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# Hemodynamic Effects of Arterial Vs. Venous Legs Compression in Normal Volunteers

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**Abstract**

**Introduction:** Compression of the legs narrows the blood vessels and reduces their blood volume, provided the compression pressure is greater than the intravascular pressure. In this study we tested the hypothesis that compressing all the blood vessels of the legs, including the arteries enhances the hemodynamic parameters of normotensive volunteers better than venous compression only.

**Methods:** The study was approved by the Eisenhower Medical Center IRB. After signing an informed consent, 35 Volunteers were screened by physical exam and legs Doppler ultrasound to rule out DVT. They were studied on two occasions, two weeks apart. On both tests, echocardiography cardiac output (CO) and stroke volume (SV), mean arterial blood pressure (MAP) and heart rate (HR) were measured before (baseline) and just after (T1), 5 minutes after (T5) and 10 minutes after (T10) application of either an arterial compression device applying 150 mm Hg on the limb (Auto-transfusion tourniquet, A-TT®), or a venous compression device applying 30-70 mm Hg on the limb (ZOEX, LIFE Wrap).

**Results:** All subjects were free of DVT and included in the study. Baseline values were the same between the first and the second test-day. Tests done with the ZOEX venous compression showed unchanged MAP and HR and slightly reduced CO and SV. MAP of subjects tested with A-TT increased from 78+11 mm Hg at Baseline to 90+11 mm Hg ($p<0.001$) at T1 and CO increased from 4.8+1.0 l/min at Baseline to 6.3+0.95 l/min at T1. HR slightly decreased with ZOEX application and slightly increased with A-TT use. All subjects rated the A-TT discomfort as higher than that of the ZOEX. Discussion: Vascular compression of the legs causes complete emptying of the blood vessels (arteries, veins, capillaries) if the subject's systolic blood pressure is below 150 mm Hg and blocks the blood return to the legs thereby increasing blood pressure and cardiac output. Conversely, venous compression of normotensive subjects lacks these effects.

**Conclusion:** Arterial compression with auto-transfusion tourniquet enhances the hemodynamic status of normotensive subjects with systolic blood pressure less than 150 mm Hg. Additional studies in emergency care of hypotensive patients are indicated.

**Keywords:** Arterial; Venous Legs; Hemodynamic; Systolic Blood Pressure; Emergency Care

**Abbreviations:** PASG: Pneumatic Anti-Shock Garment; MAST: Military Anti-Shock Trousers; NIASG: Non-Inflatable Antishock Garment; A-TT: Auto-Transfusion Tourniquet; SET: Surgical Exsanguination Tourniquet; MAP: Mean Arterial Pressure; SV: Stroke Volume; HR: Heart Rate; CO: Cardiac Output

## Introduction

The concept of external counter pressure on the legs or lower body was first described in 1903 by George W Crile [1] who utilized a pneumatic rubber suit to augment the blood pressure of patients undergoing head and neck surgery. During and after World War II pressurized trousers became essential to prevent g-induced blackout or loss of consciousness [2-4] with the understanding that the counter-pressure is needed to keep blood pressure and cerebral blood flow sufficient to sustain oxygen supply to the brain. This physiological understanding and aviation technology migrated to medicine during the Vietnam war as a device used to emergently treat severe shock - the Pneumatic Anti-Shock Garment (PASG) [5].

The PASG, also known as the Military Anti-Shock Trousers (MAST) was rapidly adopted by EMS personnel who felt that using it in severe shock patients increased blood pressure and survival. The PASG/MAST has inflatable bladders over the legs and the abdomen that, when pressurized, compress the underlying tissues, including the veins and the arteries. The maximum compression pressure of the PASG/MAST is 104 mm Hg. However, a prospective randomized evaluation of the MAST by Mattox et al [6,7] published in 1985-7 showed inconclusive results, particularly when chest injuries were involved. More recently, force strategically applied by the calibrated tensile strength of the uniquely designed ZOEX Non-Inflatable Antishock Garment (NIASG™) material has been shown to help stop internal and post-partum bleeding while it also shunts blood from the patient's legs and abdomen to the critical areas of the body where it is needed most—in the heart, lungs and brain [8].

The pressure applied by the NIASG depends on the strength of the person applying (pulling) it but has been shown to vary between 30 to 70 mm Hg [9-14]. Both the PASG and the NIASG apply pressure to the legs AND to the abdomen. Another device used to compress the legs and their blood vessels is the Auto-Transfusion Tourniquet (A-TT®) also known as the Surgical Exsanguination Tourniquet (SET) or HemaClear® and HemaShock® (Oneg HaKarmel Ltd., Tirat Carmel, Israel). This is an elastic ring wrapped by an elastic tubular stockinet and pull-straps [15].

When the straps are pulled, the A-TT ring rolls up the leg while exerting pressure on the tissues of 150 mm Hg. The A-TT does not have an abdominal/pelvis compartment and exclusively shifts the blood from the legs to the core. The A-TT is used in emergency medicine in severe shock and cardiac arrest [16,17], while the SET is used in the orthopedic operating theatre to provide a bloodless surgical field [18,19]. In the present study we compared the hemodynamic effects of the A-TT arterial and venous compression with that of the NIASG predominantly venous compression in normotensive volunteers. The tested hypothesis of this pre-clinical study is that compressing all blood vessels, including the arteries, has stronger effects on blood pressure and cardiac output than compressing the veins alone.

## Methods

This study was approved by the Eisenhower Medical Center, Rancho Mirage, California IRB #17-007. Thirty-five subjects, 19 males and 16 females, 18-57 years old (average 29.5 years), were recruited and tested in this randomized open-label non-blinded study where each subject was his or her own control. Racial breakdown was 22 (62.8%) White, 11 (31.4%) Hispanic, 1 (2.8%) Black and 1 (2.8%) Asian. Participants were instructed to fast starting midnight prior to each of their two tests with the goal of them being mildly hypovolemic. All subjects confirmed they complied with this instruction.

Participants were examined on two separate days, two weeks apart. On day one they were consented, had ECG, vital signs, brief physical examination, and venous ultrasound of both legs to rule out occult DVT. If there were no findings that would preclude them from participating, there was a toss of a coin to randomize which device would be used on the first day.


**Figure 1:** ZOEX NIASG during application.



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## Devices

Two devices were used in this trial

a) ZOEX NIASG (Zoex Non-Inflatable Anti-Shock Garment (NIASG) (zoexniasg.com)) to effect distal-to-proximal and abdominal venous compression (Figure 1).

b) A-TT SET (HemaShock®, OHK Medical Devices, Tirat Carmel Israel www.hemashock.com) to cause distal-to-proximal arterial and venous legs compression (Figure 2).


**Figure 2:** A=TT®.

The ZOEX NIASG is an elastic neoprene wrap, segmented to enclose each leg (3 segments) forcefully and tightly, the groin/pelvis area and the abdomen by pulling its edges around the body members. It is equipped with Velcro® fasteners that maintain tight compression on the tissues beneath the wrap. The stretching of the wraps is done section after section from the distal end of each leg to the proximal, followed by the pelvis compression and abdominal pressurizing. The A-TT ring is placed on the toes and is rolled up the leg by pulling the straps all the way up to the groin.

## Procedure

Baseline echocardiogram was performed in the lateral recumbent position (Baseline), and heart rate (HR), mean arterial pressure (MAP), stroke volume (SV) and cardiac output (Q) were measured at the time of each echocardiogram. After the baseline measurements the ZOEX NIASG or the A-TT was randomly placed in the supine position. The subject was then turned on the side, supported by a foam wedge behind them for the following 10 minutes. Echocardiogram measurements were again performed right after the device was placed (T1) and 5 and 10 minutes later (T5 and T10, respectively). The study ended after the Time T10 measurement was completed and the device was removed. Two weeks later, the participants returned to be studied in an identical procedure with the alternate device.

After the second session, the subjects were asked to comment on the extent of discomfort caused by each device and on their perception of being able to self-apply each device. All data were entered into an excel spreadsheet and average values of HR, MAP, SV and Q were calculated. We used ANOVA and Student's t-test to determine the statistical significance of differences between baseline and T1, T5 and T10 values within each device and in between the corresponding values among the devices. Statistical significance was determined if p value was less than 0.05 in a two-tail test.

## Results

None of the 35 volunteers were rejected due to DVT or any other reason. The completion of both tests was accomplished by 33 + 2 subjects with no difference between the test groups. (Table 1) shows the baseline values among the NIASG and the A-TT tests. (Figures 3-6) show the effects of ZOEX NIASG and A-TT on MAP, HR, Q and SV, respectively at Baseline, T1, T5 and T10 (Table 2-5). All subjects reported significant discomfort with the A-TT, but not with the ZOEX NIASG. All subjects felt that they could self-apply the A-TT, but not the ZOEX NIASG.

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**Table 1:** Baseline values of MAP, HR, Q and SV at Baseline with ZOEX and with A-TT.

| Baseline | ZOEX NIASG Mean (SD) | A-TT Mean (SD) | P | Significance |
|---|---|---|---|---|
| MAP [mm Hg] | 79.8 (9.1) | 78.3 (11.1) | 0.91 | NO |
| HR [beat/min] | 67.8 (8,9) | 69.7 (8,9) | 0.19 | NO |
| Q [L/min] | 4.66 (0.82) | 4.75 (1.03) | 0.53 | NO |
| SV [ml] | 70.7 (9.2) | 70.0 (11.3) | 0.98 | NO |

**Table 2:** shows the mean and SD values of MAP with ZOEX and A-TT at each time point and the corresponding p-values relative to the baseline by one-way ANOVA and between the groups by Student's t-test.

| MAP | ZOEX | | A-TT | | |
|---|---|---|---|---|---|
| | Average | SD | Average | SD | p |
| Baseline | 79.8 | 9.1 | 78.3 | 11.1 | 0.54 |
| T1 | 80.9 | 11.5 | 90.3 | 11.4 | 0.0014 |
| T5 | 80.6 | 11.9 | 90.4 | 9 | 0.00033 |
| T10 | 81.3 | 10.9 | 85.7 | 12.2 | 0.13 |
| ANOVA p | 0.95 | | <0.0001 | | |

**Table 3:** T1, T5 and T10 heart rates were compared between the two compression methods they were found to be significantly higher with A-TT.

| HR b/min | ZOEX | | A-TT | | |
|---|---|---|---|---|---|
| | Average | SD | Average | SD | p |
| Baseline | 67.8 | 8.9 | 69.7 | 8.9 | 0.4 |
| T1 | 64 | 8.1 | 73.6 | 11.8 | 0.00033 |
| T5 | 64 | 9.2 | 72.5 | 11 | 0.0015 |
| T10 | 64.3 | 9.3 | 71.3 | 11.4 | 0.011 |
| ANOVA p | 0.24 | | 0.51 | | |

**Table 4:** Cardiac outputs with A-TT at T1, T5 and T10 were significantly higher than baseline (p<0.0001).

| Q [l/min] | ZOEX | | A-TT | | |
|---|---|---|---|---|---|
| | Average | SD | Average | SD | p |
| Baseline | 4.66 | 0.82 | 4.75 | 1.03 | 0.79 |
| T1 | 4.22 | 0.85 | 6.28 | 0.95 | <0.0001 |
| T5 | 4.13 | 0.83 | 5.86 | 1.04 | <0.0001 |
| T10 | 3.98 | 0.76 | 5.45 | 1.16 | <0.0001 |
| ANOVA p | 0.95 | | <0.0001 | | |

**Table 5:** Significantly higher than baseline with A-TT at T1 and T5 (p < 0.0005) but not at T10 (p = 0.077) and significantly higher than with ZOEX (p<0.0002).

| SV [ml] | Zoex | | A-TT | | |
|---|---|---|---|---|---|
| | Average | SD | Average | SD | p |
| Baseline | 70.7 | 9.2 | 70 | 11.3 | 0.98 |
| T1 | 66.5 | 10.7 | 82.5 | 13.3 | <0.0001 |
| T5 | 65 | 9.8 | 79.1 | 14.3 | <0.0001 |
| T10 | 63 | 9.9 | 73.4 | 12.7 | 0.00012 |
| ANOVA p | 0.014 | | 0.0016 | | |



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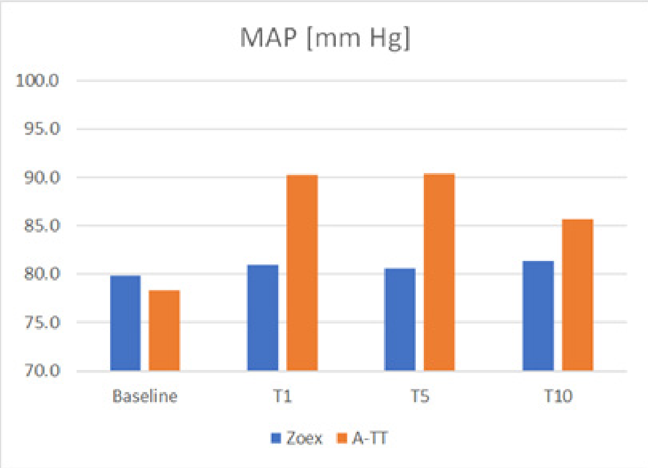


**Figure 3:** Shows the MAP with Zoex and with A-TT.

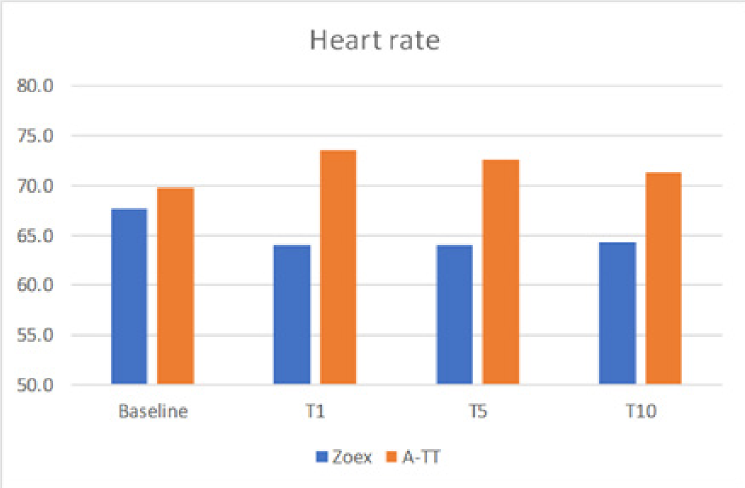


**Figure 4:** Shows the heart rate with Zoex and with A-TT.

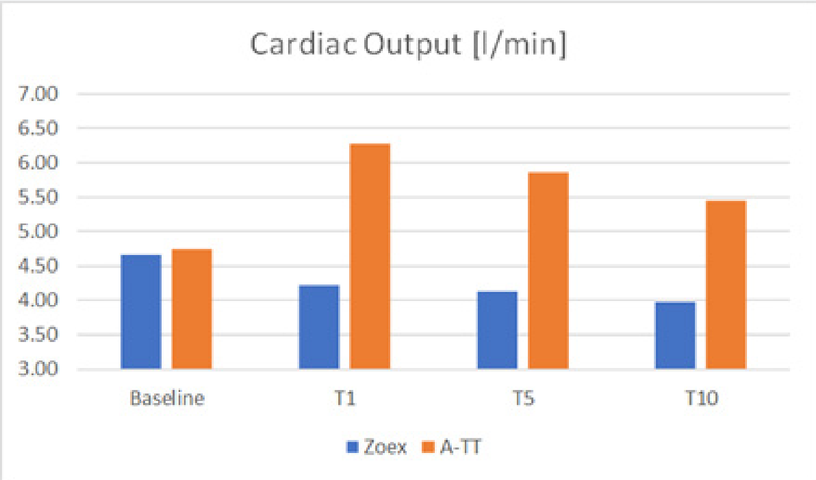


**Figure 5:** Shows the cardiac output with Zoex and with A-TT.



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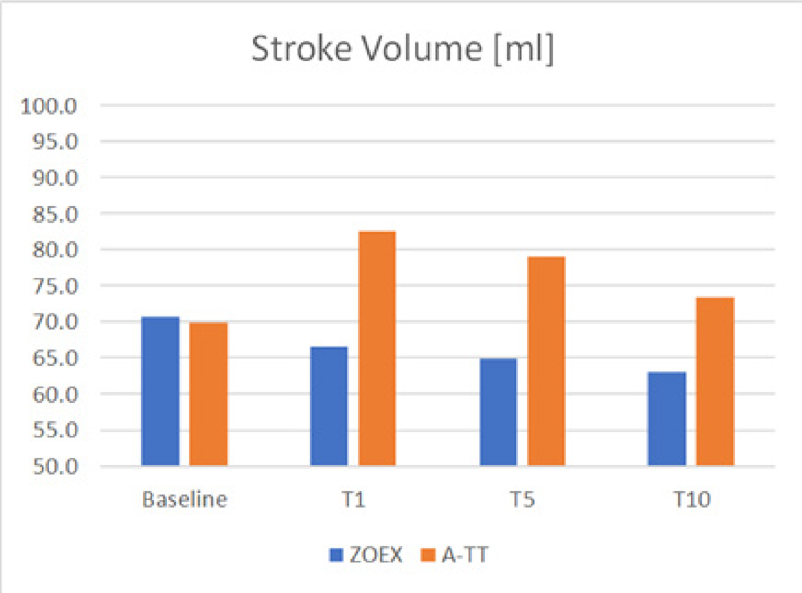


**Figure 6:** Shows the stroke volume with Zoex and with A-TT.

## Discussion

In this study we compared the short-term effects of venous compression of the limbs and abdomen by the ZOEX® wrap vs. complete vascular compression with auto-transfusion of the legs by the A-TT® in normotensive volunteers. Mean arterial pressure (MAP), cardiac output (Q), stroke volume (SV) and heart rate (HR) have all significantly risen relative to baseline when A-TT was applied, but not with ZOEX venous compression. In fact, with ZOEX application both cardiac output and stroke volume have dropped relative to baseline, while MAP and heart rate remained unchanged. The hemodynamic effects of the A-TT in normotensive subjects must also be tested in hypotensive patients to confirm its potential enhancement of the perfusion pressure of the heart and the brain and the increased cardiac output, predominantly due to the increased preload of the heart and retaining the entire cardiac output in the core. These effects are also desired when a patient is in severe shock or undergoing CPR due to cardiac arrest. On the other hand, the hemodynamic effects of the ZOEX, which compresses the veins at 30-70 mm Hg seen in this study tentatively indicate that its use in persons with normal or elevated blood pressure may be suboptimal. This does not mean that in patients in compromised cardiovascular status such as during uncontrolled post-partum hemorrhage it will not be helpful. In fact, the literature about the global use of ZOEX is quite compelling [8-14]. This is presumably because in a person with normal blood pressure, the placement of a venous occlusion device can trap blood in the periphery, thereby actually decreasing the core blood volume. This is the opposite to what is happening when applying the A-TT which compresses the arteries at >150 mm Hg. The ability to apply the A-TT in less than 20 seconds on each leg makes it an ideal EMS new tool that requires minimal skill and invasiveness.

## Limitations

This study was done on relatively young normotensive adults. Additional data on older adults and on patients in shock should be sought. The use of normal volunteers in pre-clinical studies is common and is an important step for assessing the safety and effectiveness of new medical products. However, direct extrapolation of these data to clinical use is discouraged and additional clinical studies in severe shock and cardiac arrest patients is indicated. A-TT should not be applied on patients with DVT to avoid dislodging of a thrombus causing pulmonary embolism. It is important to teach caregivers to identify DVT to preempt A-TT application when DVT is present. Like all tourniquets, the A-TT should not be kept on a limb for more than 120 minutes. As such, the time of A-TT placement should be clearly marked on a label placed in a visible area such as the forehead or the chest of the patient.

## Conclusion

This non-invasive study in normotensive subjects confirms the enhancing effects of the A-TT on blood pressure and on cardiac output. As such, it lends credence to the use of supra-systolic limb compression with auto-transfusion to support the central circulation when the latter is compromised.


## Acknowledgements and Conflicts:

- Martin Pallares Perez - no reported COIs




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- David H Tang MD - no reported COIs
- Prof. Noam Gavriely is an officer and stakeholder of OHK Medical Device Inc.

All studies were managed by Dr. Tang and Dr. Perez who also participated in analyzing the data and in writing the manuscript. Prof. Gavriely analyzed the data, prepared the diagrams, and wrote the first draft of this manuscript.

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