Research article

Simple measures to reduce tourniquet related deaths include: increased availability, proper training on correct use, dispelling amputation fears and simple but economic redesign

Abstract

As far back as the times of Neanderthal caveman, skeletons show obvious limb amputations suggesting tourniquet use. Yet even today thousands of people's deaths are tourniquet related, both military and civilian. These deaths are preventable. Why do they still occur? How can they be prevented?

Recent terrorist attacks in US and abroad, catastrophic natural events such as tornados and earth quakes and even just motor vehicle or hunting accidents can all result in injuries treatable with tourniquets. Not all tourniquet related deaths occur in war/conflict areas or are military related.[1–3] Danger is ever present, but simple and economical measures can be instituted to greatly reduce the incidence of tourniquet related deaths, both military and civilian.

Keywords: tourniquet, amputation, heart attack, femoral arteries, venous thrombosis, traumatic brain injury

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Abbreviations: TBI, traumatic brain injury

Background

Tourniquets do save lives, if properly and timely applied to bleeding limbs. Since before recorded history there is evidence that not only were tourniquets used, but also that tourniquet usage is associated with limb amputation. When a tourniquet is applied with enough force to stop all blood flow, there is no circulation under the tourniquet and distally to that spot, causing tissue necrosis and eventual death of the individual if it is not removed timely. It is this association of tourniquet use with amputation that has resulted in tourniquet use being limited to only in cases of last resort.[4] However, since not using one when needed, causes death, new regulations are requiring availability to those at greatest risk, first responders, military in conflict areas and in public places while providing protection from law suit under Good Samaritan laws similar to those associated with defibrillators. The availability and proper use of defibrillators has proven to save lives. We need to do the same for tourniquets.

Neanderthal amputations suggest that even they used tourniquets, for amputation for without their usage; these would result in death, even today. However the materials needed to make a tourniquet then, were decomposable and have not survived. Romans too have documented the use of tourniquets to stop exsanguinations and limb loss.[5,6] Much has changed much since the days of caveman or the Roman Empire and some things have not. Through the ages the percentage of tourniquet related deaths have progressively reduced, primarily due to better transportation, medical technologies and ready availability of tourniquets at the time of need. Unfortunately, the number of traumatic limb injuries that require tourniquet use is also on the rise, but then so is the survivability from these injuries.

i. During WWI only 20+% survived with tourniquet able injuries

ii. During Iraq Conflict of 2011 survival increased to 89+%.[7,8] As good as that sounds, the actual numbers were still too high, almost 1300 US military deaths were tourniquet related during the Iraq Conflict.

iii. Only 6% of people with tourniquets during Iraq Conflict needed amputations.

iv. Sadly, "in the Afghanistan Conflict, 80% of otherwise survivable injuries resulted in death from exsanguinations".

v. An additional 38-60% of US deaths were US subcontractors.[9]

All of these people could have lived if they had tourniquets, used them properly and timely. Before applying a tourniquet follow these 4 basic steps to preventing exsanguination. If bleeding stops after any step,[10] do not proceed to the next step:

i. Apply Pressure to bleeding site

ii. Elevate bleeding site above the level of their heart

iii. Apply pressure to Pressure Point

iv. Apply a tourniquet

When a tourniquet is necessary, several proposed simple and economical steps could reduce tourniquet related or preventable deaths, both civilian and military:

1. Increased availability of tourniquet at time of need
   a) Seconds may determine whether a person lives or dies.
   b) Fear of amputation may limit a person from carrying one.

2. Education of Proper placement of tourniquet on limb
    a) Reduce waste of tourniquet improperly placed that does not stop bleeding.
    b) Reduce fear of amputation to increase availability.
3. Proper placement and use marked on the tourniquet strap itself
    a) 2-3 inches above bleed (cut artery may pull up in limb).
    b) Under stress may forget training on proper use.
    c) Person may not be the one to apply tourniquet.
    d) Instruction sheet is lost.
4. Quick application of tourniquet
    a) Just 60 seconds can mean life or death with femoral bleed.
    b) May need to be done one-handed.
5. Quick transport to medical removal of tourniquet. Time is critical, as it is both in stroke and heart attack: the "golden hour" is actually 78 minutes for "life" or "death" of the person and a functional limb. In most urban areas and current theatre of operation, the time from application to removal by medical personnel is not an issue.

Ideal placement of a tourniquet is two to three inches above the major bleed, on the **upper section** of the limb. The lower part of the extremities, lower leg or arm, have two bones with the vessels protected between them. If a tourniquet is placed here, the bones will break before even superficial circulation is stopped. However, people will try to place a tourniquet below the joint, elbow or knee, to preserve the joint it in case an amputation occurs. Doing so risks the life of the bleeding person.

Even on the battlefield where war fighters are taught how to apply tourniquets, stress or fear of amputation have caused the tourniquet to be applied below the joint, instead of above it. Up to 7 tourniquets have been used to stop bleeding in a limb without success. That means 6 tourniquets are not available to the next person who may need it. Additionally, the joint still may not be saved and the life may be lost. (It should be noted that in the military they are trained if bleeding does not stop, a tourniquet is never removed, but another is placed above the previous one.) If even trained personnel place a tourniquet incorrectly, what chance does a non trained person have to place it correctly?

Both these diagrams from Wikipedia show the variation of the branching of the femoral artery, right, and potential for circulatory preservation with dual pressure flexible to urniquetation (Figure 1). Each limb has both deep and superficial branches, but lower sections of both upper and lower extremities have two bones which protect vessels within so that bones will break before circulation is stopped. Proper placement is critical to survival.

The femoral artery supplies very little in the thigh itself. The thigh is mainly supplied by a branch of the femoral artery, the profunda femoris (profunda=deep) (Figure 2). From the profunda arise:

i. Medial and lateral circumflex femoral arteries; the ascending, transverse and descending branches of which supply the front and sides of the thigh from the iliac crest to the knee.
ii. Perforating branches (there are usually 4); these pass through adductor magnus to supply the back of the thigh. The second perforator is normally the nutrient artery of the femur.

A cascade of medical events occurs when a tourniquet is applied with enough pressure to stop arterial flow. When arterial flow is stopped it also means that return blood flow is stopped. This has many deleterious effects, directly related to the amount of pressure and length of time it is used, underneath and distal to the tourniquet:

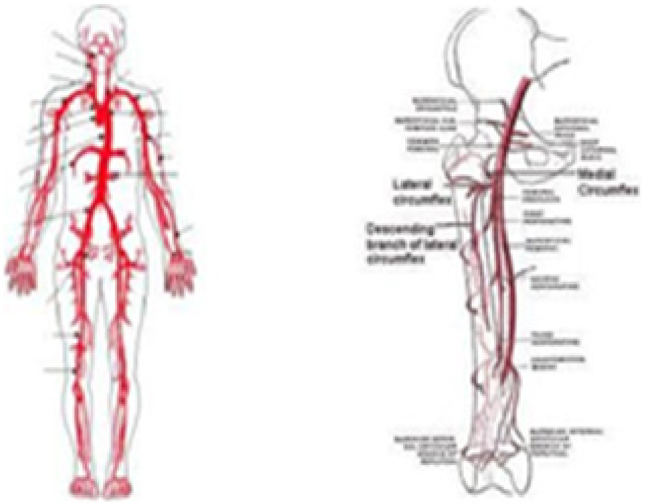

Figure 1 Major circulation splits.

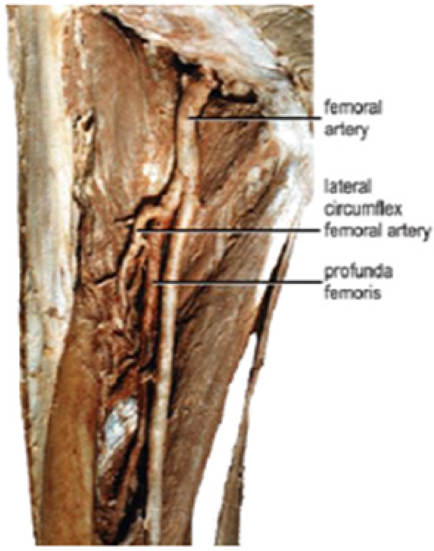

Figure 2 Circulatory preservation.

Initially

i. Nutrients do not get down to the cells.
ii. Oxygen does not get down to the cells.
iii. Waste products of metabolism are not removed.
iv. Concentrations of the arterial and venous blood pool, diluting concentrations of each. Diluted, passive osmosis cannot get the nutrients into the cells or the toxic waste products out.

As time increases

i. Toxic Reaction due to quick release of toxins when tourniquet is loosened providing less tendency to go into shock, Vs. Slow release due to open circulation when toxins are released in low doses over time.

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ii. Amputation necessary due to cell death.

iii. Embolism and Deep Venous Thrombosis potentially life threatening.

iv. Tourniquet paralysis syndrome due to Nerve damage resulting in limb paralysis, partial or complete, paresthesia - pain, loss of sensation, etc.

v. Post Tourniquet Syndrome.

vi. Compartment Compression Syndrome.[11]

vii. Pressure sores, skin damage.

viii. Hyperthermia especially when more than one is used o Sepsis.[12]

ix. Rhabdomyolysis - metabolic breakdown of cells.

x. Tachycardia, Pyrexia, Pain, tenderness, edema and hemorrhage, Dark urine and oliguria.

xi. Increased Cerebral Blood Flow which can be dangerous in persons with increased intracranial pressures.

xii. Tourniquet Pain syndrome[13] (most tourniquets apply 400 mm/Hg and if you had your blood pressure cuff pumped to 200+ you know how painful it can be, now leave it on for almost an hour - many people who have had one save their lives, say they would rather die than go through it again).

A recent study indicates that pressures of 250 to 300mm/hg should not be exceeded for survival of tissues distal to the tourniquet.[14] (Current tourniquet with 90% of market provides 400mm/Hg) Furthermore, they recommended that: The lowest pressure to stop the bleeding is applied, to preserve the extremity tissues,[15] allow venous return and that the tourniquet be applied as soon as need is evidenced either by bleeding or internal swelling. There are specific ratios of the diameter of the area on which the tourniquet is to be applied and the amount of pressure that should be used, but these require measurements, calculations and equipment that may or may not be available at the time and in the field. On a practical level, stop adding pressure when the bleeding stops.

In practice, especially military, there is a fear of deep and unseen bleeding so the medics are taught to stop all potential bleeding to the area. They pull tourniquet on as tight as possible once in position, wait a moment, then pull again. Too much pressure is dangerous, e.g., too much pressure tightening a screw too often results in the screw being stripped and thus rendered useless. High pressure will indeed stop deep circulation as well as superficial but may in itself cause tissue damage, though this can be transient, especially when transit time to medical health is short. Also consider that if the unseen bleeding it above placement of tourniquet, tightening the tourniquet will not stop that bleeding. If mild, this unseen bleeding may not be significant with short transport time. There is also the strong possibility that there is no unseen bleeding, in which case creating tissue damage has no benefit, but may create much harm. Stopping bleeding to save a life is the primary concern for the person applying a tourniquet, but for the bleeding person, the future use of their limb is of great concern.

Potential loss of limb causes significant mental and physical distress, about 90% more,[16] than does traumatic brain injury (TBI). Presumably, the more immediate and visible the disability is, the more it causes stress.[17] The actual disability of limb loss is often less disabling than TBI, yet it is feared more." "If the patient had an extremity wound with a tourniquet they had a fighting chance of survival, but if they did not have a tourniquet or they had a tourniquet that wasn't effective, they died.[18]" Yet, during the Iraq Conflict, only 6% of tourniquets applied resulted in limb loss. This fear persists.

Loss of limb is expensive even when lifelong disability is not considered. "Orthopedic-related disability,[19] (or 76% of those with an orthopedic diagnosis as the primary unfitting condition[20]), has a significant impact on the affected patient, the health care system and, in the case of wounded service members, on military strength and readiness". Lower extremity amputations cause the most disability. In 2007 the VA provided artificial limbs to Veterans who needed them at a cost of over $50Million which is over 1/3 increase over 2006. Quality of life issues aside, additional costs will result if the Veteran or civilian looses his/her independence, due to loss of mobility, since loss of mobility is the primary cause for loss of independence, which is again more costly to the system.

Even if you become disabled, there are various levels of disability and a disabled person can still have a "life" they want. Whether or not a person is disabled, "life" does change with age and time. Limb loss is just another change. Early on in disability, the disability can create drastic changes in life style, but as you live with them, you find out that it is not as bad as you thought, and while your life is different and you have to do things differently, you have a life. Life is still worth it. Most disabled people will figure out a way to do what they really want to, if they are given a chance or take that chance. You just have to figure out what you want or need to do, then figure out a way you can do it. Additionally current increases in technology and capabilities may mean that robotic parts or shells may actually even increase physical abilities over actual limbs.[21]

There are two types of tourniquets, pneumatic and non-pneumatic. The pneumatic tourniquets, which have to be pumped up to apply pressure like a blood pressure cuff, seem to cause less tissue damage than non-pneumatic tourniquets which are often even pressure straps, with sharp edge or edge becomes sharp when pulled tightly. The shape of the edge of tourniquet is one factor in tissue damage. The rounded edges of a pneumatic tourniquet vs. a sharp edge of some non-pneumatic tourniquets, is less likely to damage tissue at its edges. Think of cutting soft cheese with dental floss Vs. with a wide diameter straw. While pressure applied is important, it is shape of the edge that can cut tissues. This article only deals with non-pneumatic tourniquets, as they are primarily used during surgery and only a few are marketed for field use. Their disadvantage in the field is that they require pumping up to use, which takes time, when time of proper application is as critical as transport time.

Method

Various known and new technology even pressure, non-pneumatic tourniquets were tested with SynDaver, Inc. SynDaver makes a new synthetic cadaver using synthetic tissues closely resembling normal human tissues both in structure and in dimension. The synthetic tissues nearly replicate human tissues of arteries, muscles, tendons, limbs and organs. This model is so accurate it can be used to train physicians in surgical procedures and to test functionality of medical devices including tourniquets. The synthetic "arteries" were hooked up to a motor that was pumping artificial fluids through them, so as to closely resemble normal arterial flow. A pulse is produced replicating "normal" circulation. Reduction of fluid flow and pulsation was the end point for tourniquets tested. This is an open system of circulation, one way design, with pulsating artificial arteries. Ranger with many years experience as medic did all tourniquet application. CAT™

tourniquet and two versions of short transit time tourniquets, one with buckle and the other without, were tested individually and compared for effectiveness in preventing exsanguination.

Results

i. CAT, industry standard and several other commercially available tourniquets were tested and were able to stop synthetic femoral bleed completely eliminating fluid loss and pulsation of synthetic femoral artery.

ii. Neoprene band with metal buckle was able to greatly reduce fluid loss by about 90% but did not completely stop loss.

iii. Double sided loop strap did totally stop fluid loss, but the laser weld attaching D rectangle broke under extreme pressure. All sewn junctions held. The strap without D rectangle section was tested alone. Both pulsation and flow of fluid were completely stopped.

Discussion

i. Neoprene band tourniquet. While it stopped 90% of flow, it had only ¾ inch rigid fabric on top of 1 inch stretchable neoprene strap. It is possible that the fabric material sewn on top of the neoprene did not totally occlude stretch, so un-stretchable fabric was changed and increased to 1 in width on top of 1 inch stretch to stop any stretch of strap to prevent both pulsation and fluid.

ii. Additional design changes were made to make tourniquet use more intuitive minimizing improper tourniquet use:

   a) Laser weld has been replaced with sewn junctions.

   b) Larger height D rectangle was used to make it easier to pull strap through.

   c) Correct Application Places clearly marked on strap.

   d) Secure hold preventing accidental removal with Dual closure*

Conclusions

Simple and economic measures can be taken to greatly reduce preventable deaths much as defibrillators have.

Education is needed:

i. Proper placement during application preferably on strap itself.

ii. Using a tourniquet does not always mean loss of limb(s).[22]

iii. Current statistics show that limb loss with proper and timely tourniquet usage is minimal, 6% when transport time is short.

iv. That extreme force is not needed, just enough to stop primary bleed.

v. The fear of living if the loss limb results, is worse before being disabled, than it is after living with and adapting to the disability. Time changes perception.

Tourniquets should also be available

i. Especially in public places especially in these times.

ii. Carried by those in emirate danger Design changes: are designed so that anyone could use them correctly instructions on strap easier to use tourniquets, even one handed.

It is the fear of the unknown and lack of knowledge of proper usage that interferes with a person's ability to correctly use a tourniquet, and do what they know they should do to save their lives. Better and need to be developed, better education on use/consequences, and availability of better prosthetics in the event of amputations are needed to prevent these unnecessary deaths.

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Conflict of interest

The author declares no conflict of interest.

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