

# Evolving Frontiers in Severe Polytrauma Management – Refining the Essential Principles

KAM Chak Wah<sup>1</sup>, CHOI Wai Man<sup>2</sup>, WONG Janet Yuen Ha<sup>3</sup>, Vincent Lai<sup>4</sup>, WONG Kit Shing John<sup>1</sup>

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<sup>1</sup> Department of Accident & Emergency, Tuen Mun Hospital, Hong Kong

<sup>2</sup> Department of Social Work & Public Admin, The University of Hong Kong, Hong Kong

<sup>3</sup> School of Nursing, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong

<sup>4</sup> Department of Diagnostic Radiology, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong



## Abstract

This editorial aims to refine the severe polytrauma management principles. While keeping ABCDE priorities, the termination of futile resuscitation and the early use of tourniquet to stop exsanguinating limb bleeding are crucial. Difficult-airway-management (DAM) is by a structured 5-level approach. The computerised tomography (CT) scanner is the tunnel to death for hemodynamically unstable patients. Focused Abdominal Sonography for Trauma–Ultrasonography (FAST USG) has replaced diagnostic peritoneal lavage (DPL) and is expanding to USG life support. Direct whole-body multidetector-row computed tomography (MDCT) expedites diagnosis and treatment. Non-operative management is a viable option in rapid responders in shock. Damage control resuscitation comprising of permissive hypotension, hemostatic resuscitation and damage control surgery (DCS) help prevent the lethal triad of trauma. Massive transfusion protocol reduces mortality and decreases the blood requirement. DCS attains rapid correction of the deranged physiology. Mortality reduction in major pelvic disruption requires a multi-disciplinary protocol, the novel pre-peritoneal pelvic packing and the angio-embolization. When operation is the definitive treatment for injury, prevention is best therapy.

**Keywords:** computerised axial tomogram, damage control resuscitation, difficult airway management, peritoneal pelvic packing, prevention, trauma, ultrasonography

## P-D-ABC-DE sequence to replace the Trauma Management ABC Priorities

The conventional management priorities have evolved from ‘ABC’ to include ‘DE’, and subsequently to PD-ABC-DE as indicated in Table 1 (1,2).

Universal precaution has transformed to encompass the appropriate personal protective equipment (PPE) including the additional facial shield besides the regular mask, gown, and gloves since the emergence of new infectious diseases

such as SARS, (3) avian flu, and human swine flu.

Prompt evaluation is important to determine the aggressiveness of treatment. Out-of-hospital traumatic cardiac (OHCA) arrests with unorganized electrocardiogram (ECG), fixed pupils (all at the scene), and cardiopulmonary resuscitation (CPR) greater than 15 min, carry grave prognosis and termination of resuscitation can be followed (4–7). Early biomarkers such as arterial lactate and base deficit (8), soluble CD40L (9), matrix metalloproteinase-9 (10), and Nt-proBNP to indicate the trauma severity and

mortality are under active research and hopefully will throw light on the frontline decision as a point of care test in the future.

The top three rapid killer conditions in trauma are the obstructed airway, deranged ventilation, and hemorrhage which can be external or internal cavity (abdomen, pelvis or thorax). Consequently, the 'ABC' steps precede the 'D' standing for decompression of the intracranium. Though, intracranial bleeding can be lethal but usually not as fast as the former three.

'E' represents the limbs as the extremities. The highly fatal scenario is the exsanguinating limb bleeding, uncontrollable by the direct compression. However, the cautious application of a proximal tourniquet (conventionally was a taboo) can be life-saving (11–14). Survival increases by 92% if applied versus not applied, 80% if applied before shock versus after shock, and 13% if applied in the pre-hospital versus in emergency department (ED) (12). The tourniquet does not cause significant risk to the nerve or limb tissues when the compression pressure and time are restricted (11–13).

### DAM/DIM – from Plans A&B to the explicit and stratified Levels 1 to 5

While the conventional plans A&B for difficult-airway-management (DAM) is confusing for being too non-specific, the modern trend is to explicitly state. The escalation levels of the DAM/DIM choices as in the algorithm of the advanced trauma life support (ATLS) update in 2008 (1) or as in Table 2 (2) showing a practical and stratified approach according to a pre-defined team work

protocol to improve the outcome (15). When difficult airway is anticipated, video-assisted airway management (VAAM) can be the first line choice to shorten the intubation interval in the difficult airway with higher success rate. In case of very severe maxillofacial injuries with inaccessible oral passage, a surgical airway starting with cricothyrotomy will be life-saving (15).

The advantages of VAAM include a higher intubation success in difficult airway (16–18), Morquio syndrome (19), and paediatric airways (20), and an enlarged and close-up visualization of the laryngeal opening, while maximizing the distance between the intubation clinician from the patient's mouth to reduce contact with blood splash during endotracheal intubation (ETI). With a high resolution viewing monitor, the assistants, or supervisors can provide more efficient collaboration. Video-recording of the ETI is feasible for both training and quality assurance (21). Besides, this VAAM is highly valuable for teaching the direct laryngoscopy (22).

The GlideScope, a VAAM-model has been successfully applied in the pre-hospital helicopter transfer services, rendering other back up devices unnecessary (23).

In the absence of the expensive VAAM, the more affordable laryngeal mask airway (LMA) or intubating laryngeal mask (iLM) can also maintain the airway, and provide ventilation as well as an alternative for endotracheal intubation (24).

The VAAM popularity rises with the decreasing cost. Emerging complications include the lingual nerve injury, palatopharyngeal wall, and palato-glossal arch perforation have

**Table 1:** Treatment Priorities in Major Polytrauma

P	Protection with PPE (facial shield + conventional mask, gown & gloves)
D	Decision: To initiate, continue or discontinue trauma resuscitation (such as fatal injuries with decapitation, torso truncation or OHCA)
A	Airway: Maintenance of patent airway with cervical spine control (head & neck immobilization) a new 5-level of DAM & DIM (2)
B	Breathing: Ensure adequate breathing or to provide ventilation
C	Circulation: Check circulation, stop external bleeding, intravenous lines + blood work, identify internal bleeding to control hemorrhage (to prevent lethal trauma triad by DCR & MTP as indicated)
D	Decompression of intra-cranium
E	Extremities and adequate exposure but to prevent hypothermia) : after controlling exsanguinating external limb bleeding, the priorities returns to C & D above

Abbreviations: OHCA = out-of-hospital cardiac arrest, DAM = difficult airway management, DIM = difficult intubation management, DCR = damage control resuscitation, MTP = massive transfusion protocol, PPE = personal protective equipment.

been reported (25–28). Obviously, careful training programmes and cautious visualization procedures must be followed in using new technology to maximize the risk-benefit ratio.

### CT scanner as the tunnel to death for hemodynamically unstable

Imaging for the damaged anatomy is not as pressing as for the identification of the deranged physiology with impending death. CT suite is an adverse venue to monitor or resuscitate a critical ill patient, not to mention the tremendous hazard of the transfer. Bed-side decision in hemodynamically unstable patients is mainly based on clinical evaluation, plain XR and USG to decide the definitive treatment; otherwise, the CT gantry will be the tunnel to death (29).

### FAST USG has superseded DPL and is expanding to USG life support process to sort out the shock and to locate the bleeding

Diagnostic peritoneal lavage (DPL) has become unpopular in the early 2000’s after its wide-spread use since 1970’s owing to its high false positive rate leading to 25% to 36% of non-therapeutic laparotomy (30–31). DPL requires more time and higher technical skills than the bed-side USG. The rising affordability of USG models and improved USG accuracy of good sensitivity (81%–93%) and high specificity (90%–98%) (31–33), and achieving 100% specificity in development world (34), have rendered DPL obsolete. Jansen has engraved the DPL Obituary (born 1965 and died 2005) (35).

The FAST USG has extended from abdominal (fluid collection in Morrison’s pouch, spleno-renal recess, and the pelvic pouch) to include the extra-abdominal scanning to include the pericardial collection as in the Focused Echocardiographic Evaluation in Life Support

(FEEL) (37). In the more sophisticated approach, USG can help identify hemothorax (at the supine lung bases) (38–43), pneumothorax (front chest in the supine position) (38–44), impaired myocardial contractility (40) and IVC diameter, and the respiratory collapsibility (45) to establish the shock aetiology and to locate the bleeding sites. The USG sensitivity and specificity for pneumothorax are respectively 92% to 100% and 91% to 100% (43).

Moreover, hand-held USG used by emergency physician is of comparable accuracy (sensitivity for FAST was 88.9%, specificity was 97.6%, negative predictive value was 99.5%, and positive predictive value was 61.5% as the bed-side abdominal USG by radiologists (46). The high portability and affordability of the former will evidently transform the future clinical practice from the prehospital care, emergency department to the critical care.

TeleUSG (telemedicine USG) can be used in remote or under resourced areas to evaluate injured patient to guide the management and the transfer decision (47–50). Telementorable USG has also been developed (48–50). Tables 3 and 4 respectively summarize the USG evolution and imaging focus in trauma.

### Trauma Imaging – Direct Whole-body MDCT

Despite controversy, there is a trend of favouring direct whole-body MDCT in major polytrauma with stable hemodynamics with CT performed outside the ED Trauma Room instead of a stepwise imaging from plain XR to USG followed by regional CT.

Direct whole-body CT in Wurmb’s study showed a reduction in the diagnostic interval from a median of 70 min to 23 min, and definitive management plan interval from another median of 82 min to 47 min (52). The NNT (number needed to treat or to scan to identify one major injury warranting operation to reduce mortality) was 302 and the NNH was 1777 (number needed

**Table 2:** Five Levels of DAM/DIM

Levels	Devices / Procedures
1	Conventional direct laryngoscopy (DL)
2	Gum elastic bougie (GEB)
3	Video-assisted airway Management (VAAM)
4	LMA or iLM (intubating LMA)
5	Surgical airway – cricothyrotomy (needle for children & open for adults) followed by tracheostomy

to harm to produce one more fatal cancer per 10 mSv of additional radiation dose over regional CT usually around 9.2 mSv). Houshian found 31.4% of missed injuries needed operation (53). Rieger identified MDCT was superior to conventional imaging in terms of the diagnostic accuracy (54).

Huber-Wagner et al., (55) revealed a substantial relative reduction in mortality of 25% by the Trauma and Injury Severity Score (TRISS) and 13% by the Revised Injury Severity Classification (RISC) Score. The number needed to scan (NNT) was 17 based on TRISS and 32 by on RISC. Whole-body CT was a significant independent predictor for survival.

The compliance with the irradiation as low as reasonably achievable (ALARA) principle is essential to minimize cancer risk due to CT scanning though new technology can reduce the radiation dose (56). Further delineation of the risk-benefit balance is indicated (57–59).

*Non-operative management (NOM) is a viable option based on the dynamic response to fluid resuscitation in shock assessment and diagnostic imaging in rapid responder*

A dynamic evaluation of shock assessment has replaced the static model of classification by percentage of blood volume loss. The response model to initial IVF resuscitation is graded into Rapid, Transient, and Non-responders to indicate the status of any on-going bleeding, volume loss, need for transfusion and operation as in Table 5 (1).

Coupled with diagnostic imaging data in the stable cases, sound decision to adopt the non-operative management (NOM) (60) with subsequent monitoring in a critical care unit has been a common trauma practice in the past decade especially in the paediatric group mainly with trauma to the liver and spleen with rapid healing of the injured organs (61,62).

**Table 3:** Evolution of USG Imaging in Trauma Management

1. FAST – originally on the abdomen only
2. eFAST – Extended FAST – beyond the abdomen to include the thorax
3. USG life support – to sort out the type of shock and the etiology
4. TeleUSG – USG as a telemedicine to evaluate trauma in remote or under-resourced areas
5. Bed-side, Portable to Hand-held USG

**Table 4:** USG Imaging Focus in Trauma (51)

1. Abdomen – intra-peritoneal free fluid (IPFF)
2. Pericardial collection – effusion, tamponade
3. Myocardial contractility & wall motion
4. Lungs – pneumothorax & hemothorax
5. IVC – diameter & respiratory collapsibility (hypovolemic/cardiogenic/obstructive shock differentiation)

**Table 5:** Response to Initial IVF Resuscitation in Trauma Shock

Response	Rapid	Transient	Non
Blood loss	10% – 20%	20% – 40%	> 40%
On-going bleeding	Nil	Yes	Heavy/+ possibility of non-hemorrhagic shock causes
Replacement	Sufficient	Insufficient	Difficult - to stop bleed immediately
Need blood	low	high	Very high
Operation need	low	likely	highly



*DCR to combat the Lethal Triad of Trauma*

The recent advanced armamentarium against the triad of trauma fatality (hypothermia, coagulopathy, and acidosis) (63–65) is the damage control resuscitation (DCR) (66–70) encompassing 3 major components as in Table 6.

Restriction of the fluid resuscitation by permissive hypotension (69) till bleeding is arrested can reduce the danger of hydrostatic displacement of the temporary clots in bleeding vessels of internal injuries before the surgical hemostasis.

Suboptimal organ perfusion is allowed to occur for a short duration. The aim is to keep the vital organ perfusion (brain and heart) with a systolic BP of around 80–90 mmHg. Bickel et al., in their landmark study, has shown an absolute mortality reduction of 8% by delayed and small IVF replacement in penetrating torso trauma with shock (71) but could not generalize the conclusion owing to the unusual short pre-hospital duration and very young age-mix.

Despite Cochrane review (72–74) has not shown mortality difference between early and delayed fluid resuscitation, the permissive hypotension approach would deserve attention to await further delineation studies.

However, Duke subsequently proved restrictive fluid resuscitation (less than 150 mL of crystalloids) in combination with DCS could substantially reduce mortality (OR 0.69;95 CI 0.37–0.91) in penetrating torso injuries (75).

Hemostatic Resuscitation aims at early transfusion by packed red cells (PRBC) with high ratios of plasma and platelet concentrate when massive blood transfusion (MBT) is indicated to reduce coagulopathy to decrease the mortality (76–81). Trauma patients with severe base deficits (less than negative 24) had higher survival benefit with MTP (82). An efficient communication and enhanced availability system could further lower the mortality (RRR–58%) (83). Early studies showed higher acute respiratory distress syndrome and multiple organ failure (ARDS and MOF) incidences with high ratio of fresh frozen plasma (FFP) (81). A later study revealed the septic shock, ventilator-associated pneumonia (VAP), abdominal compartment syndrome

(ACS), heart failure, liver failure, and MOF rates were lower in MBT with high component ratios (84). Besides, mortality (85–87) and the total amounts of blood products transfused (85) were both decreased with massive transfusion protocol (MTP). The current blood product ratio recommendation is 1:1:1. The on-going researches are to identify the most optimal ratios (88). The impact to paediatric trauma survival (89), to analyse if there might be a survivorship bias (creation or inflation) favouring MTP (90) and to delineating the real benefit impact (91,92).

Another new research arena is on the immunoregulator to treat the dysregulated inflammatory response in major trauma (93). Low-volume hypertonic saline resuscitation versus normal saline in head injury after DCS to control the torso bleeding can reduce the 30-days mortality from 15.2% to 5.3% as well as decreasing the ARDS, MOF and ICU stay duration (94).

*Damage Control Surgery (DCS) is to correct the patho-physiology and not to have an immediate total repair of the destructed anatomy*

The target of DCS comprising of the procedures in Table 7 (14,69,95–99) is to restore or optimize the deranged physiology instead of definitive anatomical repair. It includes hemostatic steps by simple methods consisting of temporary clamping, ligation, shunting or packing if definitive operation is not feasible if multiple, and extensive liver lacerations or unduly lengthens laparotomy and aggravate the hypothermia. Afterwards, is the decontamination of the injured body cavities such as bowel perforation by temporary closure, resection without anastomosis with a proximal fecal diversion colostomy. Third is the rapid closure of the laparotomy incision to prevent hypothermia (heat loss via the exposed viscera) together with commercially available or improvised topical dressing (modified Bogota Bag or sterile silastic sheet) when necessary to reduce the risk of abdominal compartment syndrome to rewarm with focused resuscitation in the intensive care unit (99) to stabilize the patient to prepare for the follow-up operation with definitive procedures 24–48 h later.

**Table 6:** Damage Control Resuscitation (DCR)

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- 1) Permissive Hypotension/Restrictive Fluid Resuscitation
  - 2) Hemostatic Resuscitation/Balanced Blood Product Resuscitation
  - 3) Damage Control Operation/Surgery (DCO/DCS)
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There has been no head to head comparative study on the DCS to evaluate the mortality impact. Historical control in a small study of major penetrating abdominal injuries showed an impressive mortality reduction for treatment with the modern DCS (42% versus 10%) (69). Another evidence to favour the DCS coupled with other enhanced trauma management was the mortality diminishment of the United States servicemen wounded in Iraq and Afghanistan (2003 and 2009) to 10% from 24% in the first Gulf War (1990–1991) and Vietnam War (1961–1973) (69).

*The success factors of mortality reduction in major pelvic disruption include a pre-set multi-disciplinary protocol, the novel Pre-PPP (Pre-Peritoneal Pelvic Packing) and the angio-embolization*

Major pelvic disruption with shock carries high mortality (100,101). There is no direct comparison of whether transcatheter angiographic embolization (TCAE) (101) first is superior to external pelvic fixation (EPF) (102) or the converse but an explicit and pre-defined protocol improves the survival outcome (101,103).

Pelvic binder followed by EPF, pre-peritoneal packing (Pre-PPP) and TCAE (102) +/- venous stenting (104,105) can be a reasonable approach since trauma surgeons are usually in-house of the hospital in contrast to the interventional radiologists.

The rapid application of external pelvic circumferential compression devices (PCCD) can promptly help arrest the bleeding by the tamponade effect in the reduced pelvic space (103,106,107). Three commonly used models are the Pelvic Binder (R), SAM-Sling (R), and T-POD (R). However, prolonged use can cause skin and tissue damage and timely switch to EPF is essential (108). EPF apposes the fracture sites to help control the bone marrow bleeding and prevent expansion of the pelvic volume to enhance the consequent pressure effect of pre-peritoneal pelvic packing (Pre-PPP) to compress the venous and potentially the arterial bleeders. pre-ppp is a

re-kindled management from Europe, America and to Asia for mechanically unstable pelvis fractures in critically injured patients (109–113). This operative treatment can be rapidly performed by the orthopods or surgeons to stop the venous bleeding with/without subsequent TCAE especially in centres with limited interventional radiology services. In the Denver studies, the first line pre-ppp has been demonstrated to reduce the mortality (from 40% to 21–25%), the need for emergent trans-catheter arterial embolization (TCAE) and the blood product requirement in high risk pelvic fracture with no acute bleeding death (110,111) though the EAST review indicated more comparative studies with TCAE are required (103).

The adoption of the Pre-PPP (or retro-PPP) first with a bundle of management changes has also reduced the mortality of major pelvic fractures from the historical 69.2% of TCAE first to 36.3% in a Hong Kong trauma centre (114). A German model of pelvic emergency simulator has been developed to train pelvic hemorrhage reduction by the Pre-PPP (115).

TCAE targets at arresting arterial bleeding by injecting gel-foam or as a permanent procedure by metallic coils in case of A-V fistula or pseudo-aneurysm. Venous stenting controls hemorrhage through the large ruptured veins such as the iliac veins. Interventional TCAE is an efficient and effective procedure for hemostasis of arterial bleeding as contrast (or blood) blush detected on MDCT in pelvic fractures. It should be incorporated into the early clinical Management protocol (116). Table 8 outlines the important management steps in major pelvic fracture.

**While operation is the definitive treatment for injury, prevention is the best treatment**

Though the golden hours of trauma resuscitation (117) are very exciting, appealing but challenging and at times disheartening, prevention is actually more important. WHO

**Table 7:** Damage Control Surgery (DCS)

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Hemostasis
Decontamination
Quick body cavity closure to rewarm patient
Focussed critical care in the intensive care unit to further improve the hemodynamic, electrolyte and metabolic status
Planned re-operation for definitive repair when physiology normalised

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(World Health Organization) reported the global road traffic injuries (RTI) killed nearly 1.3 million people annually in the Global Status Report on Road Safety in 2009 (118) and would become the fifth leading cause of death by 2030 if the trend did not change. Besides, there were 20 to 50 million sustaining non-fatal injuries each year.

The results revealed RTI continued to be an important public health problem, particularly for low-income and middle-income countries. Nearly 50% of the deaths were of pedestrians, cyclists and motorcyclists, signifying the urgent need for these road users to be given more attention in road safety programmes and law enforcement.

As a prestigious trauma surgeon, Donald Trunkey is certainly one of most dedicated advocates on trauma prevention, who has shown motor vehicle crash, homicide, burns, alcohol and drug abuse constitute the major problems (119).

Helmets though simple devices are important to reduce head and maxillofacial injuries and death in bicyclists and related activities whereas the safety belts decreases mortality in motor vehicle crashes (120–128), not to mention the tremendous reduction in financial burden (125,126). While drunk driving persists as an important cause for trauma mortality (129), drugged driving is another emerging problem with the high respective prevalence rate of 18.5%, 13%, 12.3% and 10% among the injured drivers (of the developed countries) of in Italy (130), Sweden (131), Belgium (132) and Hong Kong (133). Education, legislation and law enforcement are the 3-pronged public health approach to

control the harm.

Trauma care quality indicators comprise of 3 levels from the prehospital, in-hospital to post-hospital (134). In the prehospital and in-hospital levels, the endeavour is to attain the secondary injury prevention by mitigating the injury severity by decreasing the impact force such as by the safety devices mentioned earlier with safe car and road design, not to mention the reduction of the trauma complications by prompt EMS and medical treatment. Tertiary prevention aims at injury recurrence while primary prevention focuses on occurrence elimination.

Therapy including resuscitation and operation may not be able to salvage mortality or wholly restore the body functions (brain or limb), resulting in not only death, permanent disability, scars, pain but burden in all forms including and not limited to physical, psychological, financial and social. Injury prevention can never be over-emphasized and deserves timely re-attention and additional resources allocation.

On 1 Oct 2012 (the National Day of China), a tragic boat collision in the Hong Kong waters led to 39 deaths among 124 passengers setting off to view the National Day Fireworks in the Victoria Harbour. If cautious navigation had been taken and the passengers especially the children had put on the life-jackets in the boat cruise in accordance with the ordinance of the mass gathering events in the sea, most fatality could have been prevented. Table 9 summarizes the potential barriers in applying the evidence into prevention practice.

**Table 8:** Key management steps in major pelvic fracture in shock

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Permissive hypotension + Hemostatic Resuscitation
PCCD – external pelvic circumferential compression devices
DCL (Damage Control Laparotomy) if abdominal USG reveals IPFF; if not, proceed to EPF
EPF – External pelvic fixation
Pre-PPP – Pre-peritoneal (Retro-peritoneal) pelvic packing
TCAE (Trans-catheter Arterial Embolization) / Angio-embolism / Endovascular stenting for large vein perforation
Second-look Pre-PPP 24 to 48 hrs later after ICU stabilization

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**Table 9:** Knowledge Translation Barriers – the 4 U’s

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1. Unaware
  2. Under-resourced
  3. Unwilling
  4. Un-prepared
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In summary, comprehensive injury management care is not restricted to the golden hours of resuscitation, but commences with pre-hospital bystander and competent ambulance services and continues with the in-patient critical care followed by high quality rehabilitation programme enhanced by future prevention for the injured and primary prevention for the at risk groups.

## Correspondence

Dr Kam Chak Wah  
MBBS (HKU), MRCP (UK), FRCSEd; FRCSCG; FCEM;  
FHKAM (Surgery), FHKAM (Emergency Medicine)  
Accident and Emergency Department  
Tuen Mun Hospital  
Tuen Mun, Hong Kong  
Tel: +852-2468 5198  
Fax: +852-2456 9186  
E-mail: kamcw@ha.org.hk

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