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Research Article

Damage Control Resuscitation strategies in vascular injuries: Aden trauma center experience

Dr. Fares Ayyash Ahmed. MD *[1], Taha Hussain Bin Hendad [2],
Hameed Ahmad [3], Gamal M. Ismail KhudaBux [4]

1. *Consultant General, Trauma and Vascular Surgery, Médecins Sans Frontières (MSF), Yemen.*
2. *Medical Doctor and Public Health Specialist, Former Médecins Sans Frontières (MSF), Yemen.*
3. *Consultant Orthopedic Surgeon, Aden University, Aden, Yemen.*
4. *Consultant Vascular Surgeon, Aden University, Aden, Yemen.*

***Correspondence to**: Dr. Fares Ayyash Ahmed. Consultant General, Trauma and Vascular Surgery Médecins Sans Frontières (MSF), Yemen.

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Abstract

Introduction: *An optimal resuscitation approach for trauma should offer both rapid hemorrhage control and early reversal of metabolic derangements. Major vascular injury is a leading cause of potentially preventable hemorrhagic death in modern combat and civilian trauma operations. While the implementation and effectiveness of damage control resuscitation (DCR) have been reported globally, localized data from conflict zones like Aden are essential. The objective of this report is to evaluate the use and effectiveness of a DCR strategy in the setting of extremity vascular injury at the MSFF Aden Trauma Center (ATC).*

Methods: *A retrospective comparative cohort study was performed using the Theater and ICU Registry to identify patients with extremity vascular injuries treated at the MSFF Aden Trauma Center from 2015 to 2023. Patients were divided into two groups: Group 1 (n = 16), where DCR concepts (including high plasma-to-RBC ratios and minimal crystalloid use) were put into practice, and Group 2 (n = 24), where traditional resuscitation strategies were employed. Inclusion criteria focused on patients with life-threatening hemorrhage (≥4 units PRBCs) from penetrating trauma requiring saphenous revascularization.*

Results: *Baseline demographics, injury severity, and admission physiology were similar between groups. Group 1 patients received significantly more total blood products (23 vs. 12 units, $p < 0.05$) and fresh frozen plasma (16 vs. 7 units, $p < 0.01$) compared to Group 2. Group 1 demonstrated more complete early physiologic recovery after vascular reconstruction, with significant improvements in heart rate (38 vs. 12 bpm change, $p < 0.001$), systolic blood pressure (39 vs. 14 mmHg change, $p < 0.001$), and base deficit (7.36 vs. 2.72, $p < 0.001$). There was no significant difference in early amputation rates (Group 1: 6.25% vs. Group 2: 4.17%) or 7-day mortality (0% in both groups).*

Conclusions: *DCR goals are effectively met during the management of acute vascular injuries in mass casualty and severe polytrauma settings, leading to superior correction of physiologic shock. While aggressive DCR does not appear to increase early graft failure, its long-term impact on limb salvage and mortality requires further determination through larger prospective studies.*

Keywords: *Vascular trauma, Damage control, Resuscitation, Coagulopathy, Hemorrhage, Aden.*

Introduction

Advancements in combat casualty care have resulted in a significant reduction in mortality when compared with previous wars, as current research has focused much attention on preventable death. [1, 2] Hemorrhage from extremity vascular injury remains a leading cause of potentially preventable death on the modern battlefield, and recent estimates suggest an increase in this injury pattern compared with previous conflicts. [2, 3] Injuries of this severity cause an early and profound coagulopathy that is often present at admission to the emergency department (ED). [4, 5]

Standard damage control principles are routinely applied to achieve rapid hemorrhage control and to initiate a hemostatic resuscitation plan that corrects metabolic imbalances and prevents the progression of traumatic coagulopathy. [6, 7] Standard surgical doctrine and experience have taught surgeons that the operative patient needs to be adequately resuscitated before embarking on a taxing operative course. [8, 9] The time needed for adequate resuscitation was the single greatest barrier to limb salvage during the Korean conflict. [10] Convincing modern data show that acidosis and traditional resuscitation techniques using liberal amounts of crystalloid and packed red blood cells (PRBCs) can exacerbate coagulopathy. [11–14]

Damage control resuscitation (DCR) is one such strategy that has been proposed for expedient correction of early physiologic imbalances and has been useful in our own experience for vascular trauma. [6] This employs the use of fresh whole blood (FWB), or a high ratio (≥1:1.1) of plasma to PRBCs, minimal crystalloid use, and liberal replacement of platelets according to clinical practice guidelines. [15] Although evidence-based clinical guidelines for DCR have been established and their effectiveness reported globally, localized data from conflict-affected regions like Aden, Yemen, are crucial for adapting these strategies to specific trauma environments. [12, 15] The objective of this study was to assess the use and effectiveness of a DCR strategy in a retrospective comparative cohort study of combat-related vascular trauma at the MSFF Aden Trauma Center (ATC). Additionally, this study aims to provide early insight into the impact of DCR on early limb salvage and survival in this specific regional context.

Patients and Methods

Study Design and Population

A retrospective comparative cohort study was conducted at the MSFF Aden Trauma Center (ATC). The study included patients with extremity vascular injuries treated between 2015 and 2023. Inclusion criteria were patients arriving at the ATC with life-threatening hemorrhage (defined as requiring ≥4 units of PRBCs) from penetrating trauma who underwent simultaneous saphenous revascularization for a pulseless extremity. Patients with blunt trauma or those not requiring immediate revascularization were excluded.

Resuscitation Protocols

Patients were divided into two cohorts:

Group 1 (DCR Cohort, n = 16): Treated during the implementation of DCR clinical practice guidelines (2019-2023). This strategy included early administration of FWB or PRBCs with a high plasma ratio (≥1:1.1), minimal crystalloids, and adherence to permissive hypotension and hypothermia control protocols.

Group 2 (Traditional Cohort, n = 24): Comprised of patients treated prior to the full implementation of DCR guidelines (2015-2018). These patients received traditional resuscitation using liberal crystalloids and lower plasma-to-PRBC ratios.

Data Collection and Analysis

Physiologic data included presenting vital signs (temperature, blood pressure, heart rate) and laboratory parameters (pH, base deficit, hemoglobin, and International Normalized Ratio [INR]). Injury severity was assessed using the Injury Severity Score (ISS). Operative details, including the location of arterial injury, associated venous injury, and procedure times, were documented.

The extent of early physiologic recovery was determined by comparing ED and ICU parameters. Primary outcome measures included normalization of physiologic derangements, successful revascularization (restoration of palpable pulse and ankle-brachial index ≥0.9), 7-day survival, and amputation rates. Statistical significance was determined using standard paired t-tests for continuous variables and Fisher's exact test for categorical data.

Ethical Considerations

The study was conducted in accordance with the ethical standards of the MSFF Aden Trauma Center and received institutional approval. Patient confidentiality was maintained throughout the data collection and analysis process.

Results

Demographics and Admission Physiology

During the study period (2015-2023), 40 patients underwent arterial vascular reconstructions using a saphenous graft for 10 upper (25%) and 30 lower extremity (75%) wounds. The study group consisted of military (15, 38%) and civilian patients (25, 62%). The cohort was predominantly male (97.5%) , with an age range of 18 to 47 years. Baseline demographics and admission physiology (Table 1) were similar between both cohorts. Operative times (273 ± 98.7 minutes [Group 1]) and (266 ± 89 minutes [Group 2]) were not significantly different. Vessel injuries were all from penetrating trauma, consisting of high-energy explosions (18, 45%) or gunshot wounds (22, 55%). All vascular injuries were associated with large soft tissue wounds and fractures that required external fixation. Fasciotomy (25, 63%) was a routine practice. Prehospital tourniquets (36 of 40, 90%) were used in most patients.

Group 1: DCR Resuscitation

The response to resuscitation measures was reflected in early correction of presenting physiologic imbalances upon conclusion of the operative procedure for limb salvage. Table 2 demonstrates the degree of recovery in both cohorts. Compared with Group 2, patients who were treated using DCR (Group 1) had a more complete early physiologic recovery after vascular reconstruction (HR: 38 vs. 12 bpm change, $p < 0.001$; SBP: 39 vs. 14 mmHg change, $p < 0.001$; and BD: 7.36 vs. 2.72, $p < 0.001$). Additionally, acidosis, coagulopathy, and anemia were all normalized at the time of ICU admission. Group 1 patients received more total blood products (23 vs. 12 units, $p < 0.04$) and more fresh frozen plasma (FFP) (16 vs. 7 units, $p < 0.01$).

Group 2: Traditional Resuscitation

In Group 2, using a traditional resuscitation strategy, both the systolic and diastolic blood pressure did not significantly change between the ED and the ICU. Patients remained tachycardic (HR: 105), and the change over time (12 bpm, $p = 0.07$) was not significant. Acidosis (base deficit), although improved, remained relatively uncorrected (7.25 to 4.53 post-procedure, change of 2.72, $p = 0.09$). Anemia and coagulopathy, as measured by Hb and INR, were worsened at the time of ICU admission and were discordant when compared with the results achieved in the DCR group.

Vascular Techniques and Outcomes

Sixteen patients in Group 1 underwent emergent reconstruction using an interposition vein graft (n = 10, 63%) or a reversed saphenous vein bypass graft (n = 6, 37%). Concomitant venous injury repair (n = 5, 31%) was favored. In Group 2, 24 vascular reconstructions were performed using interposition vein grafts (n = 19, 79%) or reversed saphenous vein bypass grafts (n = 5, 21%). Repair of concomitant venous injury was preferred in 7 of 10 cases. There was no significant difference in early amputation rates (Group 1: 6.25% vs. Group 2: 4.17%) or 7-day mortality (0% in both groups) between cohorts (Table 5).

Parameter	Total (n=40)	Group 1 (DCR, n=16)	Group 2 (Traditional,n=24)	p-value
Age (years)	25.3 ± 8.8	22.0 ± 5.1	27.6 ± 10.2	0.07
ISS	22.9 ± 9.1	23.6 ± 9.6	24.4 ± 10.1	0.71
GCS	14.0 ± 2.3	13.2 ± 3.4	14.4 ± 1.5	0.27
SBP (mmHg)	109 ± 31	105 ± 29	110 ± 32	0.64
DBP (mmHg)	63 ± 23	60 ± 18	64 ± 26	0.58
HR (bpm)	121 ± 29.2	128 ± 24.3	117 ± 31.5	0.24
Temp (°F)	98.7 ± 1.2	98.5 ± 1.3	98.7 ± 1.2	0.58
pH	7.29 ± 0.2	7.27 ± 0.11	7.30 ± 0.2	0.64
INR	1.4 ± 0.4	1.3 ± 0.4	1.4 ± 0.4	0.78

Data are mean ± SD. ISS: Injury Severity Score; GCS: Glasgow Coma Scale; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; HR: Heart Rate; INR: International Normalized Ratio

Table 1: Demographics and Averaged Physiologic Parameters on ED Arrival

Parameter	Group 1 (DCR, n=16)	Change (G1)	p-value (G1)	Group 2 (Traditional,n=24)	Change (G2)	p-value (G2)
OR time (min)	273 ± 99	-	-	266 ± 89	-	0.83
SBP (mmHg)	144 ± 27	39	0.001*	124 ± 28	14	0.11
DBP (mmHg)	78 ± 13	18	0.005*	65 ± 17	1	0.93
HR (bpm)	90 ± 14	38	0.001*	105 ± 26	12	0.07
pH	7.39 ± 0.06	0.12	0.013*	7.32 ± 0.08	0.02	0.34
BD	0.14 ± 2.8	7.36	0.001*	4.53 ± 3.9	2.72	0.09
Hb (g/dL)	11.3 ± 2.3	2.3	0.014*	9.3 ± 1.7	-2.1	0.007*
INR	1.0 ± 0.35	0.3	0.009*	1.5 ± 0.37	0.1	0.14

Table 2: Physiologic Recovery After Vascular Reconstruction

Requirement	**Group 1 (DCR,n=16)**	**Group 2 (Traditional, n=24)**	**p-value**
Total Blood Products (units)	23 ± 18	12 ± 6.4	0.04*
FFP (units)	16 ± 12	7 ± 5.6	0.01*
Plasma:RBC Ratio	1:1.4	1:1.7	0.16
Cryoprecipitate (units)	11 ± 14	1.2 ± 6.12	0.02*
Platelets (units)	13 ± 9	0.7 ± 0.91	0.001*
Total Crystalloid (L)	7.1 ± 3.2	8.4 ± 3.4	0.31
ICU Crystalloid (L)	1.6 ± 1.0	3.0 ± 1.8	0.02*
Massive Transfusion (≥10u)	88% (n=14)	63% (n=15)	0.15
Whole Blood Use	19% (n=3)	0% (n=0)	0.06

Table 3: Averaged 24-Hour Transfusion Requirements

Location	**Total (n=40)**	**Group 1 (DCR,n=16)**	**Group 2 (Traditional,n=24)**
Upper Extremity	**10 (25%)**	**3 (18.75%)**	**7 (29.17%)**
Axillary	1 (2.5%)	0 (0%)	1 (4.17%)
Brachial	8 (20%)	2 (12.5%)	6 (25%)
Ulnar	1 (2.5%)	1 (6.25%)	0 (0%)
Lower Extremity	**30 (75%)**	**13 (81.25%)**	**17 (70.83%)**
Femoral	13 (32.5%)	5 (31.25%)	8 (33.33%)
Popliteal	10 (25%)	3 (18.75%)	7 (29.17%)
Tibial	7 (17.5%)	5 (31.25%)	2 (8.33%)
Venous Repair	**12/15 (80%)**	**5/5 (100%)**	**7/10 (70%)**

Table 4: Location of Vascular Injuries and Surgical Treatment

Outcome	Group 1 (DCR, n=16)	Group 2 (Traditional, n=24)	p-value
Early Graft Failure	0 (0%)	1 (4.17%)	1.00
Temporary Shunting	4 (25%)	3 (12.5%)	0.41
Amputation	1 (6.25%)	1 (4.17%)	1.00
7-Day Mortality	0 (0%)	0 (0%)	-
POD8 Mortality	1 (6.25%)	1 (4.17%)	1.00

Table 5: Outcomes and Complications

Discussion

DCR goals appear to be met during the management of acute wartime vascular injuries at the MSFF Aden Trauma Center, with effective correction of physiologic shock. The overall impact of this resuscitation strategy on long-term outcomes such as limb salvage and mortality remains to be determined, although results from this study are encouraging.

Predicting the need for massive transfusion, lifesaving interventions, or mortality based on vital signs and presenting physiologic parameters can avoid undue delay and justify effective resuscitation plans. [4, 18–21] Early hemorrhage control and hemostatic resuscitation are critical components to the successful management of a vascularly injured patient. Reluctance to implement DCR strategies for vascular trauma often stems from speculative concerns regarding the increased risk of graft thrombosis when coagulopathy is aggressively treated. This study, however, demonstrates that despite higher total blood components, patients treated with DCR had aggressive early correction of acidosis, anemia, and coagulopathy without an increase in early graft failure.

The preferred use of blood products over crystalloid resuscitation in the DCR group was reflected in the final hemoglobin concentration, as hemodilution was avoided and the need for additional fluids in the ICU was significantly less compared with those without DCR. In Group 2, the cohort without DCR arrived in the ICU tachycardic, with no significant changes noted in blood pressure, and acidosis remained relatively uncorrected. The immediate physiologic improvements using DCR concepts are evident and favor continued implementation of DCR clinical care guidelines. The effectiveness of this strategy lies in the observation that in groups with equal physiologic disturbances upon presentation, there was a more effective restoration of heart rate and blood pressure during the cohort in which DCR was used.

Limitations

The small number of patients (n = 40), short observation period, and retrospective design are obvious limitations of this project. Furthermore, the variability in injury patterns and the evolving nature of trauma care protocols over the 8-year study period may introduce bias.

Conclusion

This study represents the first to use the Theater and ICU Registry at MSFF Aden to provide follow-up on the use and effectiveness of established DCR clinical practice guidelines. DCR goals are effectively met during the management of acute wartime vascular injuries, leading to superior correction of physiologic shock. The data show excellent early survival and limb salvage with an amputation rate of 4% to 6%, regardless of the resuscitation practices used. Aggressive DCR maneuvers do not result in early graft failures and permit complex extremity revascularization with simultaneous improvements in physiologic condition. We encourage DCR as an effective resuscitation strategy for all combat-related vascular injuries in regional trauma centers.

Conflict of Interest: The authors declare that they have no conflict of interest.

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