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Damage control resuscitation: REBOA as the new fourth pillar

Resucitación en control de daños: REBOA, el cuarto pilar

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Abstract

Damage Control Resuscitation (DCR) seeks to combat metabolic decompensation of the severely injured trauma patient by battling on three major fronts: Permissive Hypotension, Hemostatic Resuscitation, and Damage Control Surgery (DCS). The aim of this article is to perform a review of the history of DCR/DCS and to propose a new paradigm that has emerged from the recent advancements in endovascular technology: The Resuscitative Balloon Occlusion of the Aorta (REBOA). Thanks to the advances in technology, a bridge has been created between Pre-hospital Management and the Control of Bleeding described in Stage I of DCS which is the inclusion and placement of a REBOA. We have been able to show that REBOA is not only a tool that aids in the control of hemorrhage, it is also a vital tool in the hemodynamic resuscitation of a severely injured blunt and/or penetrating trauma patient. That is why we propose a new paradigm "The Fourth Pillar": Permissive Hypotension, Hemostatic Resuscitation, Damage Control Surgery and REBOA.

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Conflicts of interest:

The authors declare not to have any conflict of interest

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Resumen

La resucitación en control de daños busca combatir la descompensación metabólica del paciente severamente traumatizado mediante tres ejes: la hipotensión permisiva, la resucitación hemostática y la cirugía de control de daños. El objetivo de este artículo es hacer una revisión de la historia de la resucitación en control de daños y la cirugía de control de daños proponiendo un nuevo paradigma basado en los recientes avances de la tecnología endovascular. Un puente ha sido creado entre el manejo prehospitalario y el control del sangrado, descrito antes de la etapa I de la cirugía de control de daños, que es la inclusión y colocación de un REBOA. Esta es una herramienta adicional en el control de la hemorragia y de soporte en la resucitación hemodinámica de los pacientes con trauma severo de tipo cerrado y/o penetrante. Por lo que se propone un nuevo paradigma “El cuarto pilar”: Hipotensión permisiva, resucitación hemostática, cirugía de control de daños y REBOA.

Introduction

Damage Control Surgery (DCS) is a strategy for the management of patients with severe trauma, these patients face a giant metabolic challenge given the severity of their injury and blood loss. The main surgical goal of DCS is to be a bridge between hemorrhage control and patient recovery. The aim of this article is to perform a review of the history of DCS and to propose a new paradigm that has emerged from the recent advancements in endovascular technology: The Resuscitative Balloon Occlusion of the Aorta (REBOA). This article is a consensus that synthesizes the experience earned during the past 30 years in trauma critical care management of the severely injured patient from the Trauma and Emergency Surgery Group (CTE) of Cali, Colombia which is made up of experts from the University Hospital Fundación Valle del Lili, the University Hospital del Valle “Evaristo García”, Universidad del Valle and Universidad Icesi, Colombian Association of Surgery, the Pan-American Trauma Society and the collaboration of international specialists of the United States of America.

History

During the second half of the XX century, surgeons exposed to trauma performed aggressive and definitive surgical management of their patients that required in most cases long complex anatomical repairs. Exsanguination, massive volume resuscitation, and subsequent inflammatory responses triggered a metabolic failure that is now known as *the lethal triad*: acidosis, hypothermia, and coagulopathy (Figure 1).

However, there were experiences contrary to this position that only until the 1980’s were coined “abbreviated laparotomies” by Stone et al, which consisted of early termination of abdominal surgeries. This subsequently was morphed into the concept of “staged management” in which intra-abdominal packing was introduced accompanied by delayed surgical completion after correcting the patients’ coagulopathy¹. At the time this newly devised concept was revolutionary and controversial although survival rates were >50%²⁻⁶. Dr. Rotondo in 1993 used the term “damage control”, an expression taken from the US Navy associated with the ability to absorb and repair a damaged warship without interrupting the mission and eventually docking the vessel to the nearest port for definitive repairs⁵. He applied this concept to a group of exsanguinating patients in three specific stages⁷:

Stage I: Control of bleeding and / or contamination, abdominal packing and temporary cavity closure.

Stage II: Resuscitation and physiologic restoration.

Stage III: Re-exploration, treatment and definitive closure.

The initial reported overall survival rate was 58% which caused the medical community of the time to reflect on its utility. An example of such reflections was Johnson *et al*, who added a Stage 0 also known as Ground Zero in which prehospital management and early triage of these patients were included ^{6,8}. This was the beginning of a conceptual revolution in trauma surgery that included the importance of a balanced resuscitation which was later named Damage Control Resuscitation (DCR) ⁹⁻¹¹. DCR seeks to combat metabolic decompensation of the severely injured trauma patient by battling three major fronts: **Permissive Hypotension, Hemostatic Resuscitation, and Damage Control Surgery** (Figure 2).

Damage control resuscitation

Permissive hypotension

The aim of this concept is to keep the blood pressure low enough to avoid dislodging a potentially forming soft blood clot at the site of traumatic hemorrhage and/or minimize the blood loss from it but high enough to continue to perfuse vital organs. Cannon and Fraser in 1918 stated that if the blood pressure rises before the surgeon was ready to control the source of bleeding then the blood that is badly needed to maintain life may be lost ¹⁰. This concept was placed in practice and reinforced by Beecher during World War II, calling it “hypotensive resuscitation” with the recommendation of maintaining a systolic blood pressure (SBP) between 70 and 80 mmHg before definitive surgical repair ⁹. Bickel and Mattox described in 1994 that resuscitating with low volumes of crystalloids in combination with permissive hypotension with a set SBP goal between 70-90 mmHg was associated with decreased mortality and adverse events ¹².

Hemostatic resuscitation

Deliberate administration of large volumes of crystalloids and packed red blood cells intravenously have been found to exacerbate coagulopathy in patients with severe trauma promoting ongoing bleeding ¹³. It is currently recommended that volumetric restoration of blood loss should be achieved via a 1: 1: 1: 1 blood component ratio of packed red blood cells, fresh frozen plasma, platelets and cryoprecipitates ^{14,15}. This strategy has shown to decrease mortality from 65% to about 19% and also decreases the overall incidence of complications including the chances of rebleeding and sepsis ^{16,17}. The following goals of blood loss

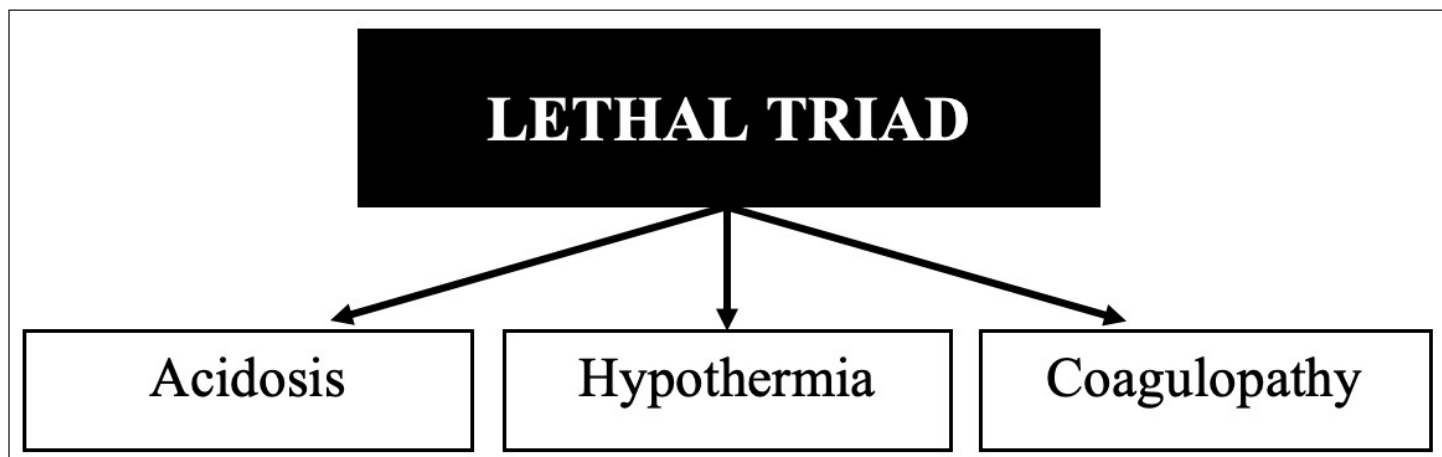


Figure 1. The Lethal Triad

replacement are sought:

- Hemoglobin of ≥ 8 g / dL
- Platelet count $\geq 100,000$ / dL
- Normalization of coagulation times (Thromboelastography / Rotational Thromboelastometry)
- Fibrinogen >100 mg / dL

Furthermore, from the recent US conflicts in Iraq and Afghanistan the military concept of whole blood transfusion has re-emerged but has had huge hurdles in its translation to civilian trauma centers because of the technical, logistical and business model difficulties that this concept implies to regional civilian blood banks ^{18,19}. On this subject, the Trauma and Emergency Surgery Group (CTE) of Cali, Colombia have been leading the crusade in Latin America and the World that whole blood contains all the essential components including red blood cells, clotting factors, and platelets which in turn can provide an effective hemostatic capacity to meet the transfusion needs of a patient with ongoing hemorrhage. Thus, whole blood applied in civilian trauma centers may in turn decrease total blood usage and complications related to massive blood transfusions ^{20,21}.

Fifty five percent of all trauma patients that are brought to a treating facility have hypocalcemia prior to receiving any kind of blood transfusion ²². This pre-existing trauma state of hypocalcemia is potentially aggravated by initial management via a DCR in which blood and blood products are transfused, because these units are typically stored in local blood banks using citrate which in turn chelates ionized calcium in the bloodstream. The early management of hypocalcemia in trauma patients may be of more significance than previously believed because as serum calcium levels drop, coagulopathy occurs, which can lead to continued hemorrhage and possible death. Ditzel and Anderson ²³ have recently included the concept of hypocalcemia as a new component of the classic lethal triad and so creating the new “Lethal Diamond” (Figure 3).

Damage control surgery

Principles. DCS is a strategy that safeguards the trauma patients physiological reserve but it can also be potentially harmful in cases that do not meet the true indications for its use ²⁴⁻²⁶. It can be applied to any compromise body cavity including chest, abdomen, pelvis, extremities,

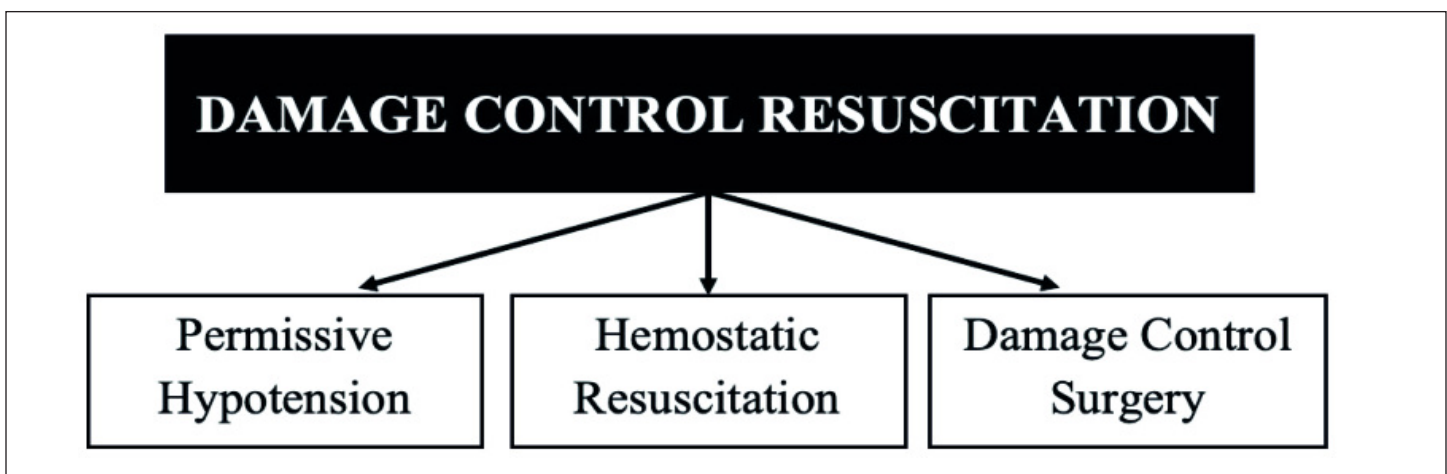


Figure 2. Damage Control Resuscitation: Classic Description

among others. This strategy is not only an intra-operative clinical decision, it must start with a series of simultaneous interventions from the identification of the patient at the scene of the accident or incident which include:

- Penetrating and/or blunt trauma with initial SBP <90 mm Hg
- Major trauma with an estimated blood loss > 1,200 mL
- Inability to control bleeding by direct pressure, wound packing and/or tourniquet (Stop the Bleed®)
- Worsening acidosis, hypothermia, hypocalcemia and/or coagulopathy

These criteria are not exclusive at the prehospital scenario but also can be applied in the ER/Trauma bay and the operating room (OR). Once the patient is under the trauma team's care, the criteria that may influence the implementation of DCS are:

- Inability to control surgical bleeding
- Inability to close the body cavity without creating associated intra-cavitary hypertension due to massive visceral edema
- Definitive surgical management exceeds intraoperative time restraints

Philosophy

DCS requires not only the coordination of various participants in order to contain the injury and prevent the lethal diamond of death (acidosis, hypothermia, coagulopathy and hypocalcemia), it also requires a complete re-thinking on their behalf. They must constantly anticipate the repercussions of potential injuries and at the same time recognize the metabolic demand of the trauma victim that is fighting for his or her life²⁷. This change of thinking is a holistic vision towards the problem which include:

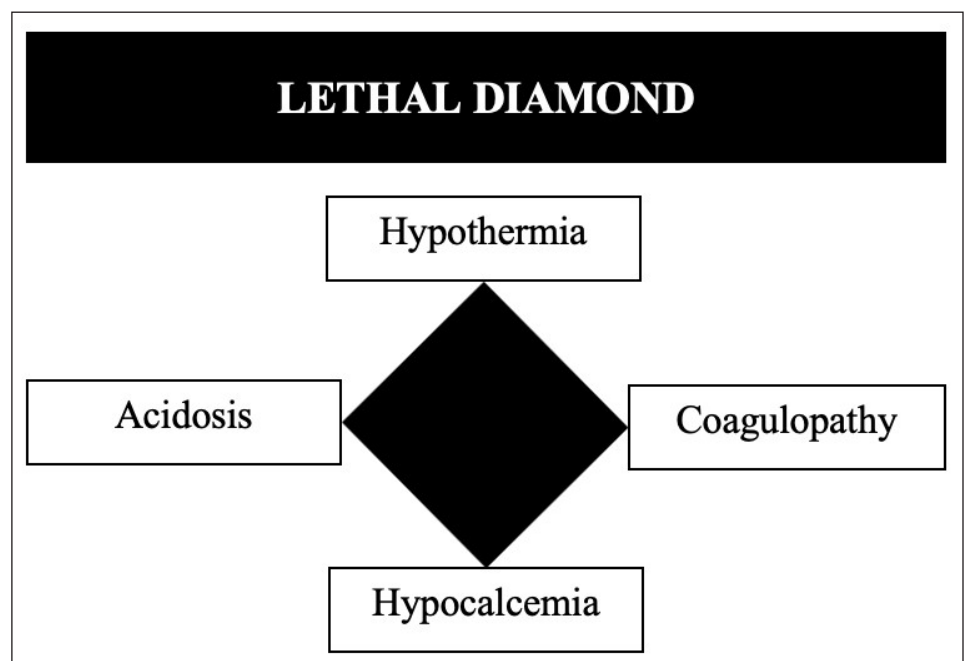


Figure 3. The Lethal Diamond

- Asking for assistance when required, which indicates good judgment
- Definitive surgical management is not the ultimate goal instead the goal should be control of all surgical bleeding, bowel contamination and the restoration of normal physiology
- The application of a four-stage approach aimed at preventing the deadly cascade of events that will culminate in the patient's death

The four stages of DCS

As previously stated, DCS is divided into four classic stages which are (Figure 4):

Ground 0: Prehospital Management

At the trauma scene, the evaluation begins with the "ABCDE" proposed by the American College of Surgeons in their Advanced Trauma Life Support (ATLS) course, in which the initial triage of the severely injured victim is recognized and the concept of "*pick and run*" is applied to achieve optimal transport times. Also, the principles of "Stop the bleed [®]" by the American College of Surgeons and the Committee on Trauma which include the recognition and control of life-threatening hemorrhage via direct pressure, wound packing and/or tourniquet application. Upon arrival to the Emergency Room (ER) / Trauma Center, a multidisciplinary team rapidly corroborates the initial prehospital evaluation and establishes the clinical management algorithm to be followed and whether the patient is or is not a candidate for DCS ⁶. If so, balanced blood product resuscitation is initiated and the patient is moved quickly to the OR.

Stage I: Control of Bleeding and Contamination

A process of containment of the injury begins in the OR. The objective of the first surgical intervention is to control the sources of surgical bleeding and to carry out quick brief interventions which include packing, vessel ligation, temporary shunts and balloon tamponading among others to achieve this goal ²⁸⁻³⁰. Hollow viscus injuries are also addressed during this initial surgical intervention and controlled also via simple procedures such as transection and ligation of ends. The surgeon must be aware that he or she is in a race against time due to the impending on slot of the diamond of death upon the patient, limiting the initial operative procedure to 60 and up to 120 minutes ^{31,32}. A temporary closure of the inflicted cavity should follow with a negative pressure system and the patient should be immediately transferred to the intensive care unit (ICU) for rewarming, correction of coagulopathy, hypocalcemia and acidosis ³³.

Stage II: ICU Management

Hemodynamic recovery of the severely injured patient requires several measures which have been initiated in the ER/OR and are continued in the ICU. These include implementation of DCR at a 1: 1: 1: 1 transfusion ratio of blood products plus the addition of tranexamic acid, hypothermia prevention maneuvers and close hemodynamic monitoring ³⁴. A tertiary review of the patient is completed with imaging studies, if needed, to rule out or assist in the control of ongoing critical injuries that need to be addressed. Also, continuous monitoring of intra-abdominal pressure (IAP) in the ICU is essential to avoid the development of both intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) even in the trauma patient with an open abdomen. This preventative measure ultimately increases the patient's overall survival after DCS ³⁵.

Stage III: Definitive Surgical Management

When the initial ICU goals of DCR have been achieved, then the patient should be taken back to the OR for packing removal, cavity washout, definitive vascular, solid and/or hollow viscus

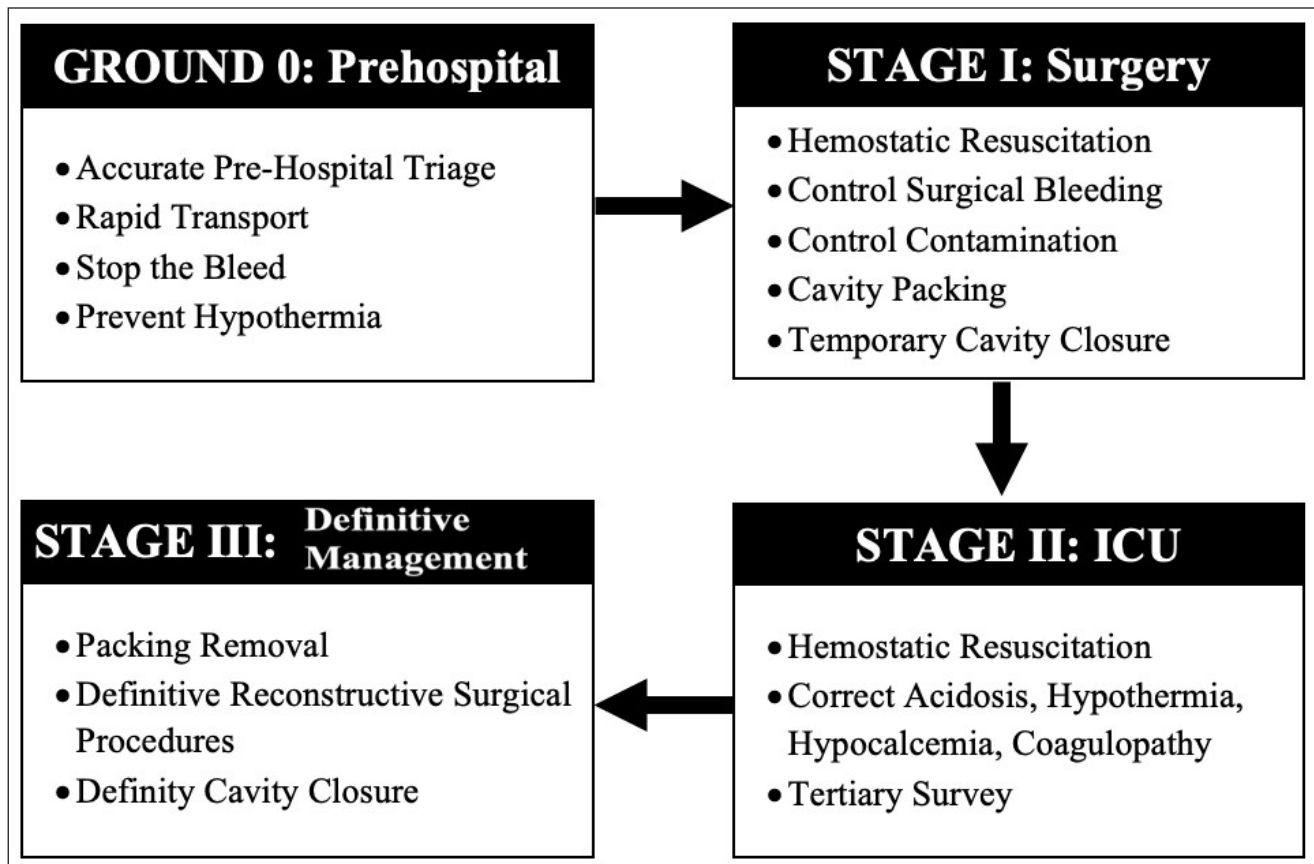


Figure 4. The Four Stages of DCS

injury repair and permanent cavity closure³⁶. However, the return to the OR may occur under a planned situation as previously described or as an unplanned scenario in which ongoing hemodynamic instability persists which is usually secondary to ongoing uncontrolled surgical bleeding, missed hollow viscus injury or a developing compartment syndrome that can develop even in patients with an open cavity. Obviously, the ideal is to return to the OR in a planned controlled manner which usually is within the first 24 to 48 hours once the resuscitation efforts performed aggressively in the ICU have restored the homeostasis of the patient^{31,37}.

Stage: REBOA Resuscitative Balloon Occlusion of the Aorta

We have just described the classic stages involved in the concept of DCR/DCS, however, thanks to the advances in technology, a bridge has been created between Pre-hospital Management and the Control of Bleeding described before Stage I of DCS which is the inclusion and placement of a REBOA^{38,39} (Figure 5).

This endovascular balloon technique is not a recent development, the first reports on this technique dates back to 1954 during the Korean War^{40,41}. However, the development of a specific balloon catheter for hemorrhage control in trauma scenarios has only occurred recently, being the CTE Cali Group an international pioneer in its clinical implementation and a source of scientific evidence that has contributed to its consolidation in the field of trauma surgery^{42,43}. Such findings have included the following:

- REBOA is not only a tool that aids in the control of hemorrhage, it is also a vital tool in the hemodynamic resuscitation of a severely injured patient allowing for the intra-vascular volumetric content to remain directed towards essential organs which include the brain and the heart^{44,45}

- REBOA is a dynamic tool that requires the placement and ongoing management by a skilled and well-trained surgeon⁴⁶⁻⁴⁸
- REBOA poses a new paradigm shift in which soon after the initial ABCDE evaluation proposed by ATLS, an introducer sheath should be placed via the common femoral artery in the Trauma Bay / ER, which allows for immediate ongoing real time blood pressure monitoring of the hemodynamically unstable severely injured trauma patient and if indicated (SBP <70 mmHg) the placement of a REBOA with the aim of reducing cell injury and hemodynamic decompensation by early proximal control of the source of bleeding in both blunt and penetrating trauma^{42,46,49,50}

It is our belief that the classic description of DCR may be leaving out one other crucial arm that may interact positively with the other three. We propose a new paradigm “The Fourth Pillar”: Permissive Hypotension, Hemostatic Resuscitation, Damage Control Surgery and REBOA (Figure 6). To this point, we have extended the indications of REBOA use and have applied it to salvage patients with penetrating and blunt trauma not only of the abdomen and pelvis^{40,44} but also of the chest which until our reported initial successful experience was considered a contraindication^{42,46,51-53}. However, we are not promoting its vast use for all trauma patients but instead its use in specific well indicated dire scenarios of hemodynamic instability from ongoing non-compressible torso hemorrhage and impending cardiac arrest⁵⁴.

Finally, we are aware that the inclusion of a REBOA program as part of a Trauma Teams’ armamentarium is costly and requires a significant investment that may be out of reach to

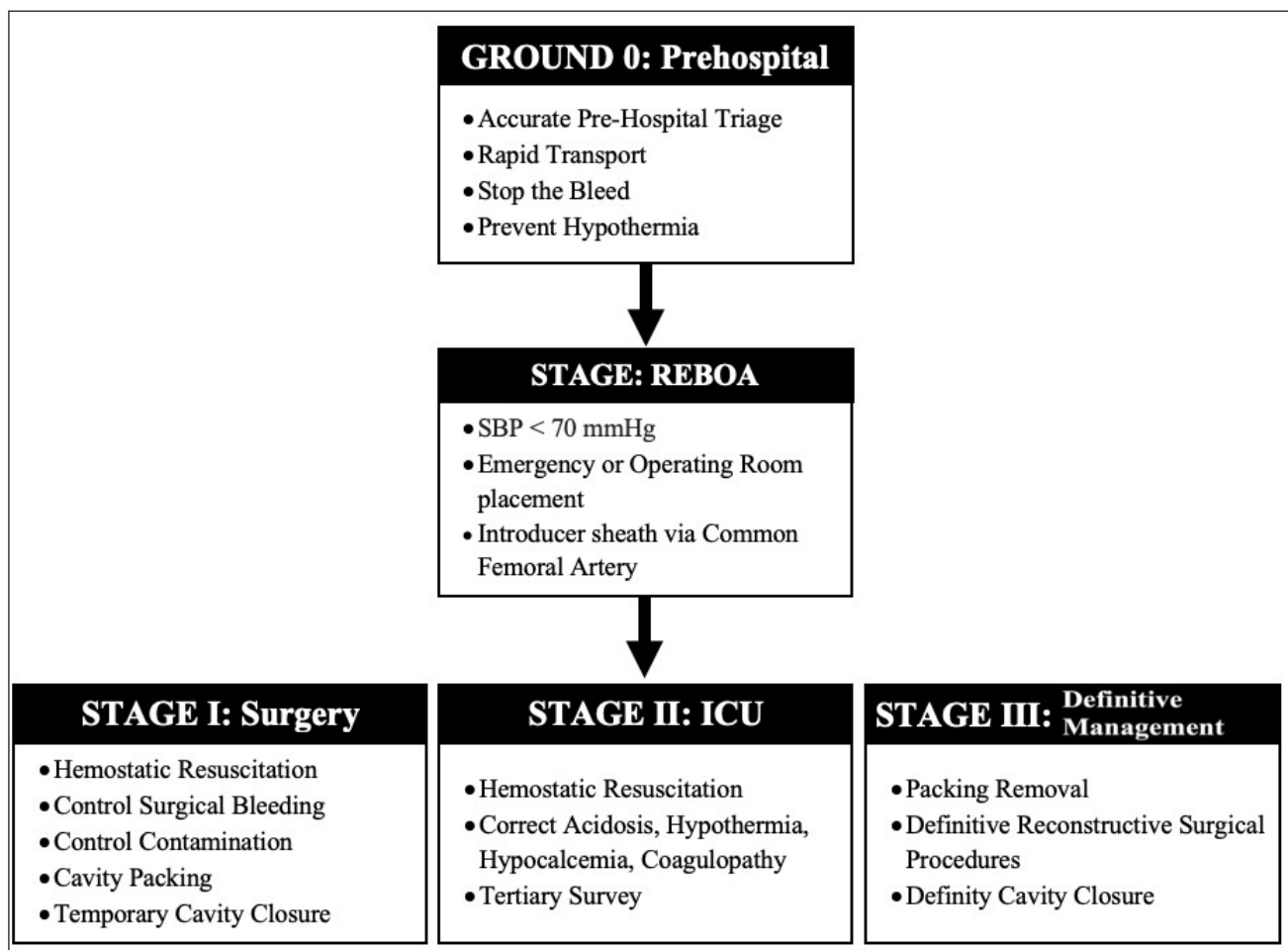


Figure 5. Damage Control Surgery: Stages including REBOA

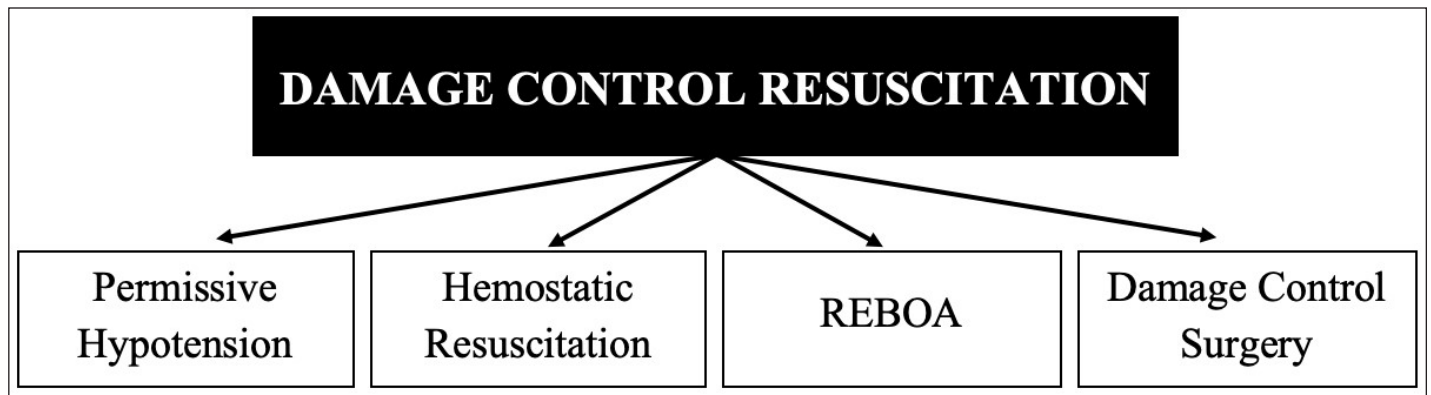


Figure 6. REBOA as an integral component of DCR/DCS

many centers in Latin America and other parts of the world but we believe that in time this technology will be accessible to all those that may benefit from its use.

Conclusion

The development of the concepts of Damage Control Resuscitation and Damage Control Surgery have been one of the most important advancements in trauma surgery. These concepts have been classically based on three fundamental pillars: permissive hypotension, hemostatic resuscitation and surgical damage control. We have introduced a fourth pillar which is the inclusion of the Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA).

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