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Auto-Transfusion Tourniquet (A-TT) Reanimation of Cardiac Arrest Patients-A Retrospective Chart Review

Martin Pallares Perez[1], David H Tang[2] and Noam Gavriely[3,4]*

[1]Facultad de Medicina, Centro de Estudios Universitarios Xochicalco Campus Ensenada, San Francisco 1139, Fraccionamiento Misión, CP 22830, Ensenada, B.C., México

[2]Jerry L Pettis Memorial Va Medical Center, Loma Linda, CA USA

[3]Department of Physiology and Biophysics, Technion, Israel Institute of Technology, Haifa, Israel (retired)

[4]OHK Medical Devices Ltd. Tirat Carmel, Israel

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***Corresponding author:** Noam Gavriely, Department of Physiology and Biophysics, Technion, Israel Institute of Technology, Haifa, Israel

Abstract

Out-of-hospital cardiac arrest (CA) with CPR has poor outcomes. We report our experience with 17 patients admitted to the Eisenhower Emergency Department (ED) in Rancho Mirage, CA, who underwent treatment with a novel autotransfusion tourniquet (A-TT, Oneg HaKarmel, Israel).

Methods: The Eisenhower IRB authorized this report. All patients were in terminal arrest after receiving CPR throughout the 22-56 minutes of transport to the ED. One or both legs received the A-TT upon arrival at the ED. This study is derived from a retrospective analysis of emergency department medical records.

Results: Seven patients were removed because (a) the collapse was unwitnessed (two patients), (b) non-cardiac etiology (four patients), or (c) improper use of A-TT (one patient). The collapse of the remaining 10 patients was witnessed and attributed to cardiac causes. Seven of these 10 individuals had ROSC within 1-5 minutes following the A-TT application. Five ROSC patients were transferred to the ICU, and one was released neurologically intact.

Discussion: As a "mechanical vasoconstrictor," the A-TT sends blood from the legs to the core and prevents the blood from returning. This directs CPR cardiac output to the vital organs. The rate of return of spontaneous circulation (ROSC) in this small cohort is higher than expected, considering the significant time elapsed since the onset of cardiac arrest.

Conclusion: Mechanical distal-to-proximal shifting of the legs' blood by the A-TT has the potential to improve the rate of ROSC when applied together with standard CPR. Earlier use of A-TT may lead to a better outcome.

Keywords: Hypoglycemia; Gastrointestinal hemorrhage; Hyperthermia; Myocardial infarction; Chronic atrial fibrillation; Cardiomyopathy

Abbreviations: CA: Cardiac Arrest; A-TT: Auto-Transfusion Tourniquet; CPP: Coronary Perfusion Pressure; CBF: Cerebral Blood Flow; ROSC: Return of Spontaneous Circulation; AICD: Automatic Implantable Cardiac Defibrillation

Introduction

Getting coronary blood flow going again by keeping coronary perfusion pressure (CPP) high enough is important for successful cardioversion and the return of spontaneous circulation (ROSC) in cardiac arrest [1,2]. Increasing chest compression cardiac output requires more blood to flow back into the heart and fill the chambers (pre-load), while also increasing peripheral vascular resistance and diastolic pressure (after-load). Both can be achieved by shifting the blood from the legs (auto-transfusion) and blocking its return to the legs (tourniquet). The first mention of expelling blood from the limbs and restricting its re-entry during cardiac arrest was by Dr. Woodward in 1952 [3]. He described a case of a 4-year-old child who had cardiac arrest during orthopedic surgery. Attempt to perform internal cardiac massage failed until Esmarch bandages were applied to the legs from toes to groin, leading to "more than doubling the size of the heart and spontaneous (temporary) return of heartbeat". This is now called "The Woodward Maneuver" in anesthesia literature. In a recent swine study, the simultaneous application of Esmarch bandages to all four limbs during induced VF cardiac arrest served to recreate the Woodward Maneuver [4]. In that study, systolic and diastolic blood pressures, coronary perfusion pressure (CPP), cerebral blood flow (CBF), and end-tidal CO2 (ETCO2) were all significantly higher in the VF pigs that were treated with limb binding than in pigs that were not.

Vasoactive drugs (e.g., adrenaline, vasopressin, norepinephrine, etc.) are routinely used during CPR to induce global vasoconstriction and in fact, adrenaline is part of the American Heart Association (AHA) protocol for CPR. In a recent study by Perkins et Al [5] (NEJM July 18, 2018) of 8000 pre-hospital witnessed cardiac arrest patients it was found that the patients who received adrenaline as part of their treatment protocol were 3 times more likely to get to the hospital in ROSC relative to those who received placebo (36% vs. 12%). Unfortunately, the ultimate outcome 30 days after the incident was as disappointing in those who received adrenaline as in those who did not (~3% survival, ~2% in acceptable neurologically condition). The rationale for the present project was to use mechanical leg compression to constrict the blood vessels in the legs and centralize the blood volume as means of auto-transfusion.

The aim of this manuscript is to describe the first uses of an elastic exsanguination tourniquet that shifts the blood from the legs to the core and blocks it reentry. This device, also known as Auto-Transfusion Tourniquet (A-TT) consists of an elastic ring wrapped by a tubular stockinet and straps. When the straps are pulled, the ring (torus) rolls up the limb up to the groin while exerting supra-systolic pressure on the tissues and blood vessels. The A-TT in a sterile version called HemaClear® is commonly used in orthopedic surgery as an "exsanguination tourniquet" to displace the blood from the limbs to the central circulation and stop the blood from coming back into the limb. This facilitates blood-free limb surgery (HemaClear®, (www.hemaclear.com) Oneg HaKarmel Ltd., Tirat Carmel, Haifa, Israel). The use of the A-TT in these patients was to centralize the blood volume to the core to increase the cardiac pre-load and after-load, similarly to the use of the Esmach bandages described above, acting as a mechanical and localized analogous to the effect of vasoactive drugs.

Methods

This manuscript reports the information collected from retrospective charts review of the first 17 cardiac arrest patients treated with A-TT in the emergency department (ED) of Eisenhower Medical Center in California between August 2011 and April 2014. The doctor who treated the patient applied A-TT units (HemaShock®, OHK Medical Devices, Israel) to the patient's leg(s). All patients were brought to the ED in terminal arrest and the A-TT exsanguination tourniquet was used as a last-resort attempt to revive them following Woodward's initiative. This was not done as part of a clinical study, hence the lack of a control group. The Eisenhower IRB authorized the reporting of this group of cases. Copies of the original ED charts that include doctors' and nurses' entries as well as lab reports were reviewed retrospectively by one of the authors, who was not among the treating physicians, for the following items:

1. Clinical information and History
2. Vital signs (systolic and diastolic blood pressure, heart rate)
3. Patient status prior to A-TT placement
4. A-TT Placement timing
5. Patient status immediately after A-TT placement
6. Description of next level of care
7. Patient outcome and disposition
8. Technical comments
9. Discussion of A-TT use in this case and critique
10. Timeline

The data was tabulated in a Case Report Form (CRF) that was used to report each of the cases. In those patients who had ROSC and measurable blood pressure for more than a few minutes, graphs of systolic and diastolic blood pressures and heart rate were drawn per the nurses' chart in Figures 1a-d and 2 with respect to the timing of A-TT placement and removal. The detailed data from all 17 patients' charts are included in Tables 1 and 2.

Table 1: Patients meeting inclusion criteria (witnessed cardiac arrest, no overdose, no internal bleeding, correct leg=size product).

Pt. #	Time from collapse to A-TT placement	Immediate A-TT effect	Outcome	Vital signs graph
002	43 min	Transient ROSC for 5-6 minutes	Deceased	no
005	34 min	ROSC within 4 minutes of A-TT	Discharged in good neuro-logical status 30 days after admission	yes
006	>30 minutes	ROSC within 5 minutes of A-TT on ONE leg	ICU under brain preser-vation protocol via air evacuation.	No (air evac)

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008	22 minutes	Spontaneous ROSC within 1 minute of A-TT placement on ONE leg.	Deceased after 12 days in ICU with brain protocol (treatment withdrawn)	Yes
009	45 minutes	No A-TT effect	Deceased in ED	No
010	56 minutes	ROSC upon A-TT placement	ICU with brain protocol. Treatment withdrawn after 6 days	Yes
011	30-35 minutes	Transient ROSC after one A-TT placed, lasting 22 minutes	Deceased in ED	Yes
013	48 minutes	No A-TT effect	Deceased in ED	No
014	37 minutes	No A-TT effect	Deceased in ED	No
015	36 minutes	Immediate ROSC after A-TT placement on both legs	ICU with brain protocol; care withdrawn after 8 days	Yes

Table 2: Patients not meeting inclusion criteria.

Pt. #	Time from collapse to A-TT placement	Reason for not being included	Outcome
001	>30 min	Pediatric A-TT models were applied to knee level (wrong size)	Deceased
003	Unknown	Unknown down time; multiple substance intoxication (OD)	Deceased
004	>25 min	Drug OD and severe hypoglycemia	Deceased
007	38 min	Collapse after double dose of Insulin. Severe hypoglycemia	Deceased
012	45 minutes	Pneumothorax/ Hemothorax	Deceased
016	Unknown duration	Hyperthermia at 110F, unwitnessed collapse	Deceased
17	Arrested in ED	Massive GI bleed, hemorrhagic shock	Deceased

Cases and outcomes

All patients were brought to the ED by ambulance staffed by paramedics, while receiving CPR per AHA protocol. All patients were in terminal arrest, had no measurable blood pressure or palpable pulse and were in coma with dilated, non-responsive pupils. Table 1 lists the 10 patients meeting inclusion criteria, namely, patient treated with A-TT whose primary cause of collapse was witnessed cardiac arrest. Table 2 lists the 7 patients treated with A-TT (one with pediatric A-TT) who did not meet inclusion criteria (unwitnessed cardiac arrest, or an apparent non-cardiac cause of collapse such as overdose, poisoning, hypoglycemia, gastrointestinal hemorrhage, or hyperthermia). Placement of A-TT had no effect on the patients who did not meet inclusion criteria and they were all pronounced dead in the ED. Among the 10 witnessed cardiac arrest patients 7 had ROSC within 1-5 minutes after A-TT was applied. In 3 of them ROSC was observed after A-TT was applied on only one leg, while in the other 4, A-TT was applied on both legs.

In two of the ROSC patients the period of spontaneous circulation was short (5-6 minutes in one and 22 minutes in the other) and they were arrested again and pronounced dead in the ED. The other five ROSC patients had sustained spontaneous circulation and were transferred to ICU with brain-preservation protocol consisting primarily of light general anesthesia and mildly reduced body temperature. Care was terminated after 6, 8 and 12 days in three of these patients due to severe irreversible brain dysfunction. One of the sustained-circulation patients was transferred to another hospital and his final disposition is not known. Figures 1a-d show the blood pressure, heart rate and A-TT status timeline in the ED of four of the ROSC patients. One additional ROSC patient (#005; Figure 2) was discharged home in good neurological status after 30 days in the hospital. This highly instructive case is described below in detail since the patient had an implanted defibrillator that recorded his ECG and defibrillation activity throughout the time he was being resuscitated.

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Case #005 Detailed Description

A 78-year-old male collapsed in witnessed arrest in a restaurant. The patient had a history of myocardial infarction, chronic atrial fibrillation, cardiomyopathy, status-post triple bypass surgery, multiple coronary stents, aortic valve replacement, inferior vena cava filter and automatic implantable cardioverter-defibrillator (Automatic Implantable Cardiac Defibrillation (AICD) [6]. Bystander CPR was started immediately and was followed by paramedics ACLS consisting of continuous CPR, numerous IV epinephrine doses, IV amiodarone, numerous AICD shocks, and external defibrillation attempts. Paramedics brought the patient to the ED about 34 minutes after he collapsed.

Upon arrival, the patient was in VF, comatose, with dilated pupils. Auto-transfusion tourniquets (A-TT) were placed on both legs immediately upon arrival at the ED. The patient was then defibrillated successfully with achievement of ROSC within 4 minutes of ED arrival, initially with extreme tachycardia and very high blood pressure followed within 8 minutes by sustained and effective cardiac rhythm at 89+14 bpm with blood pressure of 110+12/75+8 mm Hg. At this point gradual removal of the A-TT was started, while monitoring closely the patient's hemodynamic status. Figure 2 shows the timeline of the patient's blood pressure, heart rate and the A-TT placement status until the patient was transferred to the ICU. The numbers in Figure 2 correspond to the timing of the AICD records shown in Figures 3 and 4.

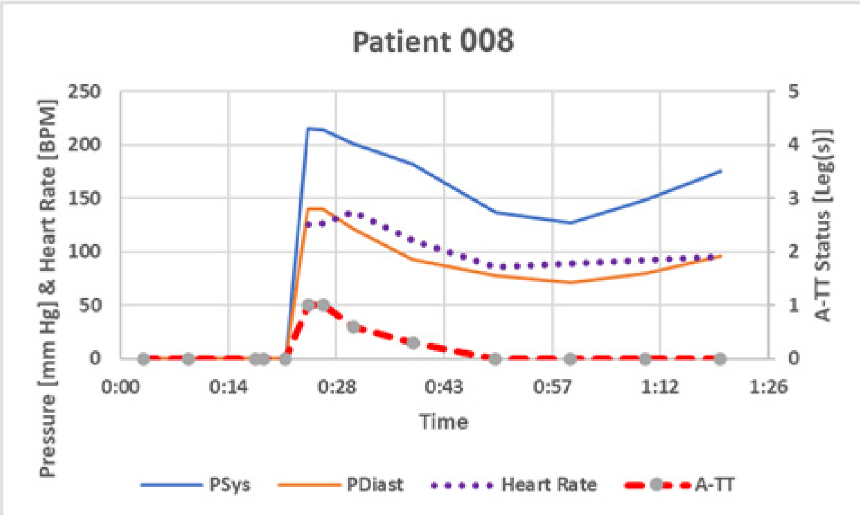

Figure 1a

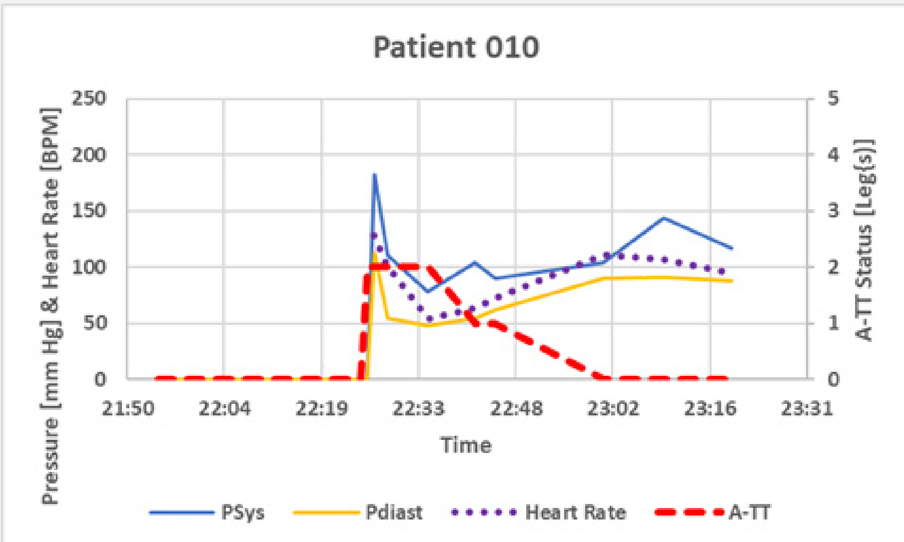

Figure 1b

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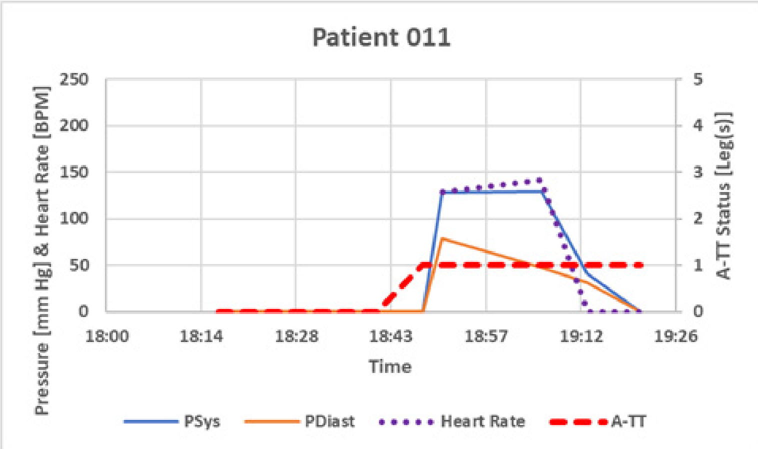
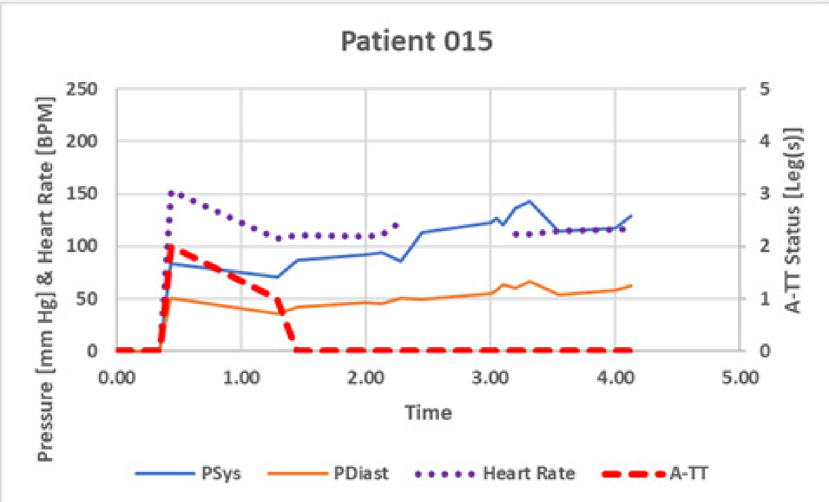


Figure 1c



Figures 1a-d: Timeline of blood pressure, heart rate and A-TT status in patients 8, 10, 11, and 15. The charts start at the time of arrival to the ED. Note the coincidence of ROSC with the placement of A-TT in these patients. Patient 011 died in the Emergency Department, while the other patients had sustained circulation and were transferred for brain preservation treatment in the ICU.

The AICD (Medtronic Protecta XT CRT-D) records showed persistent VT/VF pattern at 150 to 273 waveforms per minute (Figure 3). The AICD discharged 10 times prior to A-TT placement with no conversion or pacing capture [Records 26 and 45 in Figure 4] and 4 additional times after A-TT placement with transient paced capture as seen in records 67 and 80. In addition, external cardioversion shocks at 200J were given multiple times before ED arrival with no conversion and additional 4 external shocks were given after the A-TTs were applied as shown in record 95, this time with transient conversion; the first ROSC was 4 minutes after A-TT placement, eventually leading to steady sustained ROSC 12 minutes after A-TT placement (record 98).

Hypothermia brain preservation treatment was started within 33 minutes of ROSC. A-TT removal started 44 minutes after they were placed. First A-TT was rolled down to knee level, and then removed followed by the second one being rolled to knee level and then to ankle and then removed completely. The removal process took 37 minutes, and the total A-TT time was 81 minutes. When the first A-TT was rolled down from the thigh to the knee, supplemental 200 cc bolus of IV NS was given to avoid a sharp drop in blood pressure. The patient was maintained in a brain-ischemia protection protocol for 7 days and gradually regained consciousness with meaningful communication and cognition during the subsequent week. Rehabilitation started and after 30 days in the hospital the patient was discharged and flown to his hometown for continued rehabilitation in good neurological status.

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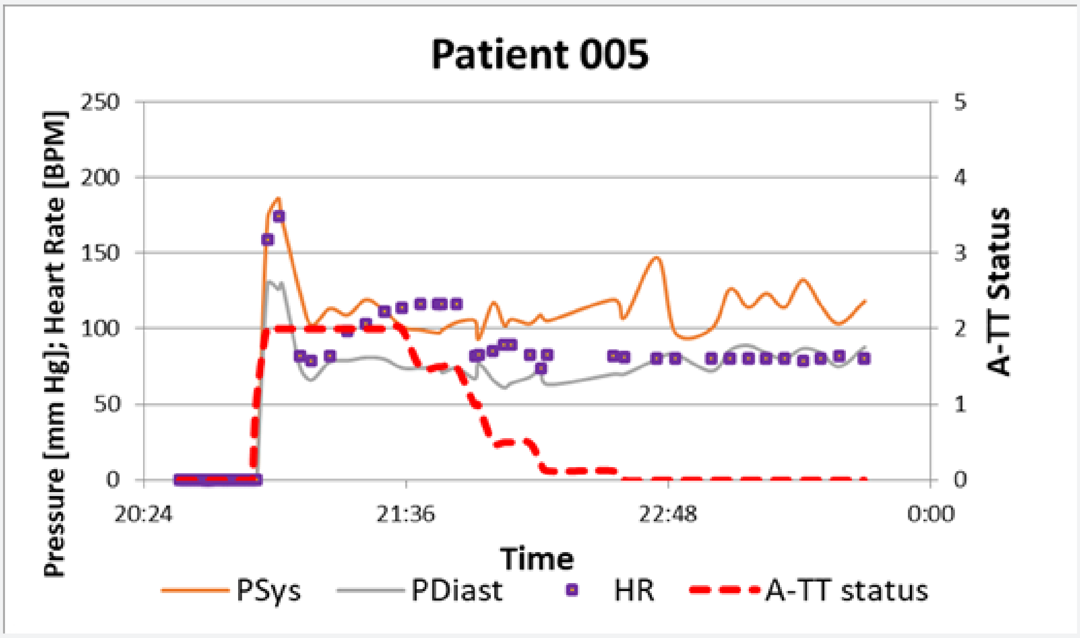

Figure 2: Timeline of the patient's blood pressure, heart rate and the A-TT status from the time of ED arrival until the patient was transferred to the ICU. The numbers indicate the timing of the AICD records shown in Figures 3 and 4. Note the stepwise removal of the A-TT (red line).

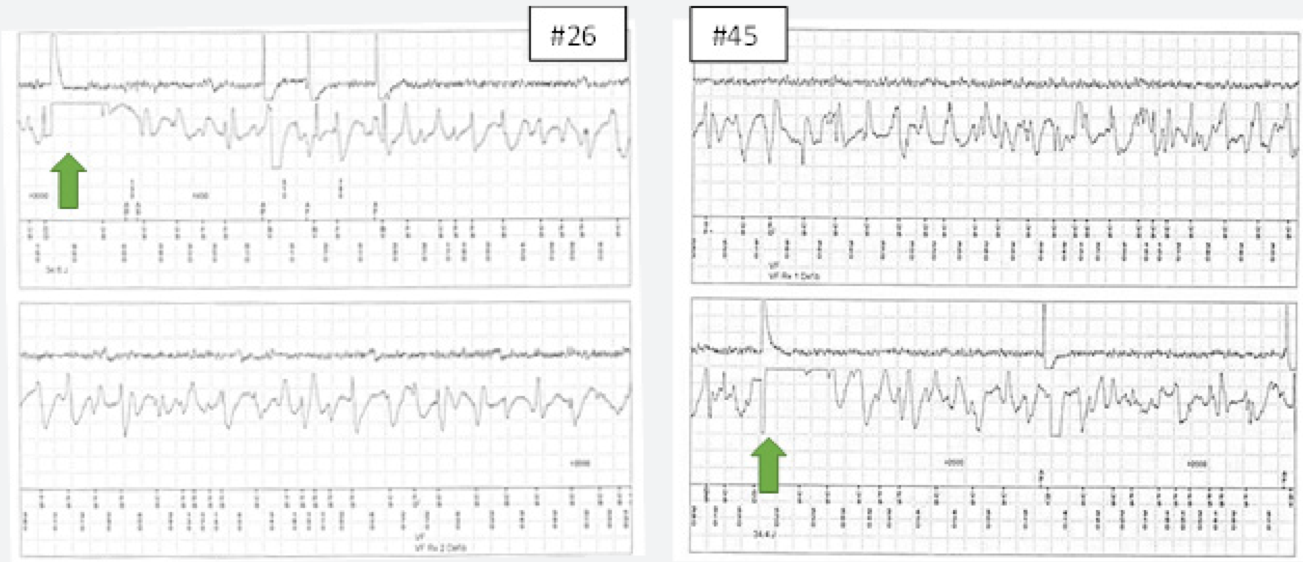

Figure 3: AICD records from before the application of the A-TT. The arrows indicate shocks applied by the AICD. Note the lack of conversion or capture.

Discussion

Pathophysiological considerations

The exsanguination tourniquet used as a last resort measure in these cases is routinely used in orthopedic limb surgery to effect bloodless surgical field [7]. It evacuates all the blood in the limb except the blood inside the bone marrow and blocks arterial flow into the limb. As such it is an ultimate mechanical vasoconstrictor, exclusively focused to the legs. It has been shown that about 500 cc of blood can be shifted from each leg of a normovolemic adult to

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the central circulation [8,9]. It is conceivable that during cardiac arrest, when the sympathetic nervous system shuts down and vasodilation occurs, the volume of blood accumulating in each leg may be even larger than normal.

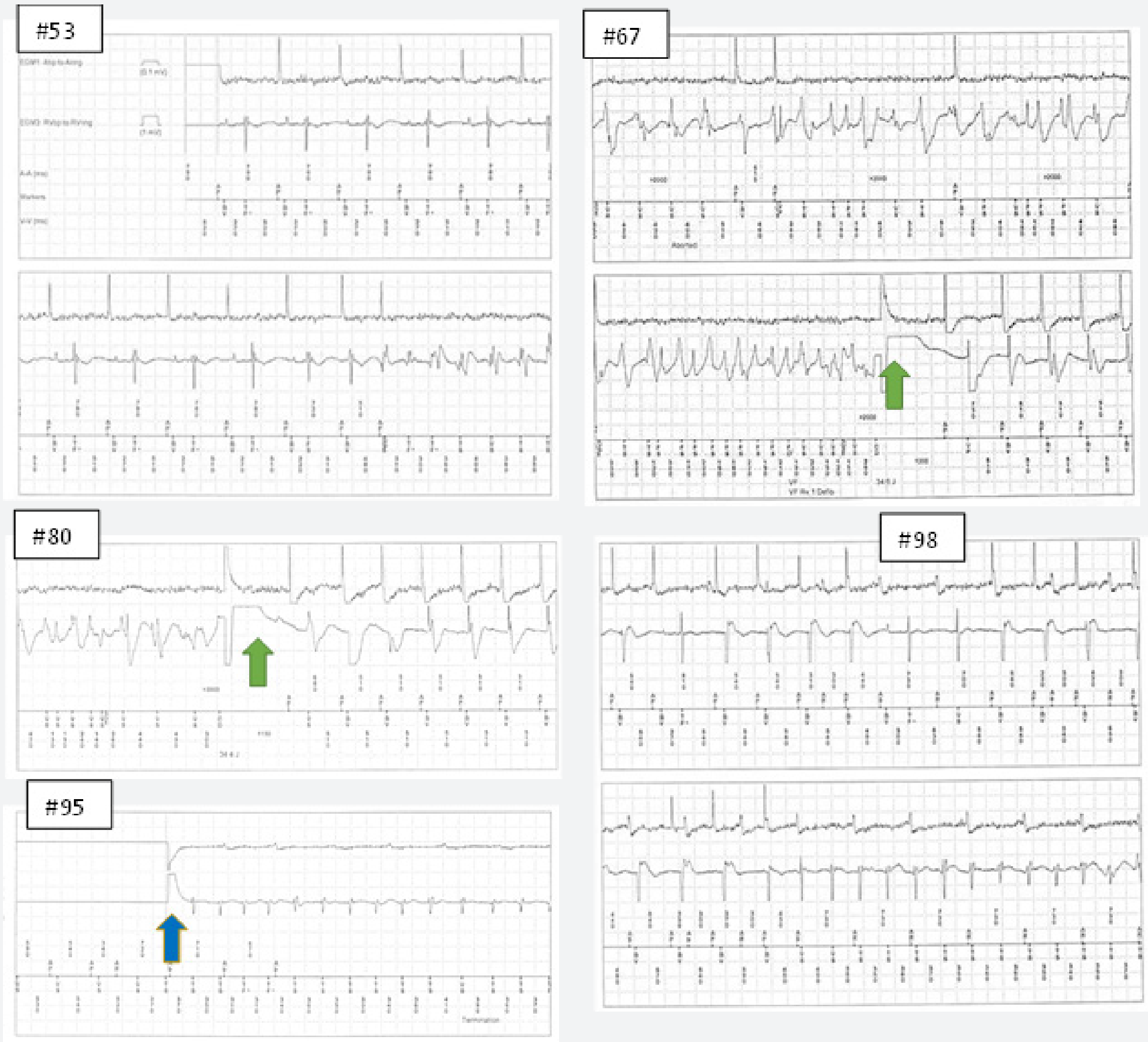

Figure 4: AICD Records from after the A-TT were applied. The numbers correspond to the numbers and the times shown in Figure 2. Green arrows show the shocks of the AICD. Blue arrow indicates an external defibrillator shock. Note the return to regular (paced and un-paced) electrical activity, which was initially transient and from record 98 on was sustained.

As such, applying the A-TT to a leg can quickly (i.e. in less than 20 seconds) displace more than a pint of whole blood with intact oxygen carrying capacity from each leg. The blood then feeds into the heart and central circulation to enhance venous return, increase end-diastolic volume of the heart chambers, and expand stressed volume of the central circulation. The results of the porcine study mentioned in the introduction [6] lends credence to this notion, while recreating the Woodward Maneuver where Esmarch bandages were used to restore heart volume in a child in cardiac arrest during open chest cardiac massage [7].

The effect of the A-TT can be viewed as a "mechanical vasoconstrictor" whose effect is focused and limited to the extremities. Chemical vasoconstrictors [10-14] are routinely used during CPR to achieve a similar effect. However, the distribution of the chemical vasoconstrictors is throughout the body and depends on the circulation time, which may be as long or longer than the half-life of drugs such as adrenaline during CPR. Moreover, studies have repeatedly shown that chemical vasoconstrictors reduce cerebral blood flow and neurological outcome. It is important to note that the shifting of blood to the core and increasing of pre-load is not the only effect of the A-TT.

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Its use also prevents blood from feeding back into the treated limbs. This promptly increases peripheral resistance and redirects the less-than-optimal cardiac output achieved with CPR to the essential organs. Experience with the use of tourniquets in orthopedic surgery [5] and in prevention of bleeding in penetrating limb trauma facilitated setting the time limit of uninterrupted application of the A-TT to 120 minutes. However, it is prudent to start removing the device as soon as possible after ROSC is achieved and do so gradually while monitoring hemodynamic parameters after each removal step.

History

The first mention of expelling blood from the limbs and restricting its re-entry during cardiac arrest was by Woodward in 1952 [7]. He described a case of a 4-year-old child who had cardiac arrest during orthopedic surgery. An attempt to perform internal cardiac massage failed until Esmarch bandages were applied to the legs from toes to groin, leading to “more than doubling the size of the heart and spontaneous (temporary) return of heartbeat”. This is now called by some “The Woodward Maneuver”, but it should not be confused with just elevating the legs.

Studies done in the 1980’s with MAST anti-shock trousers or Abdominal Binding during CPR did not have an overall beneficial effect on the measured parameters nor on the outcome [15-21]. The general perception is that their use restricted respiration by compressing the lower ribs and upwards shifting of the abdominal content and the diaphragm. The logistics and time delay for applying the MAST were a likely additional factor in their not becoming a standard of care.

The logic of trying to shift blood from the dilated periphery to the core prompted the invention of Compression-Decompression CPR devices [22] as well as the inspiratory impedance threshold valve [23-25]. Both methods attempt to maintain negative intra thoracic pressure to induce a pressure gradient along the vena cava(s) and increase venous return and end diastolic volume of the heart chambers. The limited success of these methods in improving ultimate CPR outcome is most likely due to difficulty sucking fluids through soft-wall collapsible blood vessels (i.e. “Starling resistor”).

Epinephrine is being used routinely in CPR. Controversies around the use of this drug continue [26-27], but the current standard of care and the AHA ACLS directives are to use adrenaline since its use increases the rate of ROSC 2-3-fold. It should be noted that with the reduced cardiac output during CPR, circulation time may take as much as 4 minutes for a dose of epinephrine to travel from a peripheral vein IV injection site to the arterial and venous vessels of the limbs, but less so to the heart, brain gut, kidneys and liver. This may exceed the half-life of adrenaline in the body, so that its constricting effect is greater on the brain and the central organs than on the periphery. In addition, the excitatory effect of adrenaline on the heart contractility and its oxygen consumption are of interest beyond the scope of this discussion [26-27].

However, we noted exceedingly high blood pressure immediately after ROSC in two of the patients (Figures 1b and 2) and the initial undulation between effective and ineffective contractions [Figure 4]. We speculate that the multiple doses of adrenaline given to these patients during transport contributed to these adverse effects. In a recent study [28], we evaluated the effect of the A-TT in a cardiac arrest porcine study in combination with a gas mixture of 30% oxygen, 5% $CO2$ and 65% Argon, with the aim to increase $O2$ transport to the brain. The A-TT was used in order to counteract the global vasodilation effect of the $CO2$, while keeping its function as cerebral blood flow enhancer as well as rightwards shifter of the $O2$-Hemoglobine dissociation curve. The study showed increased ROSC rate and higher cerebral blood and oxygen transport.

In Another study we evaluated the practicality of applying the A-TT during cardiac arrest simulation [29] in order to ascertain that the quality of CPR is not affected. This study showed that when a team of 4 caregivers is available, application of the A-TT on both legs takes less than a minute and there is no interference with the quality of standard CPR parameters whatsoever.

Summary of Observations

The information gained by systematically reviewing the charts of the 17 patients treated with the A-TT may be summarized as follows:

1. No A-TT effect was seen when there was un-witnessed arrest with unknown down time.
2. No A-TT effect was seen when arrest is due to overdose.
3. No effect was seen when the time from arrest to A-TT placement was very long.
4. A-TT had no effect on a patient with severe hypoglycemia (36 mg/dl) due to Insulin (Lente) OD.
5. A-TT had no effect on a patient with suspected pulmonary embolus.
6. A-TT cannot be placed on a leg that has an intraosseous (IO) port in place. As soon as possible, peripheral IV should be started and IO removed so that second A-TT placement is possible if needed.

Limitations and contraindications

The fact that ROSC happened quickly after the A-TT was placed on patient 005 and that the AICD [26] recording showed that the cardioversion shocks had no effect before the A-TT was placed, but converted after the A-TT placement is compelling. Encountering additional such patients will be beneficial. The A-TT should not be placed on a leg that has known deep vein thrombosis (DVT) in it. It is not contraindicated to place it on the other leg or on the arms. Only the use of the A-TT in cardiac arrest is discussed here. In patients with severe shock, other instructions apply to the A-TT application, which include gradual placement to allow a more

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controlled increase in blood pressure and avoid any excessive increases. In all cases, the removal of the device should always be done by rolling it down gradually and in steps while monitoring the patient's hemodynamic status.

In all the cases described here the A-TT was placed in the ED with a relatively long delay (22-56 minutes, (Table 1) from collapse to placement. It is conceivable that doing so earlier, by field caregivers could improve the outcome. This needs to be evaluated by a dedicated pre-hospital clinical study. As always, the successful care of the near-death patient is the result of combining many elements. As with the AED, some 20 years ago, the addition of the A-TT as an added link in this chain should be critically studied in large, controlled groups, optimized and, if proven useful, meticulously implemented.

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