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ORIGINAL ARTICLE

Indications and interventions of damage control orthopedic surgeries: an expert opinion survey

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Abstract

Objectives The objectives of this study were to gather an expert opinion survey and to evaluate the suitability of summarized indications and interventions for DCO.

Background The indications to perform temporary surgery in musculoskeletal injuries may vary during the hospitalization and have not been defined. We performed a literature review and an expert opinion survey about the indications for damage control orthopaedics (DCO).

Methods Part I: A literature review was performed on the basis of the PubMed library search. Publications were screened for damage control interventions in the following anatomic regions: "Spine", "Pelvis", "Extremities" and "Soft Tissues". A standardized questionnaire was developed including a list of damage control interventions and associated indications. Part II: Development of the expert opinion survey: experienced trauma and orthopaedic surgeons participated in the consensus process.

Results Part I: A total of 646 references were obtained on the basis of the MeSH terms search. 74 manuscripts were included. Part II: Twelve experts in the field of polytrauma management met at three consensus meetings. We identified 12 interventions and 79 indications for DCO. In spinal trauma, percutaneous interventions were determined beneficial. Traction was considered harmful. For isolated injuries, a new terminology should be used: "MusculoSkeletal Temporary Surgery".

Conclusion This review demonstrates a detailed description of the management consensus for abbreviated musculoskeletal surgeries. It was consented that early fixation is crucial for all major fractures, and certain indications for DCO were dropped. Authors propose a distinct terminology to separate local (MuST surgery) versus systemic (polytrauma: DCO) scenarios.

Keywords Damage control surgery · Indication · Intervention · Polytrauma · MuST surgery · Extremity · Soft tissues

Introduction

Multiple system injuries in trauma patients continue to represent one of the main causes of death and morbidity worldwide, especially in patients under the age of 40 [1]. Certain management strategies have been adapted to improve the outcomes in those patients, such as defined transfusion protocols (point of care strategy), permissive hypotension (damage control resuscitation) and surgical strategies to limit the amount of bleeding in the first operative intervention [damage control surgery (DCS)]. It is widely accepted that one should differentiate between those patients who can tolerate a prolonged surgical procedure and those for whom it is not advisable [2–4]. Unstable or critically ill patients can be temporarily stabilized and definitive fixation can ensue right after normalization of the patient's physiologic status [5].

There are several approaches to fracture fixation. For many years, a dichotomic approach had been discussed. Some authors propose fracture fixation of all fractures in a single step [early total care (ETC) or early appropriate care],

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while others advocate a temporary fracture fixation (DCO) [4, 6]. Neither strategy appears to fully respect the dynamics of some patient's physiology. Therefore, a "safe definitive surgery " (SDS) concept has been introduced, which is thought to represent a dynamic synthesis of both strategies, tapered to the individual patient response [7]. This concept requires a dynamic rather than a static approach, where the first series of fracture fixations are performed after admission and assessment of the response to resuscitation, whereas further therapy is guided by an intraoperative reassessment and after the first series of temporizing surgeries. Due to repeated re-evaluation and assessment of patients regarding their physiology, dynamic classification and adaptation of the treatment strategy are possible.

In certain situations, temporary external fixation is also recommended for isolated musculoskeletal injuries. Among these are fractures accompanied by severe closed soft tissue injuries, severe vascular injuries, open fractures with gross bacterial contamination, sustained segmental bone loss and complex articular fractures. In these cases, although patients are physiologically stable, an indication for a staged procedure exists. While the indications for truncal injuries have been clearly defined by an expert panel [8, 9], a similar approach is not available for fracture fixation and DCO (extremities, pelvis, and spine). Therefore, an expert panel was created, representative of multiple orthopaedic and trauma societies around the world to discuss these issues.

The aim of this study was to discuss indications and interventions of DCO in unstable polytrauma patients and in those with stable isolated musculoskeletal injuries. In addition, we set out to evaluate the opinion of experts according to the appropriateness of indications and interventions.

The authors test two hypotheses based upon literature and expert opinion consensus: (1) A DCO procedure may be indicated in isolated musculoskeletal injuries, which need to be distinguished in further studies; and (2) not all minimally invasive procedures and DCO interventions are considered standard in unstable polytrauma patients.

Methods

Part I: development of the questionnaire

Literature search and search strategy:

The main aim of the literature search was to summarize a complete list of damage control indications and intervention to develop a questionnaire. We performed an electronic literature search (January–February 2019) using relevant keywords (MeSH terms: multiple trauma, isolated trauma, damage control surgery, damage control orthopaedics, spinal injury, pelvic injury, extremity injury, soft tissue injury, indications) and restricted our search to articles in English. Please find a list of MeSH terms included in Table 1. All MeSH terms were used in combination "and" / "or". Publications were screened for damage control interventions and abbreviated surgery in the following anatomic regions: "Spine", "Pelvis", "Extremities" and "Soft Tissue Injuries". A combination of keywords was also used to avoid overlooking potentially relevant studies. In addition to the database search, experts in the field of trauma surgery were asked for potentially relevant studies. Titles and abstracts were searched for relevant synonyms and their plural forms.

Study selection

Authors (RP und YK) initially reviewed all of the retrieved references by title and abstract, if the inclusion criteria were met. Studies were included if they were published between January, 1st. 1990 and January, 1st. 2019, and filled the following criteria: written in English, included isolated injuries and multiply injured/polytrauma patients treated with DCO or other abbreviated surgical interventions. Review articles were also included. Studies that did not contain traumatized patients were excluded. Subsequently, both authors independently reviewed the full-text articles initially identified in the title and abstract screening for final inclusion. Any conflicts were discussed to achieve a consensus. Articles that met the inclusion criteria were selected for data extraction.

Other reviewers (LL, IM, PG and HCP), all with methodological expertise and with content expertise, assessed the studies for feasibility and plausibility of the content regarding the conclusions made.

Grading of the literature

Previously defined parameters were extracted independently and documented in a spread sheet. Cross-check of the extracted data was performed by study members. Any disagreement was resolved by a consensus discussion with all authors. Surgical interventions and abbreviated surgery identified in the literature review were listed in a table according to anatomical locations. Injuries and injury patterns, which represent surgical indications for abbreviated interventions, were matched to their anatomic regions and surgical procedures. A standardized questionnaire was developed, including a list of the above-mentioned DCO interventions and associated indications. All panelists (RC; LL; RK; PG; FH; RP; IM; FP; GO; YW; KW; HCP) were asked to rate (harm versus benefit) all surgical procedures in patients with monotrauma (isolated musculoskeletal injuries) or polytrauma. The expert panel had to rate on a scale ranging from 1 to 5 points, where 1 point indicates that the surgical intervention is expected to be harmful, 3 points indicates that the expected benefits and harms are about equal, and 5

Table 1 Keywords used in systematic review according to indication and surgical intervention

Topic	Search	Results	Title	Inclusion
General DCO	Damage control orthopaedics	893	60	10
	Damage control orthopaedics indication	9	9	
	Damage control orthopaedics polytrauma	131	40	
	Damage control orthopaedics polytrauma indication	3	3	
Compartment syndrome	Compartment syndrome forearm	740	20	3
	Compartment syndrome thigh	316	20	
	Fasciotomy indication	243	20	
	Compartment syndrome damage control orthopaedics	18	18	
Pelvis	Pelvis damage control orthopaedics	28	28	23
	Pelvis damage control orthopaedics indication	1	1	
	External pelvic fixation	730	20	
	External pelvic fixation indication	46	20	
	External pelvic fixation damage control orthopaedics	19	19	
	C-clamp	116	20	
	C-clamp damage control orthopaedics	2	2	
	Percutaneous screw fixation indication	158	20	
	Percutaneous screw fixation damage control orthopaedics	4	4	
	Pelvic packing	314	40	
	Pelvic packing damage control orthopaedics	2	2	
	Pelvic packing indication	16	16	
Reboa	REBOA	283	20	7
	REBOA indication	18	18	
	REBOA damage control orthopaedics	2	2	
Spine	Spine damage control orthopaedics	108	40	11
	Spine damage control orthopaedics indication	0	0	
	Halo fixator	42	20	
	Halo fixator damage control orthopaedics	0	0	
	Halo fixator indication	11	11	
	Percutaneous dorsal instrumentation	134	20	
	Percutaneous dorsal instrumentation indication	16	16	
	Percutaneous dorsal instrumentation damage control orthopaedics	1	1	
Extremities	External fixator damage control orthopaedics	15	15	20
	External fixator indication	95	20	
	Traction indication	803	20	
	Ilizarov damage control orthopaedics	3	3	
	Traction damage control orthopaedics	9	9	
	Closed reduction and cast indication	71	20	
	Closed reduction and cast damage control orthopaedics	1	1	
	Primary amputation indication	508	20	
	Primary amputation damage control orthopaedics	8	8	
	VAC indication	71	20	6
	VAC damage control orthopaedics	2	2	
Duplicates	Duplicates excluded			− 6
Total		5917	646	74

points indicates that the surgical intervention is expected to be beneficial (see Supplement 1). Anatomical regions were separated according to the current practice of orthopaedic surgeons (spine, pelvis, extremities, etc.).

Part 2: development of the expert opinion survey

To identify the standard indications for DCO in severely injured patients, an expert panel of trauma surgeons and

experts in trauma care was established. Twelve certified experts in trauma management from around the world participated in the consensus process. We strived to include multiple scientific societies and focused on experienced surgeons familiar with the care of severely injured patients. Among the societies were the American Association for the Surgery of Trauma (AAST), Orthopaedic Trauma Association (OTA), Société Internationale de Chirurgie Orthopédique et de Traumatologie (SICOT), European Society for Trauma and Emergency Surgery (ESTES), Deutsche Gesellschaft für Unfallchirurgie (DGU), Dutch Trauma Society (DTS), British Trauma Society (BTS), Slovenian Association of Surgeons (SAS), Israeli Orthopaedic Association (IOA), and Schweizerische Gesellschaft für Chirurgie (SGC). These experts answered the questionnaire by performing an independent review and assessment of each associated surgical intervention.

Time table

A series of meetings were held under the auspices of the European Society for Trauma and Emergency Surgery (ESTES) [time table of the consensus process (Table 2)]. The idea for these meetings was generated at the polytrauma course in Zurich in September 2017, which was held by members of the ESTES, AAST, OTA, DGU, and SGC. Thereafter, experts were contacted regarding their availability for a kick-off meeting in Frankfurt, Germany on March 18th and 19th 2019.

The overall strategy included:

1. to perform a structured review of the literature,
2. to decide upon indications for DCO on the basis of the literature review and expert opinions, and
3. to propose a nomenclature.

The next in person meeting was held in Prague on May 5th 2019 during the Annual European Congress of Trauma and Emergency Surgery. The subsequent consensus meeting was performed in Zurich on September 12th 2019. In preparation for the final meeting, numerous discussions over email and telephone took place. The consensus was confirmed during the final meeting. Based on discussions during the prior meetings, all members of the panel agreed on the following: indications for damage control procedures need to be distinguished between indications due to patient's instability (hemodynamic changes, coagulopathy, and acid base changes) and those related to the severity of the extremity injury (bone loss, articular fracture or soft tissue defects, and vascular injury).

Statistical analysis

All results of the expert survey were described as median and mean value of the rating score, describing how often panellists scaled a certain value as described previously [8, 10]. Mean values < 2.5 points were deemed to indicate an agreement that DCO is inappropriate for the mentioned indication. All results were described as median, mean, and scale rating. Mean values between 2.5 and 3.5 points indicate a disagreement of the expert group regarding the appropriateness of DCO. Mean values > 3.5 points indicate an agreement that a DCO intervention is beneficial in the mentioned indication. Finally, all agreements to use damage control surgery were summarized in two tables, distinguished between "Damage Control Orthopaedics" in polytrauma and "Damage Control in Extremities" in patients with isolated trauma.

Results

Part I (development of the questionnaire)

Study Selection

Our systematic literature search using the above-mentioned methodology (Table 1) revealed a total of 6040

Table 2 Timetable of the consensus process

Initiation of consensus meeting	Zurich, CH, PT course, 9/2018
Invitation of group members	Berlin, DKOU 2018
	Montreal, SICOT 2018
Preparative systematic literature review	Zurich CH, 9/2018–12/2018
First in-person group meeting: development of preliminary suggestions	Frankfurt, GER, ESTES 3/2019
Second in-person group meeting: consensus discussion according to the previous session and literature	Prague, ESTES 5/2019
Third in-person group meeting: consensus discussion according to the previous session and literature	Zurich, PT Course 9/2019
Further refinement of the manuscript	9/2019 to 11/2019

Abbraviation: *PT* Polytrauma Course

publications dealing with damage control surgery in musculoskeletal injuries. Figure 1 demonstrates how studies were included in the present review. After initial screening of titles and abstracts, 646 papers were screened for inclusion according to their focus on anatomical region. Ten publications were included covering general indications for polytrauma, 11 were included covering spinal injuries, 30 covering pelvic trauma including resuscitative endovascular balloon occlusion of the aorta (REBOA), and 29 covering extremities and soft tissue injuries. Finally, we identified 80 relevant publications, 6 of which were duplicates and were excluded, thus leaving 74 articles for inclusion in the present literature review.

Both indications and interventions were listed within the questionnaire. Twelve damage control-related interventions were identified and these suggested 73 surgical indications in musculoskeletal trauma: SPINE: halo fixation (11 indications), percutaneous dorsal spine instrumentation (6 indications)/ PELVIS: external fixation–pelvis (8 indications), C-clamp–pelvis (4 indications), percutaneous screw fixation–pelvis (12 indications), pelvic packing (3 indications), REBOA (3 indications)/ EXTREMITY: external fixation–long bones (12 indications), traction–long bones (6 indications)/SOFT TISSUES: debridement and negative pressure therapy (VAC) in soft tissues (5 indications) and compartment fasciotomy in extremities (3 indications).

Part II (results of the expert opinion)

Part IIA: isolated trauma (Table 3)

Spine Halo fixation can be used to achieve temporary reduction and stabilization of cervical spine fractures. For isolated cervical spine trauma, there was a strong disagreement regarding indications for halo fixation (median 2 or 3 points, mean ≥ 2.5 and ≤ 3.5 points). However, thoracolumbar spine percutaneous dorsal instrumentation was graded as a beneficial intervention according to injury type and biomechanical stability of the fractures (median 4 or 5 points, mean > 3.5 points).

Pelvis In complex or open injuries of the pelvis and concomitant injuries in lesser pelvic organs, temporary stabilization with external fixation was considered as useful (median 4 or 5 points, mean > 3.5 points) damage control intervention in isolated trauma. The temporary stabilization of an unstable pelvic girdle with a C-clamp was graded as beneficial with respect to unstable pelvic fractures (median 4 or 5 points, mean > 3.5 points).

All other indications in isolated injuries showed disagreement (median 2–3 points, mean ≥ 2.5 and ≤ 3.5 points). Percutaneous screw fixation of sacral fractures was rated as beneficial in isolated pelvic ring injuries. However, percutaneous

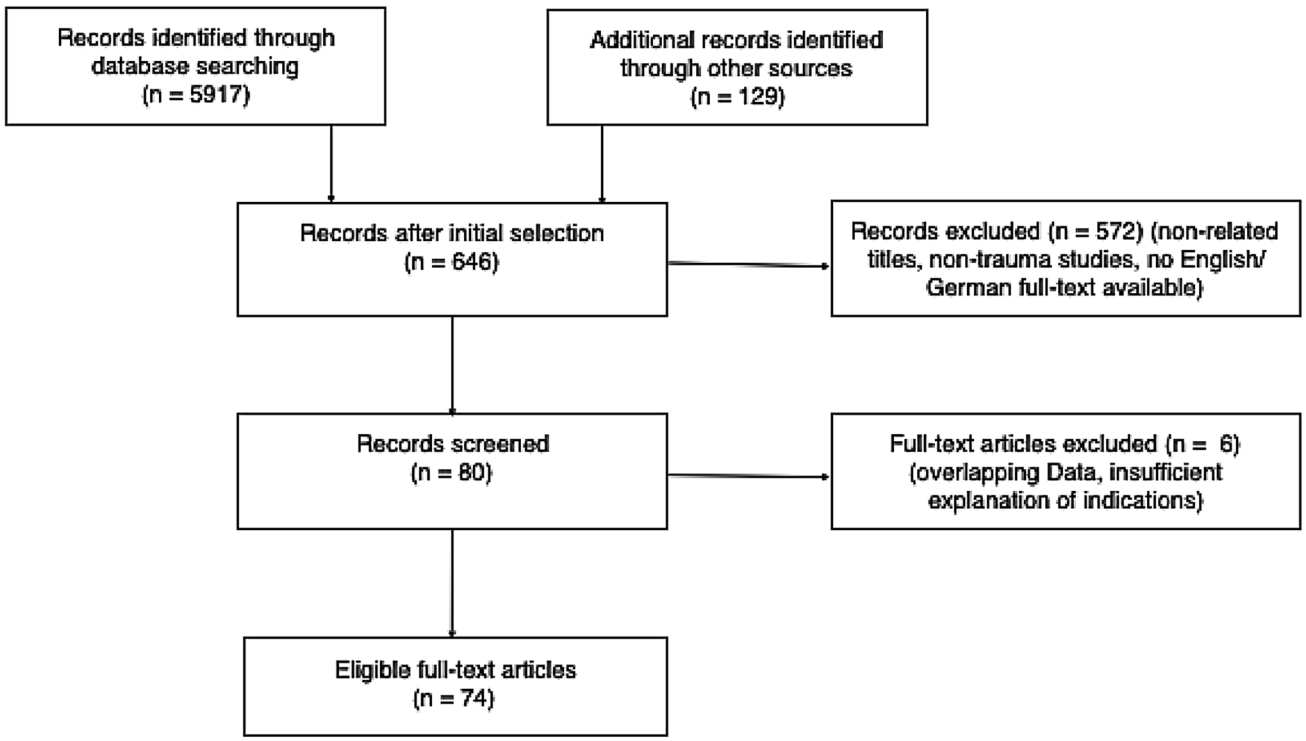

Fig. 1 Flowchart of selection criteria

Table 3 Indications and interventions with agreement for "Must Surgery" in isolated musculoskeletal injuries

	Indications	Interventions
Spine	Unstable thoracic and lumbar spine fractures	Percutaneous dorsal instrumentation
Pelvis	Complex pelvic ring injuries with concomitant nerve or vascular injuries	External pelvic fixation
	Open pelvic injuries	External pelvic fixation
	Stabilization of the pelvis for pelvic packing	C-clamp
	Posterior pelvic ring injuries	Percutaneous screw fixation
	Hemodynamic instability with unstable pelvic fracture	Pelvic packing
Extremities	Open fractures with soft tissue contamination	External fixation of long bones
	Open fractures with large soft tissue defects	External fixation of long bones
	Large bone defects	External fixation of long bones
	Complex intra-articular fractures	External fixation of long bones
	Fractures with concomitant vascular injuries	External fixation of long bones
Soft tissues	Morell-Lavallée lesion	VAC therapy
	Soft tissue contamination	VAC therapy
	Large soft tissue defects	VAC therapy
	Compartment syndrome	Compartment fasciotomy
	Mangled extremity with uncontrollable haemorrhage	Amputation

interventions with the aim to stabilize the anterior pelvic ring and acetabular fractures have shown strong disagreement in the panel group (median 3 points, mean ≥ 2.5 and ≤ 3.5 points).

Extremities Temporary external fixation of long bones in cases of severe bone loss, severe comminuted injury, and complex articular fractures was graded as a safe strategy that allows a staged approach to a complex problem (median 4 or 5 points, mean > 3.5 points). On the other hand, traction in any of the above-mentioned indications was considered potentially harmful, as evidenced by disagreement amongst the expert panel (median 3 points, mean ≥ 2.5 and ≤ 3.5 points).

Soft tissues In soft tissue defects with severe contamination, tissue debridement and negative pressure wound therapy (NPWT) was advocated by panellists (median 4 or 5 points, mean > 3.5 points). In case of an isolated mangled extremity, early amputation was considered beneficial in cases with concomitant uncontrollable haemorrhage or an avascular limb (median 4 or 5 points, mean > 3.5 points). The expert panel did not reach agreement regarding the amount of bone loss and degree of neurologic damage necessary to indicate an amputation in such cases (median 3 points, mean ≥ 2.5 and ≤ 3.5 points).

Part IIB: polytrauma (Table 4)

Spine

Disagreement among the expert panel occurred for almost all indications for halo fixation. Halo fixation has been rated as a beneficial therapeutic strategy (median 4; mean 3.9) only in occipital–cervical dislocation. In unstable thoracic and lumbar fractures, percutaneous dorsal instrumentation was considered a beneficial procedure in severely injured patients (median 4 or 5 points, mean > 3.5 points).

Pelvis

The stabilization of unstable pelvic ring injuries in haemodynamically unstable patients with standardized external fixation was advocated and supported by the panellists. The use of the C-clamp in unstable posterior pelvic ring injuries showed high agreement rate amongst the experts, suggesting that the mentioned intervention in DCO is appropriate (median 4 or 5 points, mean > 3.5 points). Percutaneous techniques were only considered beneficial in cases of sacral fractures or sacro-iliac dislocations. Percutaneous fixation of acetabular and iliac wing fractures in severely injured patient was discussed as inappropriate interventions in DCO (median 3 points, mean ≥ 2.5 and ≤ 3.5 points). The use of pelvic packing or REBOA in the management of pelvic ring fractures with haemodynamic instability was considered valuable by the panellists (median 4 or 5 points, mean > 3.5 points).

Extremities

The temporary stabilization of long bone fractures using an external fixator in patients with an indication for DCO showed broad agreement for all mentioned indications (median 4 or 5 points, mean > 3.5 points). Marked disagreement was observed between the panellists regarding the treatment of fractures

Table 4 List of indications and interventions with agreement for damage control surgery of musculoskeletal injuries in polytrauma

	Indications	Interventions
Spine	Occipito-cervical dissociation	Halo fixation
	Unstable thoracic and lumbar spine fractures	Percutaneous dorsal instrumentation
Pelvis	Unstable pelvic ring fractures	External pelvic fixation
	Complex pelvic ring injuries with concomitant nerve or vascular injuries	External pelvic fixation
	Open pelvic injuries	External pelvic fixation
	Posterior pelvic ring injuries	Percutaneous screw fixation
	Type C pelvic fracture disruption of sacroiliac joint and sacrum fracture	C-clamp
	Hemodynamic instability with unstable pelvic fracture	Pelvic packing
	Exsanguinating haemorrhage related to pelvic injuries	REBOA
Extremities	Open fractures with soft tissue contamination	External fixation of long bones
	Open fractures with large soft tissue defects	External fixation of long bones
	Large bone defects	External fixation of long bones
	Complex intra-articular fractures	External fixation of long bones
	Fractures with concomitant vascular injuries	External fixation of long bones
	Complex peri-prosthetic fractures	External fixation of long bones
Soft tissues	Morell-Lavallée lesion	VAC therapy
	Soft tissue contamination	VAC therapy
	Large soft tissue defects	VAC therapy
	Compartment syndrome	Compartment fasciotomy
	Mangled extremity with neurologic injuries	Amputation
	Vascular injuries with ischemia more than 6–8 h	Amputation
	Mangled extremity with uncontrollable haemorrhage	Amputation

and dislocations with traction as a damage control procedure (median 3 points, mean ≥ 2.5 and ≤ 3.5 points).

Complex soft tissue injury

The management of complex soft tissue injuries and large defects by debridement and negative pressure wound therapy (NPWT) is advisable and represents a recent standard according to the expert panel (median 4 or 5 points, mean > 3.5 points). Similar results were observed for fasciotomy in cases of extremity compartment syndrome (median 4 or 5 points, mean > 3.5 points). Primary amputation was considered a DCO procedure in mangled extremities with neurologic deficits, in cases of prolonged ischemia (6–8 h), in patients with uncontrollable haemorrhage, and in trauma victims with an avascular limb of more than 6 h (median 4 or 5 points, mean > 3.5 points). The experts did not reach agreement on the use of amputation in cases of segmental bone defects of more than 20 cm in polytrauma cases.

Part IIC: nomenclature for the use of DC in isolated injuries and polytrauma

In certain musculoskeletal injuries, it is evident that staged management is performed for the following reasons, even in a physiologically stable patient:

(1) severe soft tissue damage, (2) gross bacterial contamination, (3) long segment bone loss, and (4) complex articular fractures.

During the final meeting in Zurich (Nov 2019), the panellists reviewed the indications and the results from the literature review and agree that isolated injuries with severe soft tissue injuries can sometimes be neglected regarding early fixation. As this is not a damage control approach—which has been developed for unstable polytrauma—they agree that a different terminology is required to indicate the urgent need for surgery. In addition, they concluded that a new terminology is needed to differentiate isolated musculoskeletal injuries that need a staged procedure due to the local conditions from multiply injured patients that need a staged procedure due to systemic/physiological instability. They agree that the term "Damage Control" should be used only for multiply injured patients. Therefore, the use of "Damage Control" in physiologically stable patients that do not suffer from multiple injuries would lead to confusion. The consensus group suggested the use of the term "MusculoSkeletal Temporary Surgery" or "MuST Surgery". This differentiation would clarify why a staged procedure was performed (local versus systemic situation) and would facilitate the interpretation and comparison of different series across studies.

Discussion

Whenever possible, polytrauma patients with multiple injuries should undergo definitive fixation of their major fracture within the first 24 h after admission. This applies especially for level I trauma centres or other centres that have adequate infrastructure (blood bank and 24 h coverage of trauma experts and anaesthesiologists). If patients with multiple injuries cannot be cleared for safe initial definitive care, DCO [11] has been incorporated as a useful and safe alternative [12, 13] tool to stabilize the osseous injury at risk of bleeding, pain, and associated inability to mobilize the patient. The strategy has been successfully applied in injuries of long bones [14], spine, and pelvis [15] until the patient is physiologically stable for conversion to definitive fixation [16]. The decision to perform a damage control procedure requires the simultaneous consideration of several factors. In an extensive scoping review of the literature, Roberts et al. [8–10] introduced several parameters and indications for a damage control in truncal injuries, including hypothermia, acidosis, and clinical and laboratory coagulopathy (< 34 °C, pH < 7.2, PT and PTT > 1.5 times normal, and the absence of visible blood clots during operation); cellular shock defined as an oxygen consumption index < 100 mL/min/m^2, lactate > 5 mmol/L, pH < 7.2, base deficit > 15 mmol/L, and core temperature < 34 °C. This surgical strategy has been applied not only in general surgery but also it has been incorporated in the management of musculoskeletal injuries [8–10].

This approach appears to be relevant and the use of parameters from different pathogenetic pathways allows for more precise prediction of complications. Likewise, our group has recently found that the use of elevated lactate levels alone is OK to predict early death from uncontrollable haemorrhage, while the addition of coagulopathy, chest trauma relevant changes and soft tissue injuries provides a prediction for both, early and late complications, such as MOF and sepsis [17].

Spine

In spinal trauma [18], a two-staged approach allows the planning of definitive surgery when an experienced spine surgeon is available. Halo fixation is an important tool in the management of spinal disorders or cervical injuries [19]. However, advances in the surgical internal fixation of the C-spine have decreased its application in the last decades [19]. Our expert survey revealed that halo fixation is not the "gold standard" in damage control of unstable C-spine injuries. Initial immobilization is mainly performed by the application of hard cervical collars. Moreover, polytrauma patients may have absolute contraindications for halo fixation, especially the presence of intracranial bleeding and cranial fractures, need for a craniotomy, severe soft tissue injuries in the head, and severe chest trauma with pulmonary contusion may be associated with higher complication rates [19].

Thoracic and lumbar fractures are common injuries and may be associated with both monotrauma and polytrauma. Percutaneous techniques for dorsal spine instrumentation appear to be a possible approach well suited for DCO [20]. An immediate or early posterior fracture reduction and instrumentation followed by elective secondary reconstruction/fusion of the anterior column may be a possible strategy in spinal trauma. Percutaneous techniques are known to reduce soft tissue injury [21], intra-operative blood loss [22], and decrease the duration of surgery [22]. All these factors minimize the degree of the secondary hit after polytrauma. Moreover, a stable spine allows early mobilization and adequate nursing (e.g., upright position in the presence of brain injury), reduces stress levels due to less pain and instability [18]. Early fixation is known to reduce rates of pneumonia and hospital stay [23]. However, the limitations of percutaneous fixation need to be considered. The presence of severe spinal dislocations with/without neurologic impairments requires decompression and spinal fusion. Regardless of the advantages of percutaneous instrumentation, contraindications need to be considered to improve patient outcomes.

Pelvis

Unstable pelvic ring injuries may present as a life-threatening condition in isolated and polytrauma patients. Therefore, several damage control strategies have been adopted over the years. Our survey has shown that the external fixation of the unstable pelvis is a "gold standard". Anterior external fixation through the iliac crest or supra-acetabular canal provides adequate temporary pelvic stability in most AO/OTA C-type injury patterns [24]. Biomechanically unstable posterior pelvic ring disruptions, such as vertical shear injuries, may require stabilization with a C-clamp [25]. Comminuted injuries need to be considered to avoid perforation of the iliac wing. In less severe posterior pelvic fractures, percutaneous SI screw placement is advocated, also in the emergency setting [26], and provides adequate stability until definitive stabilization and fixation can be obtained.

Extraperitoneal pelvic packing has been rated as beneficial and a standardized damage control procedure by the panellists in our survey. Pelvic packing is used to control haemorrhage in patients with pelvic-related haemodynamic instability [24]. It can reduce the need for transfusion and angioembolization [27]. Prior fixation of the pelvis is required to prevent further displacement [28]. REBOA is

another adjuvant technique that has gained more interest in the literature over the last decade. REBOA represents an alternative to open aortic cross-clamping and allows temporary occlusion of the aorta until definitive haemostasis has been achieved [29]. Clear indications and contraindications for REBOA are still under debate. Its broad use cannot be advocated yet [30].

Extremities

In long bone fractures and extremity injuries, external fixation is widely accepted. The expert panel agreed that temporary external stabilization is a reliable damage control procedure. As mentioned above, in musculoskeletal trauma, local factors (e.g., bone and soft tissue defects, contamination, etc.) are also of importance. Neugebauer et al. summarized that definitive primary treatment can only be considered if the expected duration of surgery is not too long, an experienced surgeon is present and the right implants are already in the hospital [31]. Numerous investigations have demonstrated that patients with abnormal physiological status and/or with concomitant truncal or brain injuries benefit from DCO [32]. On the other hand, damage control strategies may be harmful in physiologically stable patients [33]. Modern resuscitation strategies are mainly guided by restricted volume replacement and ROTEM/TEG controlled blood component transfusion therapy [34]. Therefore, a modified description of the borderline polytrauma patient has recently been described [35].

Traction is not considered a "gold standard" for temporary long bone stabilization. However, this surgical technique can be used as a salvage procedure if external fixation is not applicable.

Soft tissues

In the presence of severe soft tissue injury, such as Morell-Lavallée lesions, grossly contaminated wounds, or large soft tissue defects, NPWT has been rated as a reliable technique by the panellists. NPWT allows temporary closure, development of granulation tissue and reduces the need for free tissue transfer or rotational muscular flap coverage [36]. Moreover, studies indicate that NPWT also decreases tissue oedema and increases tissue perfusion [37]. In mangled extremities, primary amputation should be considered in life-threatening situations (e.g., uncontrollable haemorrhage or limb ischemia due to vascular injury). According to Class et al., the limb salvage rate with an ischemic time of less than 6 h was 87%; however, if the ischemic time exceeded 6 h, the salvage rate decreased to 61% [38]. Bosse et al. pointed out that peripheral nerve deficits are not sensitive in predicting for failure after limb salvage procedures [39] Numerous scoring systems for decision-making have been mentioned in the literature. The current literature suggest that amputation scores are limited in use and do not predict functional outcome [40].

The existing literature on the context of DCO mainly focuses on fixation of long bone fractures or major injuries, and randomized control trials are lacking [41]. With this systematic review of the literature and expert survey, we aimed to increase the evidence as well as to standardize surgical decision-making in DCO. According to previous large studies, the estimated number of patients that required damage control interventions was approximately 15% [42]. However, large databases indicate an apparent overutilization of the damage control strategy (up to 40%) [43] in current trauma practice. We believe this is in part due to the use of the term, even in patients with isolated injuries, where the indication for staged surgical fixation is chosen due to soft tissue injuries or other accompanying factors as reviewed above. This issue was discussed during the in-person meetings (3/2019 and 9/2019), and it was believed that a new term is required to differentiate between these isolated musculoskeletal injuries from those with physiology-related indications for staged procedures. The group coined the term "Musculo-Skeletal Temporary Surgery" ("MuST Surgery") to describe abbreviated early surgical interventions to account for local injury conditions. This differentiation would clarify why a staged procedure was performed and would facilitate the interpretation and comparison of different series across studies.

We feel the indication for damage control procedures in orthopaedic trauma is not only made by physiologic parameters and hemodynamic stability. According to Roberts et al., the indication for damage control surgery is not only made according to patient physiology (57.6%) but also by focusing on injury severity (38.9%), injury pattern and haemodynamic instability (14.3%) [8–10]. This might be the reason for discrepancies between the above-mentioned studies focusing on indications and real existing damage control interventions. Future studies may be required to specify those patients where DCO provides beneficial effects on survival and outcome. To distinguish between DCO as defined by physiologic derangements and abbreviated interventions for a primary treatment of local injury patterns, we suggest using the term "MuST Surgery" in patients with severe but isolated musculoskeletal trauma. Criteria for "MuST Surgery" might be large bone defects, severe contamination, vascular injuries or ischemia, and complex articular fractures in the absence of a physiologically relevant trauma load.

We feel that these patients MUST have access to operating roome for definitive care of both, their fracture and the associated lesion (vascular, soft tissue or others). We hope that the differentiation between DCO and "MuST Surgery" may help clarify the indications in current trauma practice.

Conclusion

This systematic review and survey have summarized indications and interventions in DCO in unstable polytraumatized patients and "MuST Surgery" in patients with isolated musculoskeletal injuries and pointed out differences in treatment between the above-mentioned indications.

Moreover, the evaluation of the expert opinion revealed current standards in technical procedures and interventions in damage control surgery in patients with musculoskeletal injuries, including the fact that definitive surgery is beneficial whenever possible. Due to the lack of randomized controlled studies and high level of evidence, this publication may provide a practical list to guide clinical practice.

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Compliance with ethical standards

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