Tourniquets for Hemorrhage Control on the Battlefield: A 4-Year Accumulated Experience

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Background: **Tourniquet application is a known means for bleeding prevention in the military prehospital setting.**

Methods: **This study was a 4-year retrospective analysis of silicone and improvised tourniquet applications by Israeli Defense Force soldiers.**

Results: **Of 550 soldiers who were treated in the prehospital setting, tourniquets were applied to 91 (16%) patients and in less than 15 minutes in 88% of the cases with almost no complications. Penetrating trauma was the main mechanism of injury. The indication was situational and nonmedical in 58 (53%) of the cases. The patients' ischemic time was 83 ± 52 minutes (range, 1–305 minutes). A total of 78% of applications were effective, with higher success rates for medical staff compared with fellow soldiers and for upper limbs (94%) compared with lower limbs (71%, $p < 0.01$).**

Conclusion: **Tourniquet application is an effective and easily applied (by medical and nonmedical personnel) method for prevention of exsanguination in the military prehospital setting.**

Key Words: **Tourniquets, Hemorrhage, Control, Battlefield.**

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Severe limb trauma, constituting as many as 20% of combat injuries, can cause rapid exsanguination and death.[1,2] In the combat zone, blood transfusion and definite orthopedic and vascular services are lacking. In the military settings, evacuation time is always prolonged. Therefore, extra importance is granted for proper and timely placement of a tourniquet if minimization of further blood loss and mortality are to be prevented.

In the last 15 years, tourniquets have been used in the prehospital military setting by the medical staff of the Israeli Defense Force (IDF). Physicians and medics assigned to combat missions carry tourniquets and use them routinely, minutes after injury. In addition, IDF combat soldiers are regularly equipped with tourniquets and trained to identify extremity hemorrhage and use the tourniquets to stop the bleeding.

Although the use of tourniquets for hemorrhage control is well established, it is surprising to discover how little has been published on this issue.[3] The standard tourniquet used by IDF combatants is an elastic band, 200 cm long and 6.5 cm wide, composed of an elastic silicone blend. To produce supra-arterial pressure, the elastic band is wrapped strongly around the limb. Another accepted tourniquet is the improvised "Russian" tourniquet. It is made of a nonelastic cotton or other strap wrapped around the injured limb and twisted by means of a wooden stick, thus tightening it. In this study, we summarize a series of battlefield tourniquet placements by IDF personnel (both medical and nonmedical).

MATERIALS AND METHODS

An analysis of all cases of tourniquet use between January 1997 and January 2001 by IDF soldiers and medical staff in the military prehospital setting was performed. Data on the prehospital phase were collected from medical reports and oral inquiries of first-aid givers (combat soldiers, medics, combat physicians) and air evacuation teams. This information, in addition to that retrieved from hospital medical records, was summarized. Retrospective analysis included demographic and anatomic data and Abbreviated Injury Scale (AIS)[4] score calculated for every injured limb. Additional information consisted of data on clinical course of the various injuries in addition to indications, effectiveness, and complication of tourniquet use. Proper situational indications for field tourniquet use were regarded as those long taught in the IDF's military medicine academy (Table 1): a case of prehospital tourniquet placement was considered as "indicated" if the clinical situation fulfilled at least one of these indications. Effective use of the tourniquet was considered when absolute control of hemorrhage distal to the injury site was achieved. When residual oozing occurred after tourniquet application, the case was categorized as a noneffective use.

"Tourniquet conversion" (done to allow reperfusion of the injured limb) was defined as replacement of the tourniquet with a direct pressure bandage. Ischemic time was calculated as the time from the application of the tourniquet to its release and limb reperfusion (i.e., removal of the tourniquet at the hospital setting or prehospital conversion).

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Table 1 Indications for Tourniquet Application

Indication	No. (%)
Failure to stop bleeding by direct pressure bandaging, injury does not allow direct control of bleeding with a bandage, or objective factors	3 (5)
Amputation	20 (34)
Bleeding from multiple locations	5 (9)
Protruding foreign body	0 (0)
Need for an immediate airway management or breathing control	3 (5)
Under fire situation	20 (34)
Total darkness	2 (3)
Mass casualty event*	33 (57)

* An event in which the number of wounded or the severity of their injuries exceeds the ability of the medical personnel to render optimal medical care.

Statistical Analysis

Comparison between the clinical variables was carried out using the χ^2 test. A value of $p < 0.05$ was considered significant. Data are presented as mean ± SD.

RESULTS

Patients

During a 4-year period, a total of 550 injured soldiers and civilians, casualties of combat or terrorist attacks, were treated by IDF medical personnel in the prehospital setting. A total of 125 (22%) casualties died from their injuries. There was no case of death resulting from uncontrolled limb hemorrhage.

A total of 110 tourniquets were applied on 91 of 550 patients (16%). Most patients (74 [81%]) needed tourniquets on a single limb, but in 15 (16%) cases, tourniquets were applied simultaneously on two limbs, and in 2 (3%) other cases, three limbs were involved.

Mechanisms and Anatomic Sites of Injury

Penetrating trauma was the mechanism of injury in 108 tourniquet applications (98%), whereas blunt trauma accounted for 2 (2%) cases only. Penetrating trauma was caused mainly by explosives and fragment injuries (79 [73%]). Bullets caused 29 (27%) of the penetrating injuries. Armored vehicle and aerial accidents inflicted the two blunt traumatic injuries.

Table 3 Types of Injuries for which Tourniquet Application Was Used

Diagnosis	No. of Tourniquet Applications (%)
Fracture	45 (41)
Superficial injury	28 (25)
Amputation	20 (18)
Limb crush	7 (6)
Vascular injury	9 (8)
Neurologic injury	9 (8)
Others	5 (4)
Unknown	5 (4)
Total	110 (100)

Table 2 presents anatomic distribution of the different injury locations, tourniquet placement, and conversions. Most injured limbs (68%) were lower limbs, with thigh injuries accounting for 34% of cases. Upper limb injuries accounted for 35 (32%) of the cases. In 13 (12%) cases, there was a joint between the location of the tourniquet and the location of the injury. Forty-two (38%) of the tourniquets were applied to patients with multiple injuries.

Table 3 depicts the types of limb injuries, as diagnosed in the hospital. The most common injuries were open fractures, followed by superficial injuries and traumatic amputations. Mean AIS score of the injured limbs was 2.46 ± 0.96. Fifty percent of the limbs had AIS scores ≥ 3. The rest of the limbs had AIS scores of 1 (22.9%), 2 (15.2%), or 4 (9.1%).

Clinical Course

Time Scale

Three time periods (in minutes) were defined: application time (between injury and tourniquet placement), 11 ± 25 (range, 1–80); evacuation time (from injury to evacuation), 106 ± 54 (range, 24–330); and ischemic time (total time of tourniquet being applied to the injured limb), 83 ± 52 (range, 1–305). Application time was 15 minutes or less in 88% of cases.

Table 2 Anatomic Locations of Injuries, Tourniquets, and Conversions

Location	Arm (%)	Forearm (%)	Hand (%)	Thigh (%)	Leg (%)	Foot (%)	Total (%)
Injuries	18 (16)	16 (14)	1 (1)	38 (34)	34 (31)	3 (3)	110 (100)
Total tourniquets	21 (19)	14 (13)	—	48 (44)	27 (24.5)	—	110
Standard tourniquets	20	13	—	30	24	—	87 (80)
Russian tourniquets	1	0	—	18	1	—	20 (18)
Improvised tourniquets	0	1	—	0	2	—	3 (3)
Effective	20	13	—	34	19	—	86 (80)
Noneffective	1	1	—	14	8	—	24 (22)
Total conversions	2	2	—	1	12	—	17
Successful	2	2	—	0	9	—	13
Unsuccessful	0	0	—	1	3	—	4

Table 4 Data on Tourniquets Used by Different Medical Care Providers

	Physicians (%)	Medics (%)	Soldiers		Total (%)
			Fellow Soldier (%)	Self-Application (%)	
Indicated	8 (44.4)	41 (55.4)	6 (40.0)	3 (100)	58 (53)
Nonindicated	10 (55.6)	33 (44.6)	9 (60.0)	0 (0)	52 (47)
Effective	15 (83.3)	58 (78.4)	11 (73.3)	2 (66.7)	86 (78)
Noneffective	3 (16.7)	16 (21.6)	4 (26.7)	1 (33.3)	24 (22)
Total	18	74	15	3	110 (100)

Indications for Tourniquet Application

Medics applied most tourniquets (74 [67%]). Others were applied by physicians, fellow soldiers, or the injured themselves (Table 4). In 58 (53%) of the cases, at least one of the indications listed in Table 1 was present; thus, tourniquet application was considered "indicated." Fifty-two (47%) tourniquets were applied without indication, and were considered as "nonindicated." The rates of indicated applications were not significantly different between medical staff (i.e., medics and physicians) and fellow soldiers (Table 4).

Of the 58 indicated tourniquets, 3 (5%) were applied because of failure to control the hemorrhage by means of a direct bandaging. Twenty-five (43%) tourniquet applications were indicated because of the character of the injury, mostly amputated limbs. No tourniquet was applied because of a protruding foreign body. Forty (69%) tourniquets were indicated by objective factors, most often a situation of a mass casualty event or the need for first-aid treatment under fire. In some cases, multiple indications for tourniquet placement were found (Table 1).

Of the 52 nonindicated tourniquets, 35 (67%) were applied to wounded but not actively bleeding limbs. Twenty (57%) of these 35 injuries were open fractures. Fourteen (27%) nonindicated tourniquets were applied over an active bleeding site without prior attempt at direct bandaging and without any other indication for tourniquet application. Three other tourniquets were applied after successful control of hemorrhage with a bandage and over a closed femoral fracture.

Effectiveness of Tourniquet Application

Eighty-six (78%) of the tourniquet applications were effective. Ninety-four percent of the tourniquets applied to the upper limbs were effective, as opposed to only 71% when the lower limb was considered ($p < 0.01$). First attempt of tourniquet application was not effective in 24 cases. In 16 cases, another tourniquet was effectively applied, whereas 2 other cases required third application and in 3 cases a direct pressure bandage eventually stopped the bleeding. The last three patients were admitted to the hospital while still bleeding. Comparing fellow soldiers to medical staff resulted in higher success rates of the latter group, although the difference was not statistically significant. Two types of tourniquets were used: the commercial silicone and the improvised type. No significant difference in the effectiveness of the two types was observed. Eighteen of the 20 Russian tourniquets were applied to the thigh. The Russian tourniquets used for thigh injuries were effective in 72% of cases (13 of 18), whereas the silicone tourniquets used for thigh injuries were effective in 66% (20 of 30) of cases ($p = 0.06$).

Three other improvised tourniquets were placed. In two cases, a belt was used, and in another, a wire was wrapped around the limb. One of the belts was successful in controlling the bleed for 10 minutes, until a silicone tourniquet was placed. The two other improvisations were unsuccessful.

Conversions

Seventeen attempts at prehospital tourniquet conversion were made. All attempts for conversion were performed when the original indication for application of a tourniquet was not injury related. Most (n = 12) of the conversions were made on the leg (Table 2). The attempts were carried out between 5 and 100 minutes after the application (mean, 31 ± 28 minutes), most of them (76%) within 40 minutes. Thirteen conversions (76%) were successful and the bandage controlled the bleeding effectively.

In-Hospital Course

Operative Procedures

The most common in-hospital surgical intervention needed was debridement, which was performed in 65 cases. Operative fracture management was performed in 38 limbs, and completion of amputation was necessary in 16 of the cases. Fourteen vascular procedures were performed.

Neurologic Complications

Neurologic complications that could be attributed to tourniquet applications were recorded in seven limbs of five patients. Ischemic time for these cases ranged between 109 and 187 minutes. One of these patients suffered from bilateral peroneal and radial paralysis. This patient's ischemic time was 187 minutes. In three other cases, forearm peripheral nerve injuries were noted. In one of these cases, exploration demonstrated intact median and radial nerves. The fifth soldier suffered from paresthesia and weakness of the distal foot.

DISCUSSION

Limb injuries caused by bullets or shrapnel are common in the combat scenario.[2] Some of these injuries pose an immediate threat to life by causing uncontrolled bleeding

leading to rapid exsanguination. Although definitive care is usually provided in a hospital setting, immediate bleeding control should be achieved as soon as possible to prevent rapid hemodynamic deterioration.

All IDF physicians and medics carry a silicone tourniquet at all times, and so do many combat soldiers. Because it poses a potential threat to the limb, IDF medical staff are taught to avoid using it whenever possible. In accordance with the known Advanced Trauma Life Support recommendations, the first line of treatment for bleeding extremity wounds is application of a tight bandage directly over the wound, creating local pressure. Applying a proper bandage may be time consuming and technically more demanding than placing a tourniquet in various situations. Thus, the use of a tourniquet is reserved for those cases in which direct pressure bandaging has failed or when application of such bandage is not possible. The military setting differs markedly from the emergency department, urban-oriented Advanced Trauma Life Support. Ongoing hostile fire as well as darkness and other extreme battlefield conditions pose a significant challenge for the immediate caregiver.[5] This might be further complicated by the need to treat multiple casualties simultaneously or when a single medical care provider has to accomplish basic resuscitative measures such as airway and breathing control promptly.

The use of tourniquets for hemorrhage control goes back to the days of the ancient Greeks.[6] Over the years, different types of tourniquets were used for controlling bleeding from severely injured and amputated limbs. The tourniquet of Jean Louis Petit in 1718 is considered a milestone, being the first formally designed and designated instrument, and replacing the earlier crude devices.[5,7] The troops of the American Civil War were issued tourniquets for use on the battlefield, to be applied immediately after injury.[5] During World War II, rubber-tubing tourniquets were widely used in the battlefield. They probably saved many lives but were responsible also for the unnecessary loss of many limbs.[8]

Despite its long medical history, little has been reported on prehospital tourniquet application. In our retrospective analysis, tourniquets were applied to 16% of the injured, leading to adequate and prompt bleeding control in the military prehospital setting. Effective applications were reported by medical and nonmedical personnel.

In our series, 53% of tourniquet applications were guided by objective and situational indications, with no statistically significant difference between physicians, medics, or soldiers. In most of the nonindicated cases, there was no prior attempt to stop the bleeding by direct pressure or there was no bleeding at all. These facts may be attributed to the stressful situation and the relatively little prior experience of most medical care providers.

A few simple principles enable correct tourniquet application within a few seconds. The strap is wrapped around the limb, with only a first loose wrap to protect the skin. A free end of approximately 30 cm is left outside the wrapping. The next wraps are performed as tightly as possible, and placed on top of each other, thus producing pressure that exceeds the local arterial pressure. To avoid unwrapping, the end of the strap is tied to the free end left earlier. Effectiveness is ensured by verification of bleeding cessation and disappearance of peripheral pulse. To allow control of ischemic time, application time is routinely and clearly written on the patient's forehead.

To minimize the damage that may be induced by the tourniquet, care providers are instructed to follow certain "rules of thumb." These include the following: placing the tourniquet as distally as possible, but at least 5 cm proximal to the injury; sparing of joints as much as possible; applying the tourniquet over exposed skin to avoid slipping; and early conversion whenever possible.

Recognizing the simplicity of placement and facing the grave prognosis of prehospital continuous perfuse bleeding from severe limb trauma, especially in the military scenario where definite treatment may be delayed, the policy of the IDF regarding tourniquet application allows medical and nonmedical personnel to use this method when indicated. As such, all military recruits in the IDF undergo a 3-day, short, first-aid medical course practicing different bleeding control techniques (pressure bandaging and tourniquet application) after which they become certified as "first-aid providers." Medical personnel further exercise this method during their training in military medicine. Indeed, the results of the applications were better among the medical personnel as compared with regular soldiers, although the difference was not statistically significant. This is probably because of the small sample size of the nonmedical caregivers.

The Russian tourniquet is a type of tourniquet improvisation originally meant to be used only when designated silicone tourniquets are lacking. Although no case of lack of silicone tourniquets has been recorded, the use of the Russian tourniquet became quite common with the common belief that it was the best tourniquet for thigh injuries. Indeed, 18 of the 20 Russian tourniquets in this series were placed around the thigh. Although not statistically significant, there is a tendency toward superiority of the Russian tourniquet for thigh bleeding control. The tourniquet can be composed of any nonelastic webbing strap and a short wooden stick. The strap is wrapped and tied around the limb, and the stick is than placed over the knot and tied over by the strap again. The wooden stick is twisted to tighten the wrapped strap. Other improvisations (i.e., the use of belts, wires, or any other device) are not advocated.

Overall effectiveness of tourniquets was high (78%). Nevertheless, it is important to distinguish between the upper and the lower limbs. Although the success rate of upper limb tourniquets was 94%, the rate for lower limbs was only 71%. In a study performed on healthy volunteers, Calkins et al.[9] demonstrated a success rate of 93% to 100% for upper extremity and 75.0% to 100% for lower extremity bleeding when using bladder, ratchet, or cargo-strap tourniquets. These

devices might merit examination as a possible solution for the low success rate of the silicone and Russian tourniquets.

The recommended routine of the IDF Medical Corps regarding failure to stop the bleeding after tourniquet application is to put another one just proximal to the first, leaving the noneffective tourniquet in place. Only three wounded arrived to the hospital with ongoing active bleeding. Thus, effective bleeding control was achieved in 97.3% of the soldiers by one or more tourniquet applications. The fact that not a single case of death resulting from uncontrolled limb hemorrhage was recorded during 4 years with 550 injured is striking. In the Vietnam War, limb hemorrhage was the cause of approximately 10% of deaths[1] and 60% of preventable deaths.

In our series, a relatively low rate of complications was recorded (5.5%). This may be attributable to the relatively rapid evacuation and early in-hospital definitive vascular and orthopedic treatment, resulting in short ischemic time (2–3 hours). According to some authors,[10,11] the primary cause of tourniquet-induced paralysis is probably ischemia. Others,[12] however, attribute the damage to the direct mechanical effect of the applied pressure.

The IDF medical staff are encouraged to convert tourniquets to pressure bandages allowing reperfusion of the limb as soon as possible. This can shorten the ischemic period, and probably reduces neurologic complications.

It is widely accepted that the use of tourniquets for short intervals is safe. The recommended time for safe application during surgery is between 1.5 and 3 hours.[10,12,13] It is remarkable that all cases of neurologic complications in our series occurred when the duration of ischemia was longer than 150 minutes, except for one case in which it was 109 minutes. The mean ischemic time for noncomplicated cases was 78 minutes. Pressure bandages in the prehospital setting should replace tourniquets only when the original indication has ceased to exist—either because of an objective factor that changed or because it was nonindicated from the start.

CONCLUSION

Tourniquet application is an easy, fast, and cheap method for prehospital control of perfuse limb injuries and might be live-saving. Because of its simplicity, this method should be taught to all that may be called on to care for the injured (i.e., medical and nonmedical personnel). Nevertheless, to minimize complications, ischemic time should be as short as possible and early conversion of tourniquets to bandages should always be considered, especially when situational indications for its application have ceased to exist.

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