outer) diameter latex tubing can achieve very reliable and effective occlusion of arterial bleeding (Figure 2)[20]. This tourniquet has many advantages, including the ability for one-handed application to the upper arm, low size and weight, and very low cost. The disadvantage is that pressure is difficult to regulate, often resulting in excessive pressure and pain. Regardless, the panel recommended that the rubber-tubing tourniquet be considered in any future down-selection process.

Until a new effective battlefield tourniquet can be identified, fielded, and issued to each soldier, the improvised tourniquet or Spanish windlass remains the principal option. The Spanish windlass tourniquet (used on the battlefield since 1674) while low tech and simple, is a reliable technique with proper instruction and practice (see Training and Education). However, because this tourniquet requires the soldier to locate a windlass resulting in the loss of valuable time, the panel recommended that soldiers be issued a six inch stick or a plastic tube as part of the hemorrhage control kit.

The panel agreed that the current strap and buckle type tourniquet (NSN 6515-00-383-0565) needs to be removed from the inventory. This narrow tourniquet rarely controls bleeding completely and cuts into underlying skin. Although following WWII it was recommended strongly that the tourniquet be discarded [20], it continues to be issued today.

The Army urgently needs an effective tourniquet system that can be carried by every soldier and is easily and rapidly self-applied [6, 14], however, the panel voiced general concern that an emphasis on one-handed operation has overshadowed critical attention to adequate control of arterial bleeding in the lower extremities. The vast majority of injuries requiring a tourniquet occur in the lower extremities (68%)[4] where one-handed application is not necessary. This fact needs to be emphasized in the design of current and future battlefield tourniquets.

When Should A Tourniquet Be Applied?

Care under fire

If a soldier is wounded under fire, a tourniquet should be used for any severely bleeding extremity wound. While under fire, the use of direct pressure, pressure dressings, pressure points and elevation may place the casualty and medic at additional risk of injury. Current Army doctrine supports a much more conservative approach to tourniquet use only after all other measures have failed. However, the liberal use of the tactical tourniquet has gained popular support among the Special Operations community, primarily as a result of lessons learned from such Special Operations missions as the Battle of the Black Sea in Somalia [2] and the subsequent studies in tactical medicine [5, 6, 21].

Other circumstances

Tourniquet use when not under fire is dictated by the inability to control bleeding by other means. The panel reiterated current policy (FM 21-11; FM 8-230; STP 21-1-SMCT) and emphasized the need to better educate all soldiers. Additional recommendations are discussed below.

When Should a Tourniquet Be Removed?

During the early part of WWII, medical personnel would briefly loosen tourniquets every 30 minutes to allow reperfusion via intact collateral circulation. As a result, death sometimes occurred from the cumulative effects of the bleeding. This led to a policy reversal in the latter part of the war, giving rise to the current belief that a tourniquet should not be loosened or removed except by a medical officer [20]. Clearly, if a more liberal application of tourniquets is advocated, we must also adopt new guidelines for removal to avoid unnecessary loss of limbs or even life. Regardless of the conditions under which a tourniquet is applied, the most effective method of limb salvage is the early, successful conversion of a tourniquet to a less damaging means of hemorrhage control. The panel recommended that combat medics adhere to the algorithm described in Table 2.

Under What Conditions Should a Tourniquet Not Be Removed?

Despite the panel's advocacy of a more liberal policy of tourniquet use and removal, there are clearly conditions that preclude tourniquet removal (Table 3).

Limb Salvage

Based on studies in orthopedic surgery, a two-hour time period generally is accepted as the safe limit before some level of functional loss occurs [3, 18, 22]. Tourniquet application beyond two hours can result in progressive neuromuscular injury. However, we do not know at what point limb loss becomes inevitable. Wolff et al., [20] reported a number of tourniquet applications of 4-6 hours without any apparent deleterious effects. Lastein et al [4] reported over 90 cases of tourniquet application in the IDF and found complications only after 150 minutes, none of which resulted in limb loss. Regardless, it is critical to limit tourniquet duration if at all possible. This means either recognizing when a tourniquet is not necessary or converting to a less damaging means of hemorrhage control as soon as possible.

Surgeons commonly employ periodic reperfusion when using tourniquets during elective procedure for bloodless extremity surgery. This practice significantly increases the length of safe tourniquet duration, and has been the basis of a good deal of scientific investigation [18, 20, 22-24]. However, this strategy is incompatible with tourniquet use on the battlefield. As discussed above, Wolff et al.[20] found that an unacceptable number of soldiers died of incremental exsanguinations from repeatedly loosening the tourniquet and the practice justifiably was abandoned.

Finally, cooling ischemic muscle profoundly reduces muscle injury [20, 25-27]. Even a 2-3 °C reduction in muscle temperature can significantly increase the return of muscle function following extended tourniquet application [26, 28]. The practice of exposing the

limb, thereby exploiting cool environmental temperatures, was credited for successful limb salvages following tourniquet applications for up to 8 hours during WWII [20]. Therefore, the panel recommended that this practice be encouraged as part of soldier training. In addition, this practice reduces the chance of overlooking an injured soldier with a tourniquet once he is transferred to a higher echelon of care.

Training and Education

Improvements in hemorrhage control will not occur without changes in current soldier education and training at all levels.

Soldier Training. Most battlefield first-aid initially is rendered by a non-medic comrade in arms. The panel agreed that current training in hemorrhage control techniques, including tourniquet use, is extremely deficient. Hemorrhage control techniques and the use of tourniquets already are Common Tasks taught to all soldiers upon initial entry training. However, a recent study of approximately 40 Advanced Individual Training students who had completed Initial Entry (Basic) Training showed that less than half could recognize and treat a life-threatening hemorrhage of the thigh in a simulated patient (personal communication, Mabry). In addition to greater emphasis on the control of life-threatening extremity hemorrhage during Basic and Advanced Individual Training, soldiers also need sustainment training with additional emphasis on this skill during Common Task Training and other training opportunities where field skills are emphasized, such as the Ranger Course, Primary Leadership Development Course and the Advanced and Basic Non-Commissioned Officer Courses. This skill also should be added to the tasks tested for the Expert Field Medical Badge and Expert Infantry Badge. Innovative training aids such as the hemorrhage simulators and

interactive patient manikins should be evaluated as adjuncts to improve training across the Armed Forces.

CLS. The combat lifesaver is a nonmedical soldier trained to provide immediate emergency care to fellow soldiers as a secondary mission when the tactical situation permits. Each squad, crew, or equivalent-sized unit has at least one member trained as a combat lifesaver[29]. The panel agreed that additional training in hemorrhage control techniques, including tourniquet use is warranted. Training should be extensive enough for the CLS to be able to evaluate the need for a tourniquet, or the suitability of a wound for another form of (less damaging) hemorrhage control. It was the panel's opinion that this training could be accomplished within the current time constraints of CLS training if the training time for establishing intravenous access was reduced or eliminated. Current tactical combat casualty care guidelines question the utility of early intravenous fluid therapy in the field. Rapid control and arrest of life-threatening hemorrhage is more beneficial and takes less time and skill than establishing intravenous access and giving fluids for resuscitation. Further, it is unlikely that the small amount of intravenous fluids available to the CLS are of much benefit and may even be detrimental to the casualty with significant hemorrhage.

Medic. In addition to knowing how to apply tourniquets, medics should be taught under what circumstances tourniquets should and can be removed. Simple guidelines should be taught, taking into account evacuation time, the tactical situation and the presence or absence of shock. The recommendations made by this panel would allow medics to judge when to remove unnecessary tourniquets to prevent further injury, while safely managing those casualties who need them.

Testing and Selection of Battlefield Tourniquet Systems

The panel advocated that a systematic testing process be developed and adopted by which any and all potential battlefield tourniquet systems are tested prior to their inclusion in the inventory. This process is critical in order to avoid fielding an ineffective battlefield tourniquet, as occurred in the case of the OHT. The process developed by the panel is similar to that of Caulkins et al [14]. Time did not allow the panel to develop the details of the testing process; general recommendations were made and agreed upon. Scores will be assigned to objective measures determined at each phase. Each score will be entered into a matrix, ultimately leading to selection of the final selection.

Phase 1: Adherence to sound principles of tourniquet design

Initial consideration of any tourniquet will be based on established scientific facts and principles of tourniquet engineering, e.g., = 1" width, no mechanical augmentation. This will allow quick rejection of tourniquets outright without further testing.

Phase 2: Laboratory testing in human volunteers

A. Lower Limb. Once a tourniquet has passed Phase 1, it will be tested on the extremities in human volunteers. Two endpoints will be determined:

- Elimination of pulse in the posterior tibial artery determined by Doppler auscultation
- Elimination of palpable peripheral pulse

Based on a recent study by Wenke et al. [12], these determinations can be made in = 30 seconds. Confirmation of complete occlusion must be demonstrated before further consideration.

A. Upper Limb. Candidates that occlude leg blood flow will then be tested on the upper limb. This is to ensure that the device(s) does not possess physical constraints that preclude effective use on small limbs.

Phase 3: Field testing

Tourniquets that meet Phase 2 requirements will be field tested by medics under environmental conditions similar to those encountered on the battlefield. Time did not permit the development of the details for field testing. The panel recommended that the details of this phase could be developed by the Army Medical Department Board and will involve soldiers, marines, and Special Operations Forces in various tactically relevant environments.

Phase 4: Safety testing

In Phase 4 the effective circumferential force will be determined in limb surrogates instrumented to determine the relationship between circumferential force and occlusion pressure. This phase is designed to ensure that the potential for tourniquet injury is factored into the selection matrix, i.e., the lower the effective circumferential force, the better the score.

Phase 5: "Practical Consideration"

All tourniquets that reach requirements to this point will be judged on such additional considerations such as size, weight, shelf-life, ruggedness, ease of application, and cost.

Panelists

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Dr. Thomas Walters, currently at the United States Army Institute of Surgical Research (USAISR) as a member of the Combat Casualty Care Research Program, is a research scientist with a background in muscle physiology. Dr. Walters received his MS in exercise physiology and Ph.D. in muscle physiology from the University of Texas at Austin. From 1990 to 2000 he performed research at Brooks Air Force Base, TX in thermal stress and its role on limiting physical performance. His current research focuses on issues related to extremity trauma, including tourniquet-related injury.

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Captain Robert Mabry, MD, is currently Battalion Surgeon for the 1st Special Forces Group, Ft. Lewis WA. He is a former Special Forces 18D medic. He received his medical degree from the Uniformed Services University of the Health Sciences at Bethesda, Maryland in 1999 and completed his residency at Brooke Army Medical Center as an emergency room physician in 2003.

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COL Clifford Cloonan, MD, is currently an associate professor and the Interim Chairman of the Department of Military and Emergency Medicine at the Uniformed Services University of the Health Sciences in Bethesda, Maryland. He is a former Special Forces 18D medic. COL Cloonan is a former dean of the Joint Special Operations Medical Training Center and is the Department of Defense representative to the National Registry for Emergency Medicine Technicians.

COL John Holcomb MC, USA

COL John Holcomb, MD, is currently Commander, USAISR, and Chief, Trauma Division, Brook Army Medical Center, San Antonio, TX. He is the trauma advisor to the US Army Surgeon General and for the USSOCOM Biomedical Initiatives Steering Committee. COL Holcomb's numerous medical assignments have included staff surgeon at Womack Army Medical Center, Ft Bragg, NC, and the Joint Special Operations Command; Chief of Trauma at WBAMC; Chief of the Military Trauma Research Branch at the USAISR; and Director of the Joint Trauma Training Center at Ben Taub General Hospital, Houston. His research interests include novel methods of hemorrhage control, optimal resuscitation techniques and medical informatics.

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Dr. Robert Mosebar is a medical consultant for the Directorate of Combat and Doctrine Development, U.S. Army Medical Department Center and School, Ft Sam Houston, TX. His military career spans over 50 years and has ranged from a combat medical aidman and litter bearer during WWII to numerous medical commands until his retirement in 1996. Dr. Mosebar introduced the concept of the Combat Lifesaver for the battlefield to the Army.

Robert Pedowitz, Ph.D., MD

Dr. Robert Pedowitz is an associate professor in the Department of Orthopaedics at the University of California, San Diego. He is the Chief of Sports Medicine and the Program Director for the UCSD Orthopaedic Surgery Residency Training Program. Dr. Pedowitz completed medical school and residency at the University of California San Diego, and

completed a sports medicine fellowship at Duke University. His PhD was awarded by the University of Gothenburg, Sweden for a thesis titled "Tourniquet-Induced Neuromuscular Injury" and he has published 16 scientific articles on tourniquet-related injury.

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Kevin Inkpen received the Bachelor of Engineering degree from Lakehead University in Thunder Bay, Ontario in 1997 and the Master of Applied Science degree from the University of British Columbia in 1999, both in Mechanical Engineering. He is currently working as a development engineer in Vancouver BC, Canada for Delfi Medical Innovations Inc., which develops and manufactures surgical and specialty tourniquet products.

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SFC (Ret) Robert Miller

Robert Miller is currently the CEO of Innovative Casualty Response and the Program Director for North American Rescue Products. He serves on the Committee on Tactical Combat Casualty Care and is an editorial consultant for the Journal of Special Operations Medicine. Mr. Miller holds a bachelor's degree in Health Sciences and is recently retired from the Ranger Regiment with 20 years experience as a Special Operations Combat

Medic. He was the primary developer of "Ranger First Responder" a war-fighter combat trauma-training course that has replaced the U.S. Army's Combat Lifesaver Course in several units within the Special Operations Command.

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SFC David Funk is a Special Forces 18D medic assigned to United States Special Operations Command. He is a founding member of the 3rd Ranger Battalion. Prior to his current assignment, he spent 10 years assigned to the 7th Special Forces Group. He received his medic training in 1995. SFC Funk is also a dive medical technician and hyperbaric chamber operator.

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Table 1

Major Recommendations

- Replace strap and improvised tourniquets
  - Remove the current strap and buckle tourniquet* from inventory
  - Candidates for replacement must undergo a systematic down-selection process prior to consideration for inclusion in the inventory
- Issue suitable windlass (6-8" x ¾" dowel or plastic tube) to all soldiers as part of hemorrhage control kit
- Medics must be trained and then permitted to loosen or remove tourniquets
- Combat Life Saver must be trained to confidently loosen or remove tourniquets
- Care under fire - use a tourniquet for any severely bleeding extremity wound
  - Medic - assess need for tourniquet as soon as the tactical situation allows
  - Attempt conversion to another means of hemorrhage control
- Do not remove tourniquet if:
  - Casualty is in shock
  - Conversion of casualty cannot be monitored regularly for re-bleeding
  - Tourniquet has been in place for = 6 hours
- Note time of tourniquet application on casualty's forehead.
- Soldier training requires greater emphasis on tourniquet use and hemorrhage control in general, To include the use of bleeding manikins and sustainment training
- All soldiers should be issued a tourniquet and trained to use it
- A pneumatic trauma tourniquet should be added to the inventory and carried in all evacuation vehicles

* NSN 6515-00-383-0565

Table 2

Care Under Fire Tourniquet Removal Algorithm

- Apply hemostatic or pressure dressing to the wound site
- Resuscitate if needed
- If the casualty shows no signs of shock and no active bleeding, THEN loosen tourniquet and inspect wound for re-bleeding
- Leave loosened tourniquet in place and monitor wound frequently
- If rebleeding occurs, retighten tourniquet
- If tourniquet is retightened it can only be removed by a medical officer prepared to control bleeding surgically
- If frequent monitoring is not possible, continue the use of the tourniquet rather than risk the failure to notice rebleeding
- NEVER intermittently loosen and retighten a tourniquet

Table 3

Under What Conditions Should a Tourniquet Not Be Removed?

- **Shock** - Removal only by a senior medical provider
- **Amputation**
- **Uncontrollable bleeding -** Wounds involving arterial injury are too great to be controlled by any means
- **Extended periods of tourniquet application -** A tourniquet applied to the leg for 6 or more hours without successful conversion should not be removed until the casualty reaches the FST or higher level of definitive surgical care
- **Inability to observe casualty -** Do not risk failure to notice re-bleeding; leave tourniquet in place

Figure Legend

Figure 1. Occlusion pressure versus the ratio of tourniquet width to limb circumference[8]. At the ratios encompassing the range of thigh circumferences representative of male soldiers, it is not possible to obtain complete occlusion with the common 1" tourniquet. Increasing tourniquet width has a dramatic impact of occlusion pressure. (Reproduced with permission from Lippincott, Williams, and Wilkins)

Figure 2. The surgical tubing tourniquet was strongly advocated during WWII[20]. C and D) A six foot piece of ½ inch latex surgical tubing can provide an effective tourniquet by making at least four parallel turns of the tubing around the leg. Starting 2" from the injury and working away; A) The end first turn is overlapped and anchored by the second turn and B) the last turn is anchored by the next to last turn. The end can be inserted through the loop to guard against accidental release during transport. Only moderate tension is required during winding, as too much tension can be damaging to underlying tissues, as well as very painful.

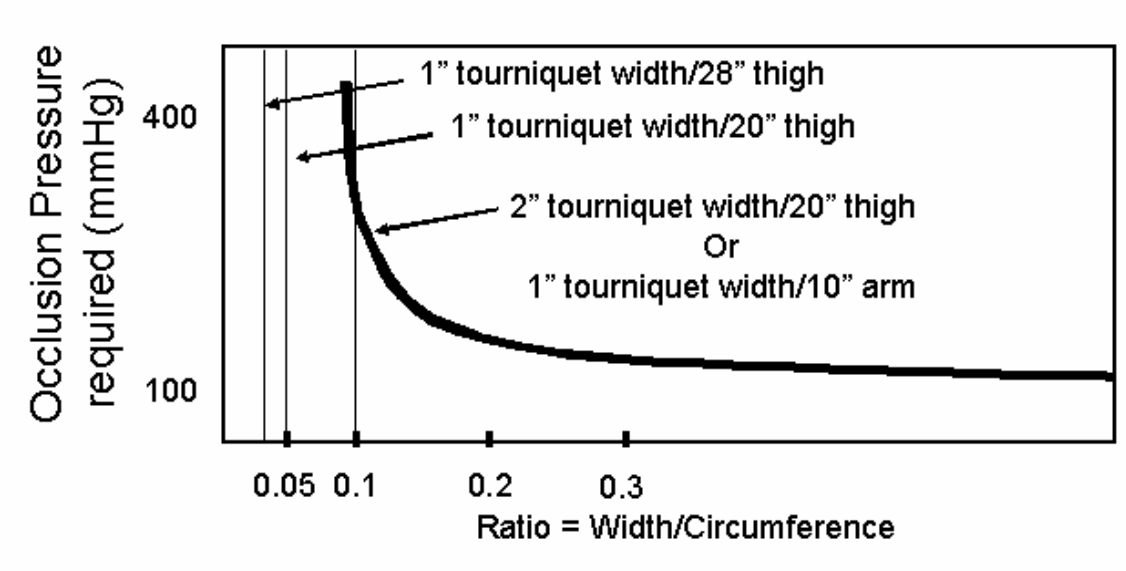
Occlusion Pressure required (mmHg)
400
100
1" tourniquet width/28" thigh
1" tourniquet width/20" thigh
2" tourniquet width/20" thigh
Or
1" tourniquet width/10" arm
0.05
0.1
0.2
0.3
Ratio = Width/Circumference

Figure 1

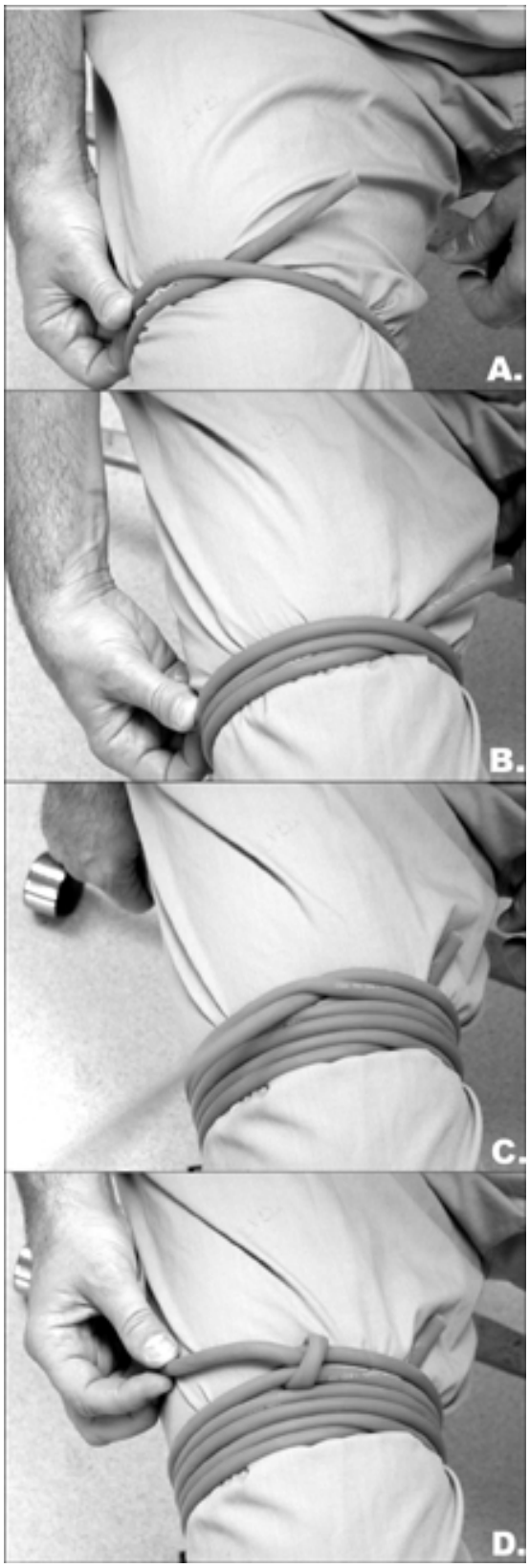

Figure 2