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GENERAL REVIEW • GENERAL ORTHOPAEDICS - TRAUMA

The evolution and impact of the "damage control orthopedics" paradigm in combat surgery: a review

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Abstract
The idea of damage control (DC) is grounded on a sequential therapeutic strategy that supports physiological restoration over anatomic repair in critically injured patients. This concept is firstly described as damage control surgery (DCS) for war-wounded patients with abdominal exsanguinating trauma. The goal was to avoid prolonged operative times and prevent the outset of the lethal cycle of hypothermia, acidosis and coagulopathy. Damage control orthopedics (DCO) is also based on this concept and it is applied in the treatment of some polytrauma patients with pelvic and long bones fractures as to avoid the "second hit" of a lengthy definitive operation and eliminate initial morbidity and mortality. It is in favor of primary fracture stabilization utilizing provisional external fixation. When the patient is in stable condition, conversion to definitive open reduction and intramedullary nailing can be done. This stepwise approach should be considered as a part of the resuscitation process, and it follows the saying "do no further harm".

Keywords Damage control surgery · Trauma · Damage control orthopedics · War

Introduction

In the last three decades, a valiant effort has been made in order to diminish the mortality of war-wounded patients. A therapeutic strategy has been developed which emphasizes on rapid restoration rather than definitive repair. This is the concept of damage control surgery (DCS). This concept has also extended in the field of orthopedics leading to "damage control orthopedics." Traditionally, the management of the multi-injured orthopedic patient remains a challenging issue. Damage control orthopedics (DCO) methodology is characterized by minimizing the impact of primary surgery. Secondary definitive management follows when the acute phase of systemic recovery has passed [1].

Concept of damage control

The term damage control surgery (DCS) is originated in the US Navy. It was described in the 1940s for control of battle damage to ships. When a Navy ship has taken fire, the sailors, at all costs, immediately put out all fires and stop any

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flooding. So the definitive repair is done later when things are under control. Therefore, it describes measures which are taken in three phases: firstly, rapid repairs to keep the ship a float, secondly, return to the port and thirdly, definitive repairs. The surgical analogy of this in massive trauma has allowed an increase in the survival of war-wounded patients [2].

Damage control surgery (DCS) was first used for patients with abdominal exsanguinating trauma as to avoid prolonged operative times and prevent the onset of the lethal cycle of hypothermia, acidosis and coagulopathy. The main difference with the standard surgical approach is the abandoning to cope with all injuries in the immediate post-injury period [3].

Triad of death

It is well-known that severe trauma and the resulting hemorrhagic shock are the roots of what is traditionally described as the lethal triad of Moore or bloody viscous circle which is composed of profound hypothermia, metabolic acidosis and clinically obvious coagulopathy. To stop the downward spiral, the surgeon must be able to recognize, treat and prevent this deadly triad [3–8].

Hypothermia

Hypothermia is in all probability the most encountered threat to the trauma patient. It is escalated in three categories. First and most often, mild hypothermia is defined as a core temperature between 34 and 36 °C. Moderate hypothermia is present below 34 °C and severe hypothermia below 32 °C. It is essential that hypothermia becomes clinically important at temperatures below 36 °C for more than 4 h. There are numerous causes which induce low core temperatures. A striking example consists of hypovolemic shock. Normally, body heat is produced as a result of oxygen consumption. Consequently, when the body is in state of shock oxygen delivery diminishes and heat production is impaired. The repercussions of hypothermia are also important: Several studies have shown that it is associated with a higher need for transfusion and with high mortality rates. Hence, it should be prevented and treated promptly when present [3–8].

Coagulopathy

Coagulopathy is defined as the inability of the blood to coagulate normally. It can be appeared immediately after massive trauma when shock, hypoperfusion and vascular damage are present. Hypothermia and academia can amplify the endogenous coagulopathy. The former is an essential contribution to coagulopathy owing to causing platelet dysfunction. Furthermore, massive blood transfusion is another important factor which causes dilutional thrombocytopenia and depletion of clotting factors. Acute traumatic coagulopathy (ATC) increases both mortality and morbidity, and it also requires a coordinated treatment which is based on damage control resuscitation [3–8].

Metabolic acidosis

Acidosis is defined as an arterial pH below 7.36 and can be metabolic, respiratory or mixed. In trauma patients, perfusion is decreased. As a result, this leads to anaerobic metabolism and the subsequent development of lactic acidosis. Nevertheless, particularly in patients with thoracic trauma and pulmonary contusion, there is a substantial respiratory component because of inadequate CO_2 elimination. Profound acidosis not only has detrimental effects on myocardial contractility but also it reduces the cardiac output. Moreover, it is interesting to note that in acidic environments, the coagulation factors are greatly inactivated. The interventions needed in order to prevent or treat metabolic acidosis should be aimed at the restoration of perfusion to the organs. The lost intravascular volume must be restored and the oxygen transport maximized. Bicarbonate can also be beneficial, and it is often administered. Other methods to increase tissue oxygenation and perfusion such as temperature-regulating units are safer if cardiac output is not compromised. Finally, it is vital that blood gases be frequently monitored.

As soon as this viscous cycle of metabolic failure is established, the correction of hemorrhage and other imbalances can be extremely difficult. In this case, prompt recognition and treatment are necessary to save the patient. So if the surgical team want to combat each part of the deadly triad, they must be acquainted with the pathophysiological mechanisms, their diagnosis and treatment [3–8].

The fourth component

Apart from the triad of death, soft tissue injuries seem to play a prominent role in terms of causing an additional burden of disease, especially in blunt trauma patients. Soft tissue injuries also known as the fourth component include extremity and truncal soft tissue damage and lung contusion. It is claimed that this fourth entity acts as a contributory factor to deteriorating the patient's clinical course. These factors can initiate mechanisms which activate the immune response system. As a result, subacute complications can be developed such as ARDS and MOF. It stands to reason that physicians should be aware of this entity and bear in mind its negative impact when it comes to establishing general management principles [9].

A three-stage surgical approach

Damage control surgery is undeniably one of the major advances in the care of trauma patients, and its concept is becoming more and more acceptable in surgical community. This approach involves three distinguished stages.

Stage one: surgery limited to control of the damage-abbreviated laparotomy

The first stage involves brief, initial surgery to determine the extent of injury, avoid contamination and control hemorrhage. The latter consists of the top priority. The most limited procedure must be done by the surgeon in order to fix what is necessary to stop the bleeding. This can be done in many ways:

- packing
- suturing
- using topical hemostatic agents
- repairing or removing ruptured organs such as the spleen
- applying a pelvic fixation device for major pelvic ring disruptions.

After the bleeding is controlled, the next step is the control of contamination. The bowel wall must be inspected. Rapid closure of the perforated viscus often prevents further contamination. This can be achieved by simple suturing, ligation or stapling. The abdomen may also be left open. If so, a hospital-sterilized plastic bag or a simple, sterile, empty 3 L IV bag known as a "Bogota bag" is temporarily sutured to the abdominal wall. On no account is reconstructive surgery undertaken at this first laparotomy. When the major hemorrhage is under control the patient is transferred to the intensive care unit (ICU) [4, 6, 10].

Stage two: intensive care unit (ICU) resuscitation

The targets of this second phase are to achieve resuscitative stability and restoration of physiological parameters within an intensive care setting. The main goals are to rewarm the patient and correct the acidosis and coagulopathy. Correction of the hypothermia is of paramount importance on the grounds that coagulopathy and acidosis can be corrected and maintained when body temperature is restored to normal. It is pointed out that it requires 24–48 h to reestablish normal physiological parameters [4, 6, 10].

Stage three: definitive surgery

The third phase always takes place after a window period of 36–48 h between the initial insult and correction of the metabolic disorder when the patient is stable and ready to return to the operation room for definitive management. Any longer delay is associated with increased morbidity and mortality due to septic risk and organ failure. In this phase, abdominal packing is removed and a complete laparotomy is performed as to reexploration of abdominal injuries which may not be detected in the first stage. Finally, special attention should be drawn to the nutritional status of these patients with early initiation of enteral nutrition [4, 6, 10].

Patient selection

There are specific clinical intraoperative parameters for the initiation of damage control. Asenio et al. were the first to describe these parameters. Damage control is used in patients who are present with or at risk of developing:

- Hypothermia < 34 °C
- Acidosis pH < 7.2
- Serum bicarbonate < 15 mEq/l
- Transfusion of > 4000 ml/l
- Transfusion of > 5000 ml and blood products
- Intraoperative volume replacement > 12000 ml
- Clinical evidence of intraoperative coagulopathy

Apart from these parameters, the principles of damage control should be initiated in high-energy blunt torso trauma, multiple torso penetrations, hemodynamic instability, coagulopathy and hypothermia on admission [6].

Tactical abbreviated surgical control (TACS)

Tactical abbreviated surgical control (TACS) is the use of damage control surgery on the battlefield (combat damage control surgery). It consists of a modified military version of damage control surgery and focuses on treating combat casualties in tactical zone. Not only does it integrate the physiological reasons for performing abbreviated surgery but it bears in mind the needs of tactical environment. However, there are differences between those two procedures. First and foremost, TACS is applied to almost all received casualties who cannot return to the battlefield after treatment reporting to the forward surgical center. As a result, there are no limitations in terms of the criteria applied. Contrary to the damage control surgery, this includes only those patients with derangement of critical physiological parameters and injury complexes. Secondly, TACS includes only phase 1 of damage control surgery. Phase 2 and 3 are completed at the next echelon of care. Recent surveys based on military care for the wounded from Iraq and Afghanistan have shown that TACS improves survival. All the same, safe evacuation

route, well-equipped transport and trained manpower are compulsory components [11].

Damage control orthopedics (DCO)

Damage control orthopedics (DCO) is based on the concepts of damage control surgery, and it follows the same principles when it comes to the management of the multiply injured patient with associated fractures of the long bones and pelvic fractures.

Historical prospects

Until the middle of the last century, the surgical fracture stabilization of long bones was not routinely performed because the multiply injured patients were not stable to survive surgical intervention. The main cause was the fear of fat embolism syndrome which is characterized by hypoxia, cerebral depression, renal failure or coagulopathy. Moreover, it was thought to be the consequence of the early manipulation of fractures. Thereby, many surgeons prefer to avoid the operation.

In 1970s, further clinical studies showed the benefit of early definitive fracture stabilization. It was then when early fracture stabilization was performed as more advanced techniques for the postoperative care and fracture fixation were available. Nevertheless, it was no until the late 1980s that the first meaningful study by Bone et al. was published, showing the salutary effect of the early stabilization on both length of stay and morbidity. Simultaneously, further evidence demonstrated that the greatest benefits were seen in those who not only had the most severe injuries sustained but also they followed early operative stabilization treatment within 24 h. This new perspective in the management was named early total care (ETC). As a result, the popular held belief that the patient was "too sick to operate on" was now substituted with the contrary view that the patient was "too sick *not* to operate on" [12, 13].

Although several studies put emphasis on this concept and its benefits, a variety of unexpected complications related to this technique was described. Thus, opposite views began to emerge during 1990s. It was proposed that the procedure which is used to fix the bone, in most cases a reamed intramedullary nail, could provoke rather than protect against the development of pulmonary complications. Many studies not only supported this concern but also inferred that the method of stabilization and the timing of surgery may have played a prominent role in the development of such complications. ETC was not considered suitable for all polytrauma patients. The findings indicated that there was a particular subgroup in which management by this approach was detrimental. On the basis of both clinical and laboratory findings, the parameters which are used to identify a patient in a borderline condition are:

- Multiple injuries with an injury severity score (ISS) > 20 with additional thoracic trauma AIS > 2.
- Multiple injuries with abdominal/pelvic trauma (> Moore grade 3) and hemorrhagic shock (initial systolic BP < 90 mmHg).
- ISS > 40
- Radiographic (CXR or CT) evidence of bilateral pulmonary contusion.
- Initial mean pulmonary arterial pressure > 24 mmHg.
- Pulmonary artery pressure increase during intramedullary nailing > 6 mmHg.

In consequence, it became clinically evident that early definitive stabilization of all fractures in all patients was not necessary and was potentially hazardous, and the management of major fractures changed to a more selective method called damage control orthopedics (DCO) [12, 13].

The second hit theory

Extremity injuries, including fractures, are often associated with soft tissue injuries and blood loss. As a result, they can lead to an immunological activation and response. This inflammatory response is described by local and systemic proliferation of different factors such as cytokines, complement factors, acute phase reactants, proteins of coagulation system and by cumulation of immunocompetent cells and leukocytes at the side of tissue injury. All these pro-inflammatory mediators in conjunction with the subsequent microvascular damage are known to contribute to the development of multiple organ dysfunction syndrome. The latter in case it is severe enough, it can lead to early death after injury. This initial traumatic injury is called the "first hit" which predetermines the patient to a contingent risk of aggravation after surgery. In this scenario, any surgical intervention may represent the "second hit" (second inflammatory insult after the initial trauma) which is observed to be composed by factors such as hemorrhage, sepsis and ischemia. Remarkable is the fact that the impact of surgery on the biological reserve depends on the type of primary stabilization and timing of final osteosynthesis. Consequently, damage control orthopedics (DCO) principles are oriented toward decreasing the degree of second hit impact [14].

DCO application

Damage control orthopedics (DCO) consists of three stages. The first stage includes control of blood loss, decompression

of intracranial lessons if necessary, and early temporary stabilization of fractures which are not stable. The next stage comprises resuscitation of the patient in the intensive care unit and restoration of his condition. Finally, in the third stage, when the patient is ready definitive surgery of the fracture is undertaken.

The commonest approach for achieving temporary stability of the fractured pelvis or a fracture of a long bone is external fixation. Not only this technique is minimally invasive but also it takes the advantage of minimizing the additional immune response which is posed by extensive surgical procedures. Furthermore, the delayed final treatment for the stabilization of long bones, specifically fractures of the femur, is often intramedullary nailing (IMN). On no account must this procedure be conducted when the condition of the patient is unstable [1, 12, 13].

One of the most crucial questions to be answered is when to perform the secondary procedure. It has been shown that the preferential window of opportunity to proceed with the definitive stabilization of the fracture is after the fourth day from the time of injury. Actually, this practice focuses on diminishing the impact of the second hit, namely the additional burden of the surgery, on the already traumatized patient. On top of that, conversion of external fixation to intramedullary nailing can be done without danger within first 2 weeks and has a low rate of procedure-related complications.

The sequence of damage control orthopedics:

Patient with multiple injuries in an unstable condition or in extremis

→ *Stage 1* Operating theater, temporary stabilization of fractures, with an external fixator–cavity decompression
→ *Stage 2* Intensive care unit, resuscitation–correction of hypothermia and coagulation- ICP monitoring
→ *Stage 3* Operating theater (after day 4), definitive stabilization of fractures [12].

Another important decision to be made is the selection of which polytrauma patient may benefit from this concept. This resolution is mainly based on the patient's general physiological condition and the severity of the injuries. After primary resuscitation, a patient can be classified as "stable," "at risk or borderline," "unstable" or "in extremis." The stable patient without thoracic trauma the early total care approach is considered safe and appropriate. The definitive treatment can be performed safely and soundly within 24 h when initial resuscitation has been completed. The endpoints of resuscitation are stable hemodynamics, stable oxygen saturation, lactate level <2 mmol/l, no coagulation disturbances, normal temperature, urinary output >1 ml/kg/h and no requirement for inotropic support. For the borderline patient, early total care (ETC) may not be considered safe unless the patient is stabilized. An unreamed intramedullary nail should be used in order to diminish the surgical burden. In any case, the patient's condition exacerbates the surgeon should be high alert to the potential to apply the damage control pathway. For the unstable or in extremis patients, the damage control orthopedics (DCO) is recommended. In these groups, any attempt to intervene surgical should be regarded as lifesaving and must be characterized by simplicity, rapidity and well organized. If severe head traumas are presented the damage control approach is advocated as

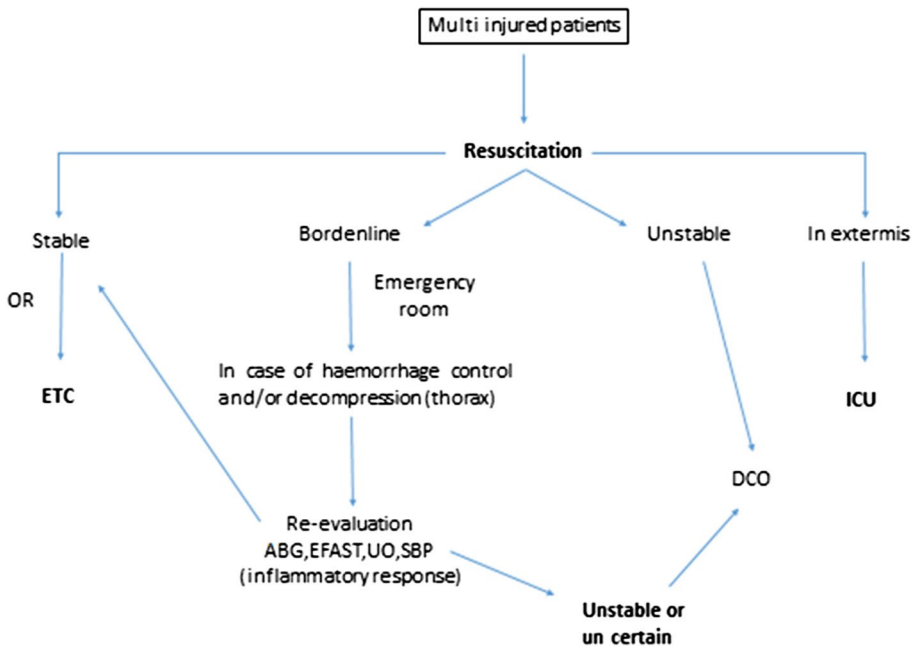

Fig. 1 The figure illustrates the algorithm for the treatment of major taking into account the impact of surgery of surgery after multi-trauma [15]. *ABG* arterial blood gas, *EFAST* focused assessment with sonography in trauma, *UO* urine output, *SBP* systolic blood pressure

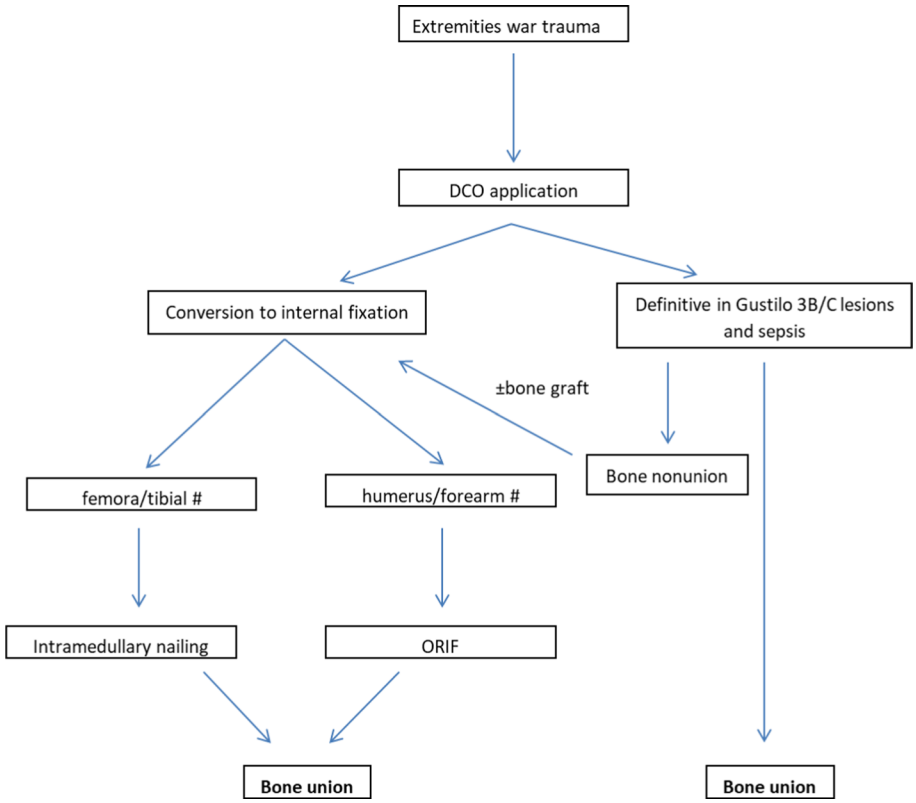

Fig. 2 The following figure describes a reliable algorithm in case of limps war trauma. A staged therapeutic management is required based on external fixation according to the principles of DCO. After the DCO application, there are two different options temporary and definitive external fixation. The latter choice is suitable when the injury is characterized by extensive soft tissue injury including periosteal stripping, massive contamination, and need for soft tissue coverage or vascular involvement (Gustilo 3b/3c). Otherwise, early conversion to internal fixation is performed [23]

well. Every possible effort must be made in order to central nervous system be protected. If not, secondary brain injury might lead to further disability and morbidity [1, 12, 13] (Figs. 1, 2).

However, there have been recent studies suggesting that some polytrauma patients actually take advantage of early definitive fracture fixation and thus the term early appropriate care was proposed. The latter consists of an evolution of DCO focusing mainly on the physiological state of the patient and the success of the resuscitative efforts [16–18]. For the borderline patient, the ideal type and timing of remains a widely debated topic. To overcome this limitation, Vallier et al. carried out a retrospective study of 1442 patients with pelvic, spinal and femoral shaft fractures and inferred that definitive management of unstable axial skeleton and long bone should be only be underwent within 36 h in case the patient has demonstrated an adequate response to resuscitation as based on improvement of acidosis with lactate < 4.0 mmol/L, pH ≥ 7.25 or base excess (BE) ≥ -5.5 mmol/L. If the acidosis insists on, a DCO protocol is utilized [18]. Finally, this new line of treatment seems to have a lot of advantages such as decreasing delay to surgery, minimizing complications (mainly the possibility of infection after external fixation and the need for additional surgery) and increasing hospitals income [19].

Pelvic ring injuries

Moreover, one subject, deserving our close attention, is undoubtedly pelvic fractures. Even though these fractures are a rare occurrence, they are often associated with high-energy injuries which can have a negative impact on outcome and survival rates [20]. As a result, management of these fractures possesses a challenge for clinicians. Despite the fact that there is a variance of classifications system, they have unfortunately failed to provide an effective decision-making algorithm. The best treatment strategy should bear in mind the hemodynamic status, the anatomic damage and the related injuries [21]. To cope with this impediment, the World Society of Emergency Surgery (WSES) has recently achieved to introduce a new classification system which is based on a combination of anatomic/mechanic and hemodynamic status providing in this way a reliable and effective management algorithm. According to this protocol, patients with minor pelvic ring injuries (WSES grade 1) which characterized by mechanically and hemodynamically stable injury patterns can proceed with no operative management. Furthermore, patients who presented as hemodynamically stable and mechanically unstable with no other lesion requiring treatment and with no positive CT-scan can continue directly to definitive mechanical stabilization. On the other hand, any unstable pelvic ring injury with associated disintegration of posterior element instability (WSES grade 2

and 3), especially in conjunction with hemodynamic instability (WSES grade 4), requires a damage control strategy with temporary external pelvic fixation [21]. In these severe lesions, recent research has stressed the great importance of pre-peritoneal packing (PPP) as an effective technique in controlling hemorrhage in patients with pelvic fracture-related hemodynamic instability despite the initial blood transfusion [22].

Damage control orthopedic (DCO) in war trauma

A staged treatment which follows the principals of damage control is extremely useful in terms of war injuries. The term "tactical orthopedic intervention," firstly used by Covey, describes the first stage of this "War DCO". This stage has three objectives:

1. Provide hemostasis
2. Eliminate wound infection
3. Stabilize the fracture prior to medical evacuation

Besides the closed fractures located to the upper limp or ankle, the utility of external fixator is demanded on the management of the closed and opened fractures of the long bones or pelvis. Although the identical anatomic requirements for pin placement, the external fixator which is used it slightly differs from the conventional one when it comes to functional and biomechanical aspect. This incompatibility is due to the fact that this fixator acts as "portable traction." Thus, its use is mainly to facilitate patient in case of medical evacuation. It is essential that this emergency external fixator be monoplane and utilize only a small number of pins. The most appropriate place for the pins is far from the fracture seeing that in this manner the risk of pin track infection is decreased in case of conversion to internal fixation. After medical evacuation and resuscitation phase, final treatment is performed. Early conversion to internal fixation provides good long-term results. Nevertheless, the major concern of contamination continues to exist. When the risk of infection is greatly possible or the severity of injury is high (Gustilo grade 3 open fractures) definitive external fixation is recommended [23].

Conclusion

Taking everything into consideration, it can be inferred that damage control orthopedics (DCO) comprises a stepwise approach for the management of severe injured patients. It is oriented to bear in mind all of the difficulties may be encountered in coping with patients who are in an unstable physiological state or in extremis. Moreover, it is in the best interests of borderline patients fluctuating between stable and unstable physiological states. In addition, it consists of a valuable treatment option in battlefield extremity injuries as a staged management of bone and soft tissues traumas. This approach should be considered as a part of the resuscitation process, and it follows the saying "do no further harm."

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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