Clinical Case Report

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Damage control orthopedics applied in an 8-year-old child with life-threatening multiple injuries

A CARE-compliant case report

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Abstract

Rationale: Damage control is a staged surgical approach to manage polytraumatized patients. The damage control approach comprises three steps. First, bleeding is controlled and fractures are stabilized temporarily; second, vital parameters are stabilized and the child is rewarmed in the intensive care unit; and third, the child is reoperated for definitive repair of injuries. We aimed to describe the feasibility of the damage control orthopedic approach in a child.

Patient concerns: An 8-year-old girl fell from the balcony of the 5th floor onto concrete pavement and was admitted to our accident and emergency ward in a stable cardiorespiratory state, but with gross deformity of the lower limbs, left thigh, and forearm.

Diagnoses: The child had sustained multiple injuries with severe bilateral lung contusion, pneumothorax, fracture of first rib, liver laceration, stable spine fractures, transforaminal fracture of sacrum, pelvic ring fracture, displaced baso-cervical femoral neck fracture, displaced bilateral multifragmental growth plate fractures of both tibiae, fractures of both fibulae, displaced fracture of left forearm, and displaced supracondylar fracture of the humerus.

Intervention: In the initial operation, we performed closed reduction and K-wire fixation of the right tibia, closed reduction and external fixation of the left tibia, open reduction and screw osteosynthesis of the femoral neck fracture, closed reduction and K-wire fixation of the radius, and closed reduction of the supracondylar fracture. Subsequently, we transferred the girl to the pediatric intensive care unit for hemodynamic stabilization, respiratory therapy, rewarming, and treatment of crush syndrome. In a third step, 10 days after the injury, we managed the supracondylar fracture of the humerus by closed reduction and K-wire fixation.

Outcomes: Growth arrest of the left distal tibial growth plate and osteonecrosis of the femoral head and neck, slipped capital femoris epiphysis (SCFE), and coxa vara of the right femur led to balanced leg length inequality 2 years after the injury. The lesion of the left sciatic nerve improved over time and the girl walked without walking aids and took part in school sports but avoided jumping exercises.

Lessons: We emphasize the importance of damage control principles when managing polytraumatized children.

Abbreviations: A & E = accident and emergency, AIS = anatomic injury score, aPTT = activated partial thromboplastin time, ARDS = acute respiratory distress syndrome, ATLS = advanced trauma life support, CCD = caput-collum-diaphyseal, CT = computer tomography, DCO = damage control orthopedics, FAST = focused assessment sonography for trauma, GCS = glasgow coma scale, ISS = injury severity score, LDH = lactate dehydrogenase, PICU = pediatric intensive care unit, PT = prothrombin time, ROTEM = rotational thromboelastometry, SCFE = slipped capital femoris epiphysis.

Keywords: Adult respiratory distress syndrome, Case report, child, Damage control orthopedics, Fracture management, Polytrauma, Rhabdomyolysis

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1. Introduction

The term "damage control" describes the staged surgical approach to manage polytraumatized patients who suffer from severe trauma.[1] The underlying principle is to stabilize only those fractures that influence the initial clinical course of the patient and that hinder subsequent resuscitation and nursing at the pediatric intensive care unit (PICU) if not stabilized immediately. Bleeding injuries causing significant blood loss and injuries with a risk of infection should be managed first. In the second step, the critically ill child undergoes resuscitation at PICU. The third step entails definitive repair and reconstruction of injuries. This last step is postponed until the hemodynamic situation and inflammatory response reaction to trauma has improved. The term "damage control" itself was originally used in the United States Navy and was defined as "the capacity of a ship to absorb damage and maintain mission integrity".[1] It was first established and applied in adult trauma centers, and most recommendations come from the adult trauma background.[2,3]

However, pediatric and orthopedic surgeons should be aware of the principles of damage control surgery and utilize it when necessary. Surgeons must recognize the so-called "triangle of death."[4] It is a vicious cycle of acidosis, hypothermia, and coagulopathy that interrelate, eventually become irreversible, and lead to death.[5]

Damage control surgery and damage control orthopedics comprise three stages. The aim of the first stage of treatment is to control bleeding, to reduce contamination, and to achieve a temporary fixation of fractures. Operating time should be kept as short as possible, preferably <1 h to 2 h. The second stage focuses on stabilization of vital parameters in the PICU and involves resuscitation of the child with rewarming, transfusion of blood and blood products, and hemodynamic support. Once the patient's condition has improved, the third and final stage is to reoperate for definitive repair of injuries and definitive fixation of fractures.[6] Our case report aims to demonstrate the feasibility and outcome of a damage control orthopedic approach applied in the management of a child suffering from life-threatening multiple extremity and thoracoabdominal injuries. Written informed consent to publish this case report was obtained from the mother of the child.

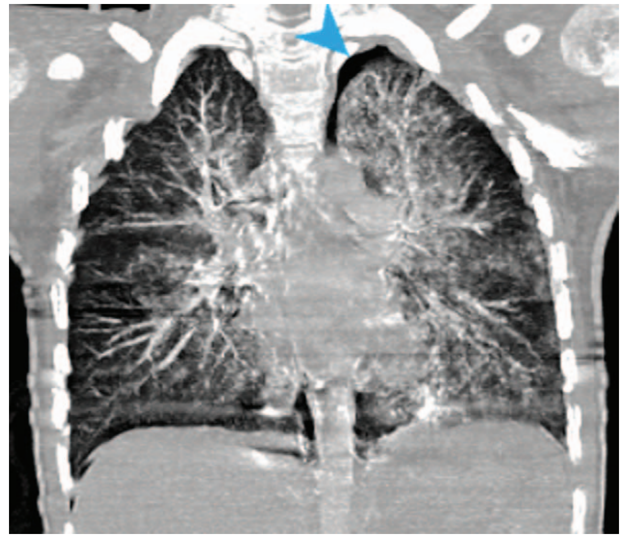

Figure 1. Trauma CT scan showing bilateral lung contusion and pneumothorax on the left side (arrow).

2. Case presentation

We present the case of a polytraumatized 8-year-old girl (body weight: 25 kg) who jumped from the balcony on the 5th floor, landing on the concrete pavement. Before transporting the child to the hospital, the emergency physician administered 500 mL of Ringer acetate solution at the site of the incident. The girl was brought to our accident and emergency (A&E) room within 45 min after the injury in a stable cardiorespiratory state with a SpO_2 of 94%, heart rate of 130 bpm (normal range for age: 75–119 bpm)[7]), blood pressure of 106/21 mmHg (normal range for age: 97–115/57–76 mmHg)[7]), and a respiratory rate of 28/min (normal range for age: 18–25/ min)[7]). On presentation she was obtunded with a GCS of 14 and showed hypothermia with a core body temperature of 36.2°. Initially, the girl was evaluated using the Advanced Trauma Life Support (ATLS 9th edition) guidelines.[8] We noted class III (moderate) hypovolemic shock according to ATLS classification.[9] Clinical examination revealed gross deformity of both distal lower limbs, compression pain of the thorax and pelvic ring, and painful swelling of the left forearm. There was minimal bleeding from a skin wound on the head as well as from a perineal wound measuring 5 cm in length.

Laboratory tests revealed acidosis of pH 7.31, base excess of −6.3, serum lactate of 7.0, hemoglobin of 118 g/L, and INR of 1.56 (Ref: 0.9–1.1). A Focused Assessment Sonography for Trauma (FAST) scan showed no free intraperitoneal fluid.[10]

We immediately performed a multiple-trauma CT scan of the head, thorax, abdomen, and pelvis.

The child had sustained severe bilateral lung contusion, pneumothorax of the left side, and fracture of the first rib (Fig. 1). A small laceration the right liver lobe was noted, but there was no free intraperitoneal fluid and pleural or pericardial effusion. The girl had suffered serial stable spine fractures of Th2, Th5-L2, and L4-L5 and minimally displaced transforaminal fracture of the sacrum. At clinical examination, we noted left sciatic nerve palsy. In addition, stable pelvic ring fracture and displaced baso-cervical femoral neck fracture Delbet type III were present[11] (Fig. 2).

Plain X-rays of the lower limbs revealed displaced bilateral multifragmental growth plate injuries of both tibiae and displaced fractures of both distal fibulae (Fig. 3). Additionally, the child had suffered a displaced fracture of her left distal forearm. Moreover, she had sustained a displaced supracondylar fracture of the left humerus. Her Anatomic Injury Severity (AIS; version 2015) score was 47, and her Injury Severity Score (ISS) amounted to 41.[12]

The coagulation profile obtained preoperatively revealed a prothrombin time (PT) of 53% (normal value: >80%), INR of 1.56 (normal range: 0.9–1.1), activated partial thromboplastin time (aPPT) of 43 s (normal range: 20–45 s), and fibrinogen of 1.80 g/L (normal range: 1.7–4.1 g/L). LDH at admission amounted to 1563 U/L (normal range <307 U/L).

Considering the clinical impact of severe bilateral lung contusions, multiple injuries, danger of rhabdomyolysis, and grade III hypovolemic shock,[9] we opted for the DCO approach

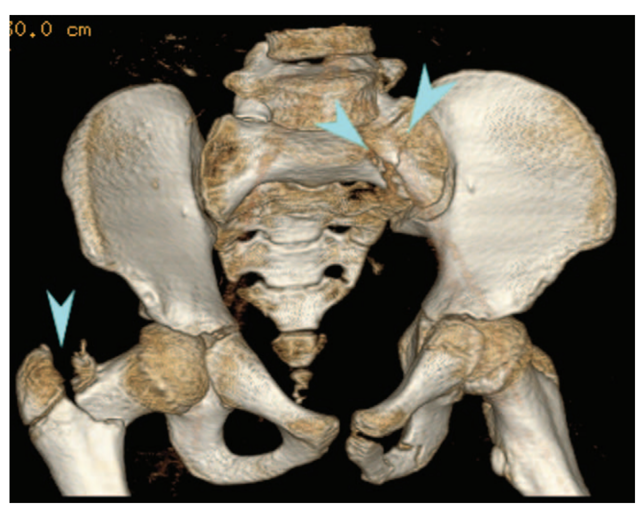

Figure 2. Reconstructed 3D-image of trauma CT-scan. The girl suffered a displaced baso-cervical femoral neck fracture (Delbet type III; marked by arrowhead) and a stable, transforaminal fracture of the sacrum with fracture of the pelvic ring (marked by 2 arrowheads).

Figure 3. The a.p.(A) and lateral (B) plain X-rays of the left lower leg and right lower leg (C, D) show complex epiphyseal injuries of both distal tibiae and fibulae. Tibial fractures ran across both distal tibial growth plates thus representing complex Salter Harris type IV injuries. Fracture displacement was more severe on the left side (A, B).

for the initial surgical management of the injuries. We chose a time-saving first operation to minimize the impact of surgical trauma.

For the first stage of damage control orthopedics, we transferred the child to the operating theatre immediately after radiologic examination to achieve fast fixation of instable fractures. The injuries of both tibiae were managed by closed reduction and K-wire fixation of the right tibia and external fixator for the left tibia (Fig. 4). Furthermore, we conducted open reduction and screw osteosynthesis of the femoral neck fracture (Fig. 5) and closed reduction and K-wire fixation of the displaced fracture of the left distal radius. We also undertook closed reduction of the left supracondylar fracture of the humerus and immobilized the left arm in an upper-arm cast. We closed the wounds on the head and perineum using absorbable sutures. Pre- and intraoperative blood loss amounted to approximately 150 mL. The coagulation profile obtained intraoperatively revealed a PT of 34% (normal value: >80%), INR of 2.17 (normal range: 0.9–1.1), aPPT of 43 s (normal range: 20–45 s), and fibrinogen of 1.80 g/L (normal range: 1.7–4.1 g/L). Intraoperative thromboelastometry (ROTEM) analysis (Fig. 6)[13] showed prolonged clotting formation time (CFT) in EXTEM and INTEM as a result of reduced hemostatic capacity, as well as a zero line in FIBTEM as a result of massively reduced fibrinogen levels. We selectively treated the hemostatic disorder by administration of fibrinogen as a therapeutic agent.

In consultation with pediatric orthopedic surgeons, we decided to manage the spine fractures nonoperatively. Overall, the surgical procedures lasted less than 2 h.

Postoperatively, the child was monitored in the PICU, and her vital functions were initially stabilized. Four days after the injury, lung function deteriorated rapidly, and the child developed severe ARDS (PaO_2/FiO_2 ratio: 48) (Fig. 7). We treated the child with conventional ventilation for 10 days with maximum FiO_2 of 100% and applied ventilation pressures up to 34/14 mmHg. To treat hemorrhagic shock, we administered a total of 6 units of packed red blood cells, which added up to 85% of the child's total blood volume. This intervention stabilized the hemoglobin levels.

In the postoperative course, the child developed massive rhabdomyolysis (maximum level of creatine kinase on day 5: 21 765 U/L).[14] Once the child's condition had improved, we conducted the third stage of DCO on day 10. We opted for day 10 because the ventilation parameters had improved by that time so

Figure 4. Closed reduction and minimally invasive stabilization of both distal tibial injuries. We applied an external fixator on the left side (A) to stabilize the complex injury to the tibial growth plate and inserted K-wires percutaneously on the right side (B).

that we expected extubation within the two subsequent days. At the same time, we considered that ongoing callus maturation at the site of supracondylar fracture of the humerus might preclude successful closed reduction if we had waited for more than 2 weeks after the injury in this 8-year-old girl. The child was reoperated to definitively fix the supracondylar fracture of the humerus. We undertook closed reduction and K-wire osteosynthesis. Because X-ray images of the lower legs, right femur, and pelvis showed adequate alignment of fractures, there was no need to undertake revision operations or additional orthopedic interventions.

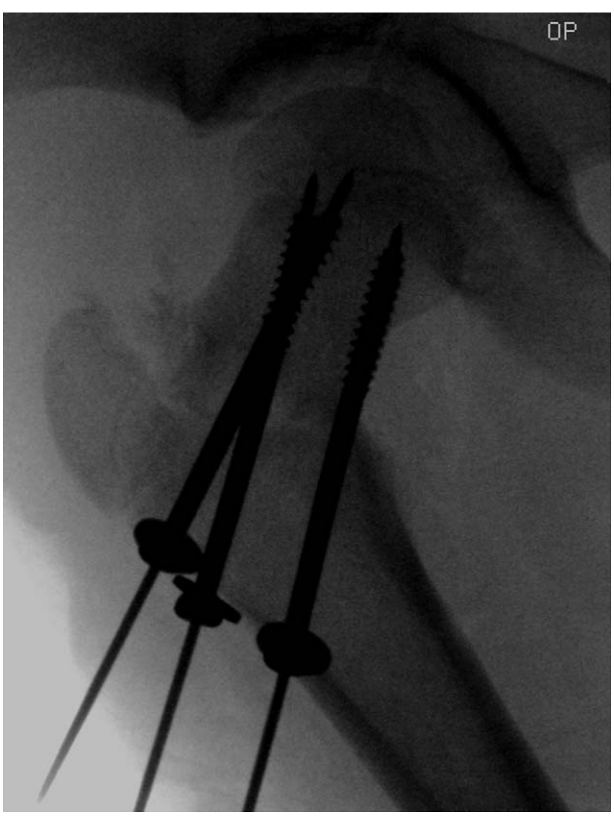

Figure 5. Femoral neck fracture was treated by gentle open reduction and screw osteosynthesis.

For the further treatment and mobilization, the girl was transferred to the pediatric surgical ward. On day 30, we removed the external fixator and K-wires.

For psychological workup and treatment, we subsequently transferred the girl to our pediatric psychiatric ward where she was hospitalized until day 74 for further treatment. Outpatient follow-up at 1 year after the injury showed improvement of the lesion of the left sciatic nerve with reduced hyposensitivity and weakness of the foot extensor muscles. Growth arrest of the left distal tibial growth plate caused shortening of the left lower leg (shortening of 1.5 cm at the 2-year follow-up). However, coxa vara of the right femur (CCD angle right femur: 123.0°, left femur 140.3°; difference of CCD angle: −17.3°) with shortening of the femoral neck of 14 mm, caused by avascular necrosis (AVN) of the femoral neck (Ratliff type III)[15] and slipped capital femoral epiphysis (SCFE)[16] led to a shortening of the right femur by 2 cm (Fig. 8). Therefore, the girl currently does not suffer from significant leg length inequality. With the help of physiotherapy and by wearing a peroneal splint and push-up ankle bandage, her mobility improved significantly over time. At follow-up after 2 years, she walked without aids with minimally limping gait. The girl took part in school sports but avoided jumping exercises. She receives ongoing psychological support. An MRI scan of the right hip obtained 25 months after the injury showed AVN of the femoral head and neck region with moderate flattening of the femoral head epiphysis, cyst formations within the femoral head epiphysis (Fig. 9A), and a minimal amount of fluid underneath the cartilage of the femoral head (Fig. 9B). We noted minimal SCFE and signs of premature closure of the femoral head growth plate and partial fusion of the growth plate of the greater trochanter accompanied by subchondral fluid formation and chondrolysis (Fig. 9C).

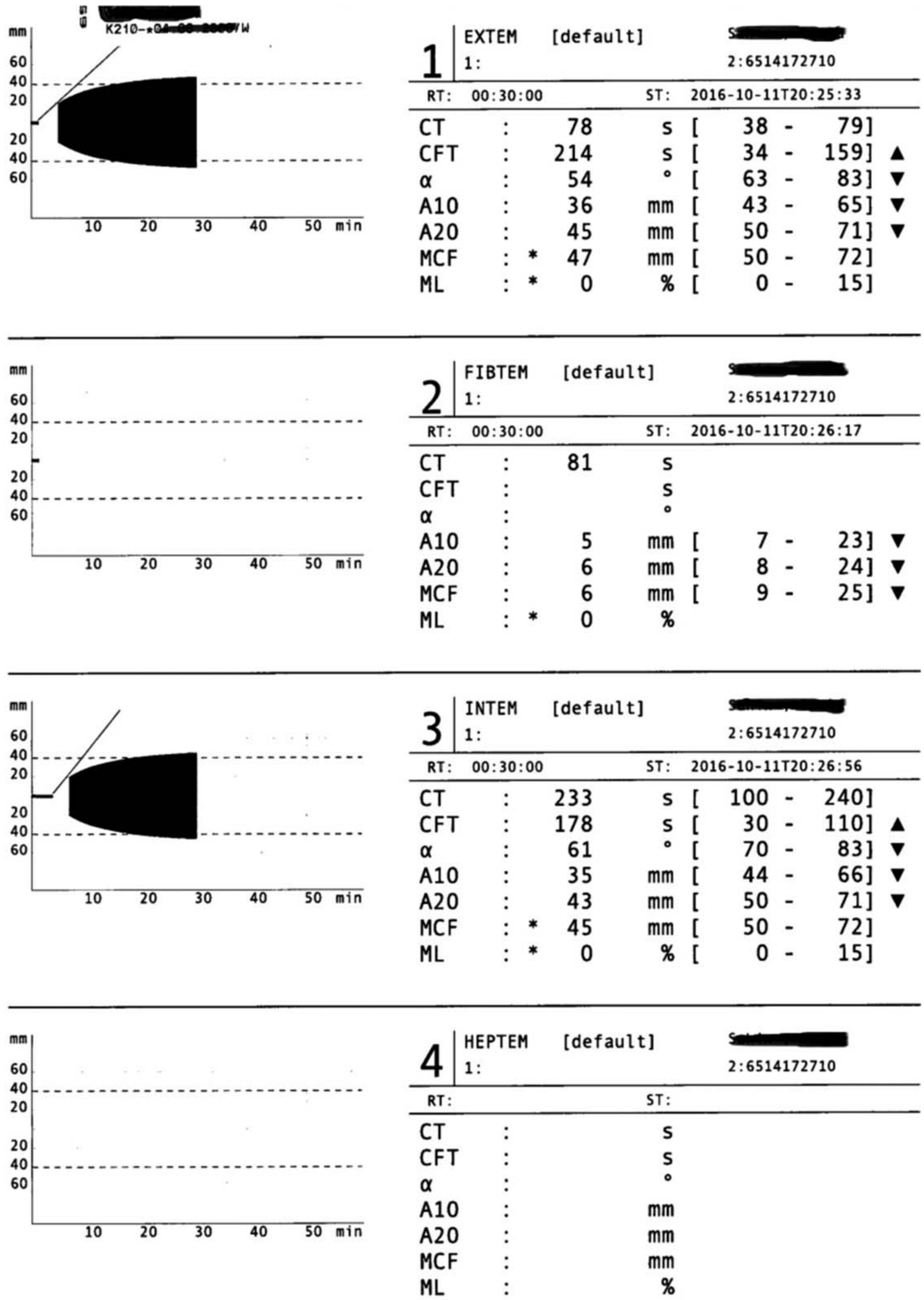

Figure 6. Intraoperative ROTEM analysis.

3. Discussion

This paper describes the treatment of a severely polytraumatized 8-year-old girl. We aimed to confirm the feasibility of DCO in polytraumatized children with multiple-trauma suffering from multiple fractures and soft tissue injuries. Surgeons who manage multiple trauma in children often lack experience in dealing with high-impact trauma. The critical step is to recognize the life-threatening situation of the child and to decide early in the initial phase of treatment when to apply the damage control strategy.

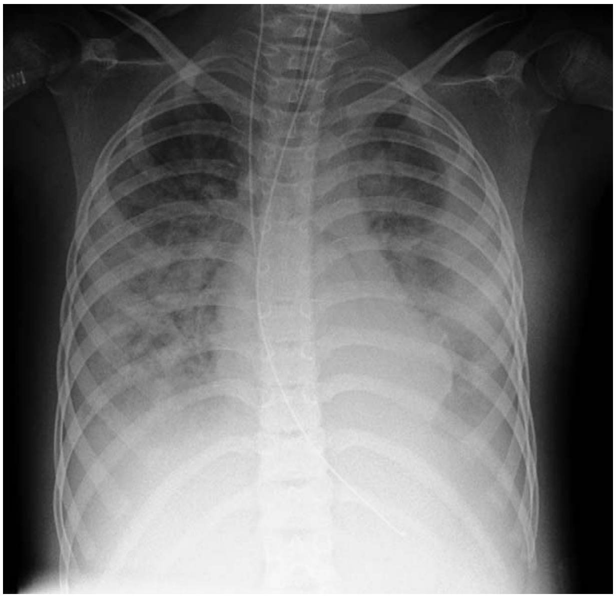

Figure 7. On day 4 after the injury, the child developed severe ARDS.

Recommendations for the indication of damage control derive from practice guidelines for adult trauma patients.[2,3,5] In adults, the lethal triad includes a preoperative core body temperature of <34°C, arterial pH <7.2, INR/PT >1.5 times normal, clinically observed coagulopathy, and blood loss of more than half the patient's blood volume.[1,4]

Nowadays, injured adults presenting in a stable condition are managed with early total stabilization of fractures, whereas traumatized adults presenting in an unstable condition are managed by DCO. Pape et al proposed an algorithm to differentiate between traumatized adults in a stable condition and those in an unstable condition requiring DCO management.[17] This approach for categorization of traumatized patients distinguishes 4 groups of patients and is based on shock severity, coagulation profile, temperature of the patient, and soft tissue injuries.[17] To the best of our knowledge, no similar algorithm has been proposed for severely injured children.

Although the child described in this report showed signs of beginning hypothermia with a body core temperature of 36.2°C, mild acidosis with a pH of 7.31, base excess of −6.3, and prolonged INR, these parameters did not meet the criteria of the lethal triad.[1,4] However, due to the high impact of the trauma and the multiple fractures and soft tissue injuries, we decided to apply the principles of damage control orthopedics. The pathophysiological background of damage control surgery is based on the systemic impact of polytrauma and the additional trauma caused by the operative intervention. This second hit theory implies that the stress caused by the surgery on top of the initial trauma bears the risk of rapid cardiopulmonary deterioration if the combination of the first and second hits is severe. Systemic inflammation, associated microvascular damage, interstitial edema, coagulopathy, and multiorgan failure may result.[18,19]

Pape et al reviewed polytraumatized patients who suffered femoral shaft fracture and compared the outcome of the patients who underwent early total care to patients who were treated by the principles of damage control.[20] They found a significantly

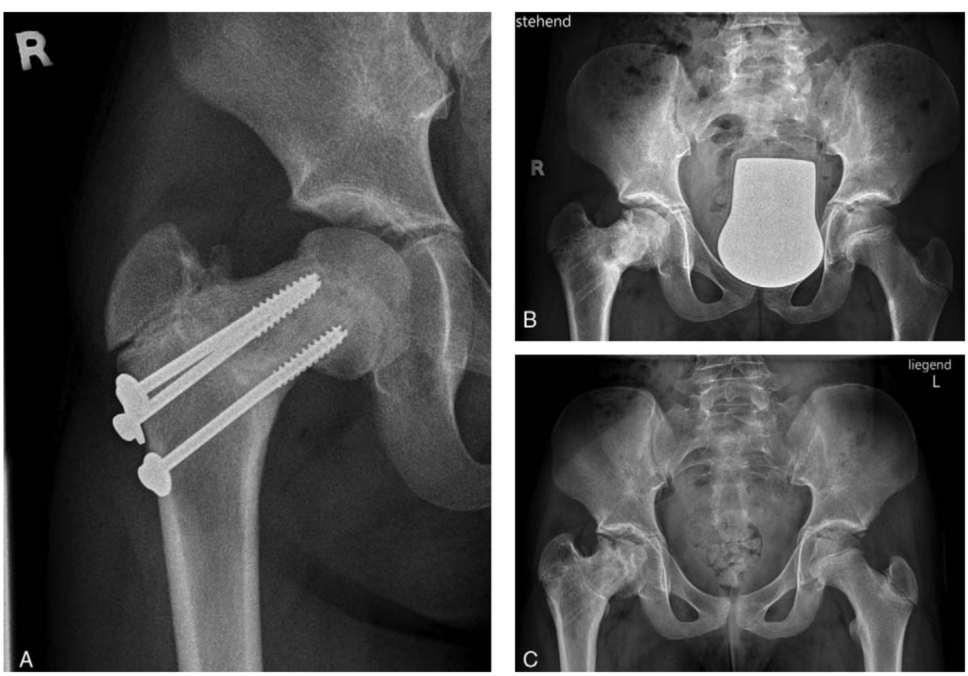

Figure 8. (A) Plain a.p. radiograph of the right hip obtained 6 months after the injury showing consolidation of the femoral neck fracture and coxa vara. (B) Plain X-ray obtained 10 months after the injury demonstrates irregular bone density of the femoral head and neck regions together with shortening of the femoral neck. We also noted an irregular shape of the femoral neck epiphysis and mild SCFE, (C) At follow-up 22 months after the injury, we noted moderate coxa vara (CCD angle of the right femur: 123.0°; CCD angle of left femur: 140.3°), AVN Ratliff type III with shortening of the right femoral metaphysis by 14 mm, mild SCFE, premature closure of the femoral neck physis, and partial closure of the physis of the greater trochanter. (D) Plain a.p. radiograph of the left ankle demonstrating premature closure of the distal tibial growth plate.

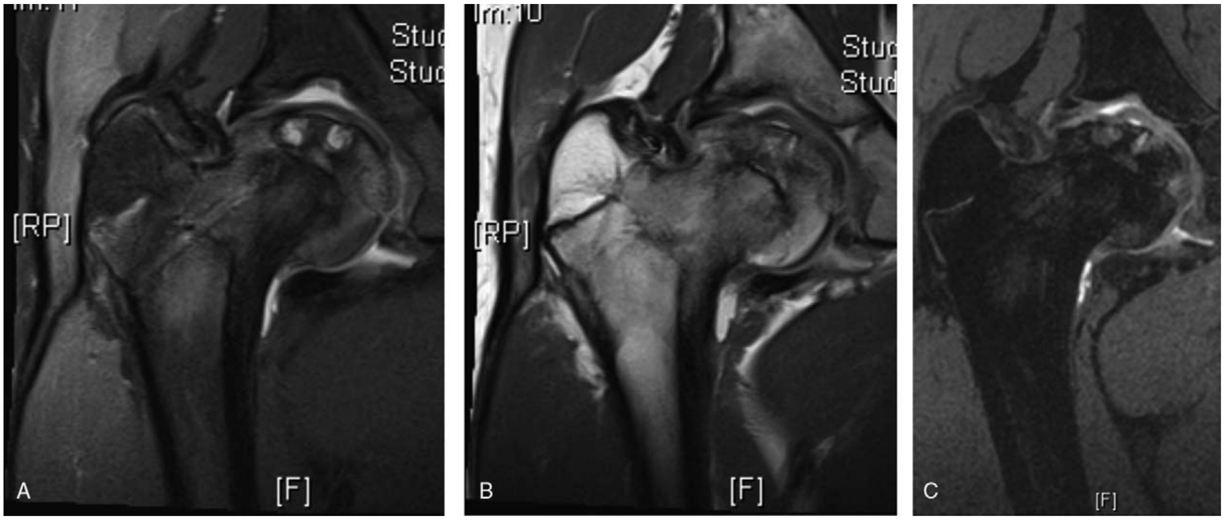

Figure 9. (A) MRI scan of right hip obtained 25 months after Delbet type III femoral neck fracture. There is minimal hip joint effusion, and two cysts are visible within the femoral head epiphysis. Note the irregular greyish color of the femoral head and neck region. The medial part of the physes of the greater trochanteric and the femoral head appear fused. Intravenous contrast agent was refused by the child and her family. (B) MRI scan of right hip shows irregular color of the cancellous within the femoral head and neck regions. Note premature fusion of the medial part of the physes of the greater trochanter and the femoral head. There is subchondral fluid in the weight-bearing region of the capital femoral epiphysis. (C) MRI scan of the right hip demonstrates subchondral fluid and chondrolysis at the cranial aspect of the femoral head.

decreased incidence of multiorgan failure in the group of damage control-based treatment, regardless of the type of fracture fixation.[20] Another study group compared the techniques to fix femoral fractures and concluded that patients who were treated with external fixation had less blood loss and a shorter operative time compared to patients treated with intramedullary nailing.[21] In this child, we opted for rapid external fixation of the left tibia fracture to save operating time. In the further course, it was not necessary to change the technique, and after consolidation we removed the external fixator on day 30 after the injury.

The girl suffered AVN Ratliff type III of the right femoral neck.[15] AVN of the femoral head and neck region after femoral neck fractures in children is a devastating but frequent complication.[15] This complication occurs more frequently in displaced femoral neck fractures Delbet type II than in Delbet type III fractures.[11] Despite vessel-protecting open reduction and cautious traction, AVN occurs frequently after displaced femoral neck fractures in children due to impaired arterial and/or venous blood perfusion in the region of the femoral head and neck.[15,22] AVN of the femoral head is considered an inevitable complication after femoral neck fractures in children.[22]

We noted first signs of AVN in a radiograph obtained 10 months after the injury. In accordance with our finding, Spence et al described that the median time to manifestation of AVN is 7.8 months (range: 2.7–31.4 months).[23] AVN is observed more frequently after displaced than nondisplaced femoral neck fractures in children.[23] We noted osteonecrosis after surgical reduction and screw fixation of a displaced Delbet type III fracture. Riley et al and Moon et al reported a rate of 8%–18% of acute osteonecrosis after Delbet type III fractures.[24,25]

We used cannulated screws for internal fixation of the basocervical femoral neck fracture to ensure fast fixation during the first operation of damage control orthopedics. To reduce the risk of progressive coxa vara in the postoperative period when using screw fixation, Eberl et al recommended insertion of interlocking screws to fix femoral neck fractures in children.[26] However, in this child, the femoral neck shaft angle increased from 119° to 123° in the affected proximal femur in the postoperative period of time. Broadman et al suggested to use the term "coxa vara" when the neck-shaft angle decreased to <120°.[27] Coxa vara is the second most common complication after femoral neck fractures in children.[27] Yeranosian et al observed coxa vara in 18% of children suffering from femoral neck fractures.[28]

We noted premature closure of the proximal femoral physis and SCFE, in addition to osteonecrosis of the femoral metaphysis. Premature closure of the proximal femoral physis after femoral neck fractures has been reported to occur in 21.8% of affected children.[28] A plain radiograph of the hips obtained in this girl 22 months after the injury demonstrated SCFE and premature physeal closure of the proximal femoral physis.

Because this child suffered from severe bilateral lung contusion (Fig. 1), it was essential to perform a time-saving first operation to minimize additional injury to the lungs. Patients with preexisting lung injury, as in our case, are at an increased risk of developing complications after surgical or orthopedic interventions.[6] Although the operating time of the first surgery was kept as short as possible, the child developed severe ARDS and rhabdomyolysis[14] during the second stage of damage control in the PICU.

Another important factor in avoiding the vicious cycle of the lethal triad is to control hemorrhage, since this poses the most significant threat to polytraumatized patients. Therefore, early administration of blood products and reduction and preliminary stabilization of grossly displaced fractures should be considered, and administration of crystalloid fluids should be kept at a minimum. A randomized trial in adults demonstrated that blood products given in a 1:1:1 ratio (1 unit of plasma: 1 unit of platelets: 1 unit of packed red blood cells) optimally controls hemostasis and lowers mortality.[29]

This child received a total of 6 units of packed red blood cells and could be kept hemodynamically stable. Furthermore, we selectively treated coagulopathy by intraoperative administration of fibrinogen after performing ROTEM analysis.[13] ROTEM analysis provides detailed information on the kinetics of hemostasis and the various stages and parameters of the coagulation process.[13] Consequently, the appropriate treatment to restitute coagulation parameters can be selected thus reducing blood loss.

Another critical decision point during damage control orthopedics is the timing of the second intervention. Immune reactions to trauma[30] peak on day 2 to day 4 after the injury and therefore do not provide the ideal condition for reoperation. Patients who underwent definitive surgery on days 2 to 4 after the injury developed a significantly increased inflammatory response compared to those who were operated only after 5–8 days after the injury.[20] We waited until day 10 when the child's condition was clinically stable and her respiratory situation had improved.

In children, dislocation of joints should be reduced as soon as possible after the injury. Because the time to fracture union in children is correlated with age at injury, the time interval for successful closed reduction of fractures in younger children is shorter than in older children. Thus, waiting for more than 1 week with definitive reduction and stabilization of growth plate injuries or for more than 2 weeks in the case of long-bone shaft fractures will increase the rate of open reductions and carries the risk of a higher rate of poor outcomes.

There is a paucity of data on the outcomes and complications of DCO in severely traumatized children. To the best of our knowledge, there exists no evidence whether applying damage control principles developed for adults can be applied safely in growing children.

The main limitation of this case report is that we described the successful application of the principles of DCO in only one child, and therefore our findings cannot be generalized. Further case series are required to confirm our result.

In conclusion, we emphasize that managing polytrauma in children who are hypothermic, acidotic, and coagulopathic under the premise of the principles of DCO may improve the outcome. Further studies are required to confirm this hypothesis. Emergency surgery represents additional trauma according to the principles of the second-hit theory. Therefore, the initial orthopedic procedures should be kept to a minimum, and operation times should be kept as short as possible to prevent further systemic insult that may lead to deterioration and even death in children suffering from multiple orthopedic or soft tissue injuries.

Author contributions

VAP, SS, DT, SH-C, and JM contributed substantially to the design and preparation of the case report. VAP, SS, and JM searched and analyzed the literature. VAP, SS, and JM drafted the manuscript. DT and SH-C critically reviewed the manuscript. All authors read and approved the final version of the manuscript.

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