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Wenfang Li (lwfang67@yahoo.com.cn)
Jun Qian (qianjun139@163.com)
Xuefen Liu (liuxfln@yeah.net)
Qiang Zhang (zhangqiang-shh@163.com)
Lv Wang (wanglv22867@yahoo.com.cn)
Dechang Chen (icudcchen@yahoo.com.cn)
Zhaofen Lin (linzhaofen2009@yahoo.com.cn)

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Management of severe crush injury in a front-line tent ICU after 2008 Wenchuan earthquake in China: an experience with 32 cases

Wenfang Li [1], Jun Qian[2], Xuefen Liu [1], Qiang Zhang [1], Lv Wang [1], Dechang Chen [1], Zhaofen Lin [1]*

1. Emergency Department, Changzheng Hospital, Second Military Medical University, No. 415 Fengyang Road, Shanghai 200003, China

2. Intensive Care Unit, The People's Hospital of Jiangyou, No. 346 middle Jinlun Road, Jiangyou City, Sichuan Province, 621700, China

***Corresponding author:** Zhaofen LIN , PhD. Emergency Department, Changzheng Hospital, Second Military Medical University, No. 415 Fengyang Road, Shanghai 200003, China.

Tel: 86-21-81885841, Fax: 86-21-63617088. Email: linzhaofen2009@yahoo.com.cn

Abstract

Introduction:

The experience on management of crush injury after a devastating earthquake is lacking, and there are even less reports on the front-line critical care of these patients. A front-line intensive care unit (ICU) was set up in a tent after the disastrous Wenchuan earthquake (May, 12, 2008, China), where 32 patients suffering from crush injury were treated from May 12 to May 26. This study summarized our experience on management of 32 crush injury patients in a front-line tent ICU.

Methods:

We retrospectively analyzed the clinical data of 32 crush injury patients treated in our frontline tent ICU. Using limited equipment, we observed the arterial blood gas parameters, blood routine, alanine aminotransferase, lactate dehydrogenase, creatine kinase, creatinine, blood urea nitrogen, and urine protein of patients. We also closely watched for changes in crush injury symptoms, urine output, and the dangerous complications of crush injury.

Results:

Eighteen of the 32 patients developed traumatic shock, 9 had acute renal failure, 6 had acute heart failure, 2 had stress ulcers and 4 had multiple organ dysfunction syndrome (MODS). The symptoms of 17 patients met the criteria of crush syndrome; hemodialysis and prompt surgical intervention were given to them when necessary.

Prompt treatment in our tent ICU improved the symptoms of patients to different degrees. The limb distension and sensory dysfunction were improved and the urine output was increased or even restored to the normal level in some patients. Serological parameters were improved in most patients after admission. Five (15.63%) patients underwent amputation due to severe infection in our group. Six (18.75%) patients died, 4 due to MODS and 2 due to acute renal failure.

Conclusions:

Severe crushing injuries and life-threatening complications are major causes of death after major disasters like earthquakes. Prompt treatment and close monitoring of the severe complications are of great importance in saving patients' lives. Establishment of a well-equipped front-line ICU close to the epicentre of the earthquake allows for prompt on the spot rescue of critical patients with crush injury, greatly decreasing the mortality rate and complications and avoiding amputation. There should be sufficient equipment to meet the needs of more patients.

Introduction

Disasters such as earthquake, debris flow and landslide can cause mass casualties. In addition to direct injuries to vital organs such as the head and heart and rupture of large vessels, crush injuries caused by prolonged pressing of the body by collapsed buildings are also major causes of death. The acute increase of muscle pressure can lead to compartment syndrome, clinically manifested as progressive swelling of the involved limbs, great pain, diminishing sensory abilities and muscle strength, and even paralysis [1~3]. When exacerbated swelling of body parts, acute renal failure shock, or hyperpotassemia is developed, crushing syndrome is due to occur. The incidence of crushing syndrome is 2%-15% in all trauma patients, and it can be as high as 30% in earthquake victims. The symptoms of crushing syndrome can last for 3-5 days in slight cases and for 1-2 weeks in severe cases. About half of the victims develop acute renal failure and the number is almost 100% in those whose symptoms last for 40 h; among the latter about 50% need hemodialysis. The mortality of patients with crush syndrome can be as high as 40% if the condition last for over 3 weeks [4-8]

Intensive Care Unit （ICU） is a setting equipped with specially trained medical professionals as well as advanced monitoring system and first aid materials. An ICU is aimed to monitor and treat patients at critical conditions such a multiple injuries, severe infections, shock of various origins, acute organ failure and disorders of the internal environment of patients. Intensive care reflects the administration proficiency and medical technology advancement of hospitals [9-11]. Close monitoring of

pediatric patients [12], aged patients [13] and patients with unstable vital signs can greatly improve their survival rate [14-16]. ICU plays an unreplaceble role in saving the lives of victims after major disasters such as earthquakes, especially those with crush syndrome and complications [17-19]. Demirkiran et al considered that immediate intensive care is vital to the survival of patients with crush injury and compartment syndrome [20]

On May 12, 2008, a catastrophic earthquake measuring 8.0 on the Richter scale struck the Wenchuan region of Sichuan province, China, causing about 90 000 deaths and even more injuries. The rescue efforts were greatly hampered by the mountainous terrain and damaged roads. Many victims developed critical crush injury and compartment syndrome after their limbs pressed for a long time during entrapment. Our group, as part of the rescue team of Second Military Medical University, was sent to Jiangyou city, a severely hit area labouring the most severely struck Beichuan Area. A field hospital was set up in the People's Hospital of Jiangyou, which had been severely damaged during the shake. We rescued some undamaged equipments from the severely-damaged ICU building and established a front-line tent ICU. From May 12 to May 26, 32 patients with crush injury were treated in our front-line tent ICU. In this paper we reported the treatments and outcomes of the 32 patients and summarized our experience in the front-line tent ICU.

Materials and methods

Establishment of front-line tent ICU

Using the undamaged equipments rescued from the collapsing hospital buildings of the People's Hospital of Jiangyou, we established a front-line tent ICU, as a unit of the field hospital set up by the rescue team of Second Military Medical University. The ICU had four beds, each equipped with a monitor (DASH3000, Am GE), manual respirator（LVT1000, Am NEWPORT）, and suction apparatus（YB. DX23D SHANGHAI MEDICALS）. Other equipments included a blood filtrum （PRISMA MACHINEGAMBRO, Swede）, a blood gas analyzer （GEMPremier3000, Am）, a biochemistry inspectoscope（CELLDYN3700, Am）, a defibrillator (HEARTSTART XL, PHILIPS, Japan), and trachea cannula and breathing sacculus (GaleMed MR-100, China), as well as routine rescuing drugs.

General information of patients

From May 12 to May 26, a total of 32 patients were admitted to our front-line tent ICU, including 21 males and 11 females, with a mean age of 45±19 years old (ranging, 13-56 years). Physical examination upon admission: the mean body temperature, 37.2 ± 0.6 ℃ (ranging 36.3-37.6℃); the mean heart rate, 115.3 ± 25.6 (rangeing 85-142) beats/min; mean respiratory rate, 26.9 ± 5.7 (ranging 21-38) /min; mean systolic BP, 121.7 ± 21.3 (ranging 78-153) mmHg , and mean diastolic BP, 59.4 ± 16.8 (ranging 42-96) mmHg.

Injuries of patients

Twenty-seven of the 32 patients had multiple injuries and five had lower limb injuries. Nine patients had unilateral lower extremity trauma and 13 had bilateral ones. Three patients had single femoral fractures and seven had bilateral femoral fractures. Thirteen patients were complicated by pelvic fractures, 11 had chest trauma，8 had cerebral trauma，6 had splenic rupture, 5 had open tibia fracture, 5 had spinal injuries, and 3 had perinephrium and retroperitoneal hematoma. The mean entrapment period of the patients was (3l±12) hour, ranging from 2 h to 121 h. All the patients had swelling and distension of extremities, various degrees of dysesthesia, and dyscinesia. Twenty-three of them had soy sauce urine. Seven suffered from anuria and 6 from pink foam phlegm. The clinical details of the 32 patients were given in Table 1. Informed consents were obtained from each patient or their guardians, and ethical approval has been obtained from the Medical Ethics Committee of Changzheng Hospital, Second Military Medical University.

Laboratory tests

Due to the limited equipments, the parameters we could obtain included PaO_2, PCO_2, PH value, and base excess. Other parameters included blood cell count, serum alanine transminase (ALT), serum lactate dehydrogenase (LDH), serum creatine kinase (CK), serum creatinine, serum urea nitrogen (BUN), and urine protein. Upon admission the blood test showed the following results: blood Hematocrit (39.6±13.4) (%) (ranging 23%-52%), Leukocytes (21562±8765) /μL (ranging 12300-32500) /μL, platelets

(136775±56745) /μL (ranging 400000-240000) /μL.

Diagnosis and treatment of patients with crush syndrome

Crush syndrome is systemic manifestations characterized by swelling and distension of limbs, dyscinesia, myoglobinuria, and hyperpotassemia, usually caused by prolonged pressing of body parts. The mortality rate of patients with crush syndrome could be as high as 50%-70%. Crush syndrome can be diagnosed when a crush injury patient develops systemic manifestations such as shock, acidosis, and acute renal failure [21-23]. The criteria of crush syndrome in our group were: over one hour pressing of the body parts, involvement of large amount of muscular tissue, development of pallor, clamminess, cold skin, pulselessness, shock, and the manifestations of acute renal failure: Oliguria (< 400ml/24h), BUN increase >40mg/dl, creatinine increase >2mg/dl, serum potassium increase >6mmol/l, serum phosphorus increase >6mg/dl or serum calcium decrease <8mg/dl. Upon admission, the patients were immediately given interventions such as anti-shock treatment, alkalifying urine, correcting water and electrolyte disturbances, diuresis, dehydration, and anti-infection treatments. Twenty-seven patients received anti-shock treatment, 25 received urine alkalization, 19 received hemodialysis, 15 received fasciotomy, and 5 received amputation due to severe infection. All patients received broad-spectrum antibiotics to control infection and tetanus antitoxin.

Acutely increased interaponeurosis pressure in victims of crush injury can lead to severe muscle necrosis, which requires surgical intervention. Prompt fasciotomy can

safe life and prevent the development of dangerous complications after crush syndrome. Indications for fasciotomy included increased turgid of pressed limbs with high tension，or/and local ecchymosis, blister in the skin，symptom of 5 “P”（ Pain，Pallor，Paralysis，Parathesias，and Pulselessness），persistent urine myoglobin，or interaponeurosis pressure higher than 40mmHg. Hemodialysis is the first choice for crush syndrome patients complicated with acute renal failure and hyperpotassemia. Indications for hemodialysis included serum creatinine level >8mg/dl, BUN>100mg/dl, serum potassium>7mmol/l, serum bicarbonate < 10mEq/l, or/and clinical symptoms of ARF, such as edema, hypertension, heart failure, nausea, and vomiting.

Monitoring of dangerous complications in patients with crush injury

The most important symptom of crush syndrome is acute kidney injury. Acute renal failure is defined when a patient with crush injury has one of the following symptoms: oliguria (urine output <400ml/24h), increases of BUN (>40mg/dl), serum creatinine (>2 mg/dl), uric acid (>8 mg/dl), potassium (>6mmol/l), phosphorus (>8 mg/dl), or decrease of serum calcium (<8 mg/dl) [12,13]. We observed the incidence rates of traumatic shock, ARF, acute pulmonary edema (APE), stress ulcer (SU), and multiple organ dysfunction syndrome (MODS) as well as the vital signs of the patient. Besides, we also closely monitored the changes of urine output, serum BUN, serum creatinine, serum uric acid, urine protein, serum CK, ALT and LDH. The decrease of amputation rate and morbidity rate were also used to evaluate the outcomes of patients.

Statistical Analysis

All the data were expressed as mean ± SD. Paired t test was used when the difference of pre- and post-treatment was in a normal distribution. When the variables did not have a normal distribution and ranked data, the Wilcoxon signed rank sum test was utilized. All data were evaluated using a Microsoft Excel 97 spreadsheet and SAS9.12 statistical software. Statistical significance was assigned at $P<0.05$.

Results

Improvement of laboratory parameters of patients after intervention

Two weeks after comprehensive treatment, the serum parameters of most patients were greatly improved (Table 2). All the six death cases had a serum CK level over than 5000 u/L; two death cases had a serum potassium level higher than 6.0mmol/L, which could not be corrected. In the 26 survived cases the CK value rapidly decreased to <1000 u/L.

Treatment of complications of patients with crush injury

Of the 32 patients , 18 (56.25%) had traumatic shock, 11 from ARF (34.38%), 6 had APE (18.75%), 2 had SU (6.25%) and 4 had MODS (12.5%); all the 4 patients developed MODS died and the other 26 had improved symptoms. After pertinent treatments, the survived patients had their swelling and distension relieved, and they recovered from dysesthesia and anesthesia. Sixteen patients had their dyscinesia symptom improved and 15 had normal urine output. A particular case in our group worth further description was a 15 years old girl, who had tibial and fibula fracture on her right leg during the earthquake. On admission she had a swelling right leg with fracture blisters on the skin and decreased pulse of dorsalis pedis artery. The doctor who first performed the emergent operation for her fractures neglected the risk of crush syndrome. On the next day after fracture fixation, the girl had an acutely reduced urine output (below 100ml/24h) combined with tachypnea, orthopnea, and expectoration of bloody sputum. Auscultation showed moist rales in bilateral lungs.

The heart rate (HR) was 140-160 beat/min and respiratory rate (RR) was 35-46/min. Pulse oxygen saturation was only 60%. Therefore she was transferred to our ICU and was diagnosed as crush syndrome accompanied by acute pulmonary edema (APE). She was immediately subjected to ventilation by mask oxygen, intravenous injection of cardiotonic and diuretics and hemofiltration. Gradually the HR and RR of patients decreased and the pulse oxygen saturation was improved.

Comprehensive treatment of crush syndrome and the outcome of patients

Seventeen (53.13%) of the 32 patients met the diagnosis criterion of crush syndrome. Eighteen (56.25%) patients had traumatic shock, 11 (34.38%) had ARF, 6 had acute heart failure, 2(6.25%) had stress ulcer, and 4 (12.5%) had MODS. Six (18.75%) patients died in our group, one due to severe capillary leak syndrome, one due to uncontrolled infection after amputation, and four due to MODS. Five (15.63%) patients received amputation due to severe infection of the involved limbs. The 26 survived patients were alive and well three months later. The major treatment of crush syndrome included anti-shock treatment, surgical intervention and hemodialysis. Totally 18 patients received prompt antishock treatment and 12 patients were successfully resuscitated. Prompt surgical interventions were given to 15 of the 19 patients who had the indications for fasciotomy; the other four patients did not receive fasciotomy due to severe infection of the wounds. 72 h later, the limb swelling was aggravated in one of the four patients who did not received fasciotomy initially, and several blisters appeared on the local skin, accompanied by local ecchymosis and

decreased artery pulse, indicating increased intramuscular pressure, and fasciotomy was performed finally, but the patient died of MODS. Eleven (34.38%) patients with proper indications received hemodialyses: all of them had different degrees of ARF symptoms, 5 had hyperpotassemia, 7 had anuria, and 4 had combined hyperpotassemia, anuria, and elevated creatinine. The mean urine output of the patient rose from (174.5±82.7) ml to (954.6±132.5) ml after treatment ($P<0.05$) , and the urine output of 15 patients restored to the normal level.

Discussion

In this paper we reported the treatment of 32 patients with crush injury in a frontline tent ICU, which was established near the epic of the Wenchuan earthquake and was equipped with facilities rescued from collapsing buildings of a local hospital. Close monitoring and prompt intervention have helped to save the life of the 26 patients. The tent ICU is of great significance in saving the lives of patients with crush injury following a major disaster. More attention should be given to set up a well-designed front-line ICU for major disasters.

Advantages of front-line ICU after an earthquake

Front-line ICU is very important for treatment of crush injury patients after disasters such as an earthquake, because it is equipped with advanced facilities and first aid materials needed for critical conditions. A front-line ICU, like ours, can be located on the site of the disasters, giving treatment in a timely manner [24-26]. It is reported that most victims of disasters and wars died on the spot they were injured. For example, in a war 40% of the patients died immediately after injury, 25% died 5 min after injury, 15% died 5-30min after injury, and 20% died 30 min after injury; it is indicated that timely treatment of these patients is vital. A front-line ICU can provide this timely treatment, relieve the symptoms of patients, improve their biochemical parameter, and reduce crush syndrome complications, allowing for surgical intervention of the patients. After a major disaster like Wenchuan earthquake, there will be large number of patients with crushing injury. When compartment syndrome, acute renal failure and

(or) other severe complications occur, the patients need to be sent to ICU immediately for closer monitoring. A tent ICU near the epic can not only provide timely treatment to the victims, but also avoid the risks of aggravation of patients' condition during the evacuation [27, 28].

Close monitoring, early diagnosis and treatment of crush syndrome

There are a large number of crush injury patients following a major earthquake, and early diagnosis and close monitoring can lower the incidence of crush syndrome. In addition to monitoring of the vital signs, more attention should be paid to observation of the blood pressure and changes of urine in order to make early diagnosis of crush syndrome. Observation of the color, volume of urine and the urine protein is also a key step to prevent the transition from crush injury to crush syndrome. Furthermore, monitoring and correcting of hypotension can prevent ARF in patients with crush syndrome. In our ICU, only limited biochemical parameters are obtainable; however, close monitoring of the above-mentioned parameters have helped us to make early diagnosis and treatment assessment. Due to the limited parameters we can obtain, observation of urine output served as an important parameter for diagnosis of patients and for predication of prognosis. The serum parameter changes caused by muscle necrosis are very important in diagnosis of crush syndrome. Unfortunately, some important s parameters could not be obtained in our ICU due to limited equipment. Sophisticated biochemical instruments are essential for a front-line ICU.

Reportedly, seven out of ten patients with crush injury after a catastrophic

earthquake developed crush syndrome, and 10% of the total casualty was due to crush syndrome. Therefore, prevention and management of crush syndrome are critical to lower the mortality rate. The survival rate of our group is 81.25%, greatly higher than that reported previously [29-31].

The major differences of treatments between crush injury and other types of traumas include that patients with crush injury need early and prompt expansion of blood volume to guarantee renal perfusion, correction of acidosis and relief of limb swelling. Most patients with crush injury are in a state of hypotension and need intravenous administration of large volume of fluids, including artificial plasma, 5% glucose, NaHCO3, aescigenin, and human serum albumin. Colloid should be used to elevate the osmotic pressure and relieve inter-aponeurosis edema; diuretics such as Indapamide should be used when circulation is stable. Although mannitol is effective in decreasing inter-aponeurosis pressure, it was not used in our cohort to avoid aggravation of renal function; instead, aescigenin, human serum albumin, and indapamide were used in our patients to relieve swelling of the injured limbs.

Surgical intervention and post-operation monitoring of patients with crush syndrome

Duman et al believed that prompt fasciotomy in earthquake victims are both life-saving and can prevent some of the severe and dangerous complications of crush syndrome [3]. In fact, not only close fractures can lead to compartment syndrome, open fractures can also result in it; radical debridement should be performed for open

fracture, and repeated debridement is needed when necessary; fasciotomy and expansion of wounds should be done to remove the necrotic tissues to ensure unobstructed drainage. The aim of fasciotomy is to prevent muscle necrosis, compartment syndrome and the need for amputation. Those who took a negative altitude toward fasciotomy in earthquake victims thought that resection of large volume of muscle together with the surrounding tissues would inevitably cause loss of fluid and increase the chance of infection. Infection secondary to fasciotomy and primary trauma of earthquake victims have always been grave challenges in clinic. Ekren reported that the incidence of severe infection was as high as 37.3% in patients with crush injury. Therefore, in a front-line ICU, the surgical wounds should be closely observed and anti-infection measures should be promptly taken when necessary. In our group, five patients have to receive amputation because of aggravated distension of compressed extremities, deterioration of ecchymosis and blister, local skin getting purple/black, hyperpyrexia and acute increase of leucocytes. Postoperatively, the patients were closely monitored and the incisions were observed. Only one patient of the five died of un-controllable infection. We believe that surgical intervention of earthquake victims should be considered for earthquake victims when the correct indications are strictly followed.

Close monitoring of severe complications of crush syndrome

The common complications of crush syndrome include traumatic shock, acute renal failure, acute heart failure, SU, and MODS; early diagnosis and intervention are vital

to the survival of patients. In our group, the incidence rates of the aforementioned complications were similar to those reported previously [32-34].

In our front-line tent ICU, energetic antishock measures were taken for 18 patients had traumatic shock to avoid the development of crush syndrome, because many severe fatal complications develop due to long period of shock. SU is a common manifestation at the final stage of patients and often develops under stress. The incidence rate of SU was about 4%~10% in trauma patients reportedly [35, 36]. Two of our patients suffered from SU. The result indicated that it was necessary to adopt early active mental intervention to relieve the mental stress. The most severe complication of crush injury is MODS. Four of our patients developed MODS and all died. So it is especially important to monitor the functions of major organs to prevent MODS in the front-line ICU. Experience with the fifteen year old girl indicates that APE can also be the first clinical manifestation of crush syndrome; and the necrosis of leg muscle as well as that of the huckle can lead to crush syndrome [37-39]. Eleven of our 32 patients had ARF, a dangerous manifestation of crush syndrome. Hemodialysis is the best choice for treatment of ARF and prevention of crush syndrome. It is reported that hemodialysis can keep the incidences of internal environment disorder and other complications to the minimum. The urine output recovered to normal level in 11 patients who received hemodialysis. Our ICU only had one hemodialyzer, patients could not receive continuous hemodialysis and four of our patients developed MODS and died. Advanced portable biochemical analyzer in the front-line ICU allows for close monitor of patients with crush injury, and a blood

dialyzer can give prompt, effective treatment to patients complicated with ARF[40,41]. When rescuing after a disaster like Whenchuan Earthquake, more portable hemodialyzer should be deployed to provide prompt treatment of patients with crush syndrome.

Conclusions

Severe crushing injuries and their life-threatening complications such as crush syndrome are common after a major earthquake like that occurred in Wenchuan. The establishment of a front-line ICU close to the epic of earthquake allows for a prompt on-spot monitoring and rescue of critical patients suffering from severe traumatic injury, which can decrease the mortality rate and complications in patients with severe crushing injury, avoid amputation, and should be encouraged.

Key messages

- Severe crushing injuries and their life-threatening complications such as crush syndrome are common after a major earthquake like that occurred in Wenchuan.
- Six (18.75%) patients died in our group, one due to severe capillary leak syndrome, one due to uncontrolled infection after amputation, and four due to MODS. Five (15.63%) patients received amputation due to severe infection of the involved limbs.
- The establishment of a front-line ICU close to the epic of earthquake allows for a prompt on-spot monitoring and rescue of critical patients suffering from severe traumatic injury, and should be encouraged and studied further.
- In addition to the monitoring of the vital signs, more attention should be paid to observation of the blood pressure and changes of urine to make early diagnosis of crush syndrome.
- We believe that surgical intervention of earthquake victims should be considered for earthquake victims when the correct indications are strictly followed.

Abbreviations

ICU=intensive care unit; ALT=alanine aminotransferase; LDH=lactate dehydrogenase; CK=creatine kinase; MODS=multiple organ dysfunction syndrome; ARF=acute renal failure; BP=blood pressure; BUN=blood urea nitrogen; APE=cute pulmonary edema; SU=stress ulcer; HR=heart rate; RR=respiratory rate; SD= standard deviation

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

WL was responsible for data collection, analysis and writing the manuscript ; JQ, XL, and QZ participated in data collection and analysis; LW and DC participated in the data collection and revising the manuscript ; ZL was responsible for the overall design of the manuscript. All the authors have read and approved the submission.

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References

1. Beetham R：**Biochemical investigation of suspected rhabdomyolysis**. Ann Clin Biochem 2000，37：581-587.
2. Naghi TM，Kambiz K， Shahriar JM， Afshin T， Reza SK，Behnam P， Bahador AH： **Musculoskeletal injuries associated with earthquake： A report of injuries of Iran's December 26， 2003 Bam earthquake casualties managed in tertiary referral centers**. Int. J Care Injured 2005，36： 27-32.
3. Duman H，Kulahci Y，Sengezer M：**Fasciotomy in crush injury resulting from prolonged pressure in an earthquake in Turkey**. Emerg Med J 2003，20： 251-252.
4. Anna T， Jan EM， Olav R：**Multifocal orterial haemorrhage in a partially stable pelvic fracture after a crush injury: a case report**. Arch Orthop Trauma Surg 2006，126：113-117.
5. Necmi K， Hasan FK，Recep D， Altaca G： **Crush Injury in Two Earthquake Disasters within a 3-Month Period**. European Journal of Trauma 2003，29：42-5.
6. Serdar HI，Harika A， Halil T， Cevdet O，Suat HA， Kerem O，Mehmet B，Cihangir T，Tolga ED： **Analysis of 33 pediatric trauma victims in the 1999 Marmara， Turkey earthquake**. J Pediatr Surg 2001， 36： 368-372.
7. Shackford SR，Rich NH：**Peripheral vascular injury**. **In：Mattox KL， Feliciano DV， Moore EE， eds**. Trauma， 4th edn. New York：McGraw-Hill， 2000：1011–1046.
8. M. Gorgu， G. Adanali，A. Tuncel， D. Senen， B. Erdogan： **Airbags and wearing seat belts prevent cut-crush injuries or reduce severity of injury in low-speed traffic accidents**. Eur J Plast Surg 2002， 25： 215–218.
9. Michael JS， Michael EM： **Reliability of vacuum phenomenon in the sacroiliac joint as a sign of traumatic injury** . Emergency

Radiology 2002， 9：100–102.

10. Gulcin K，Raymond V，Serhan T， Haken A， Mehmet K， Cetin O： **Acute renal failure due to crush syndrome during Marmara earthquake**. Am J of Kidney Diseases 2002， 40： 682-689.
11. Reintam A， Parm P， Kitus R， Kern H，Starkopf J： **Primary and secondary intra-abdominal hypertension-different impact on ICU outcome**. Intensive Care Med 2008， 34：1624-1631.
12. Plotz FB， Bouma AB， vanWijk JA， Kneyber MC， Bokenkamp A： **Pediatric acute kidney injury in the ICU： an independent evaluation of pRIFLE criteria**. Intensive Care Med 2008，34： 1713-1717.
13. Yeolekar ME， Mehta S：**ICU care in India--status and challenges**. J Assoc Physicians India 2008，56：221-222.
14. Gortzis LG，Sakellaropoulos F，Ilias I，Stamoulis K， Dimopoulou I： **Predicting ICU survival： a meta-level approach**. BMC Health Serv Res 2008，8： 157.
15. Beloucif S： **How to fight against refusals of admission to ICU of elderly patients**? Ann Fr Anesth Reanim 2008，27： 470-471.
16. Rabbat A， Chaoui D，Lefebvre A， Roche N， Legrand O， Lorut C，Rio B， Marie JP，Huchon G： **Is BAL useful in patients with acute myeloid leukemia admitted in ICU for severe respiratory complications?** Leukemia 2008， 22：1361-1367.
17. Acharya SP， Pradhan B， Marhatta MN： **Application of "the Sequential Organ Failure Assessment (SOFA) score" in predicting outcome in ICU patients with SIRS**. KUMJ 2007，5： 475-483.
18. Mahoney EJ，Biffl WL，Cioffi WG：**Mass-casualty incidents： how does an ICU prepare?** J Intensive Care Med 2008，23： 219-235.
19. Mellert F， Lindner P，Schiller W， Gersing E， Heinze I， Kreuz J， Welz A， Preusse CJ： **Therapeutic Optimization of Atrioventricular Delay in Cardiosurgical ICU Patients by**

Noninvasive Cardiac Output Measurements versus Pulse Contour Analysis. Thorac Cardiovasc Surg 2008， 56：269-273.

20. Demirkiran O，Dikmen Y，Utku Y，Urkmez S：**Crush syndrome patients after the Marmara earthquake**. Emerg Med J 2003，20：247-250.
21. Honore PM，Joannes BO，Boer WJG，Gressens B：**Acute kidney injury in the ICU: time has come for an early biomarker kit**! Acta Clin Belg Suppl 2007，2：318-321.
22. Ali IG，Huseyin C，Ayhan D，Goksel O，Ercan K， Huseyin S，Izzettin G，Mustafa D， Oktay B， Mustafa AY，Mehmet SS：**Early and vigorous fluid resuscitation prevents acute renal failure in the crush victims of catastrophic earthquakes**. J Am Soc Nephrol2004，15：1862-1867.
23. Mehmet SS，Raymond V，Norbert L：**Management of crush-related injuries after disasters**. N Engl J Med 2006，354：1052- 1063.
24. Rocco M，Carbone I，Morelli A，Bertoletti L，Rossi S，Vitale M，Montini L，Passariello R，Pietropaoli P：**Diagnostic accuracy of bedside ultrasonography in the ICU：feasibility of detecting pulmonary effusion and lung contusion in patients on respiratory support after severe blunt thoracic trauma**. Acta Anaesthesiol Scand 2008 ， 52：776-784.
25. Mahoney EJ，Biffl WL，Cioffi WG：**Mass-casualty incidents：how does an ICU prepare**? JIntensive-Care-Med2008 ，23： 219-235.
26. Velmahos GC，Demetriades D，Ghilardi M，Rhee P，Petrone P，Chan LS：**Life support for trauma and transport： a mobile ICU for safe in-hospital transport of critically injured patients** . J Am Coll Surg 2004，199： 62-68.
27. Alvarez GM，Cambronero GJA，Nevado LE，Trascasa MM，Connor ME，Sanchez GM：**Effect of the availability of a medicalized mobile ICU (MMICU) on the hospital admissions after an out-of-hospital**

cardiorespiratory arrest. Rev Clin Esp 2003 ，203： 517-520.

28. Yue MX，Zou DW，Zhang J， Liu ZG， Cui SJ，Fang WW，Zhou XF，Gao TS， Hua N：**Establishment of a mobile intensive care unit** . Chin Crit Care Med 2004 ， 16： 589-591.
29. Jeffrey BK，Lynda KB，Andrew C， Robert JK，Kenneth DL， Paul EM，Paul M， Nauman Q，Sarah AY：**Kidney patient care in disasters： lessons from the hurricanes and earthquake of 2005** . Clin J Soc Nephrol 2007，2：814-824.
30. Arjan VDT，Asrar H，Memhet SS，Stefaan C，Wim VB，Eric H，Samuel K，Raymond V：**Impact of local circumstances on outcome of renal casualties in major disasters**. Nephrol Dial Transplant 2008， 8： 1-6.
31. Raymond Vanholder：**Intervention of the renal disaster relief task force (RDRTF) in the Kashmir earthquake** . Nephrol Dial Transplant 2006，21：40.
32. Sakka SG，Klein M，Eeinhart K，Meier-Hellmann A：**Prognostic value of extravascular lung water in critically ill patients**. Chest2002，122：2080-2086.
33. Kario K，Matsuo T，Shimada K，Pickering TG：**Factors associated with the occurrence and magnitude of earthquake-induced increases in blood pressure**. Am J Med 2001， 111：379-384.
34. Levy MM，Fink MP，Marshall JC，Edward A，Derek A，Deborah C，Jonathan C， Steven MO， Vincent JL， Graham R： **2001 SCCM/ESICM/ACCP/ATS/SIS International sepsis definitions conference**. Crit Care Med 2003，31：1250-1256.
35. Meybohm P，Cavus E，Bein B，Steinfath M，Weber B，Hamann C，Scholz J，Dorges V：Small volume resuscitation：**a randomized controlled trim with either norepinephrine or vasopressin during severe hemorrhage**. J Trauma 2007，62：640-646.

36. Xingyi Y，Wenfang L，Ming Y，Dechang C，Liang Z，Zhaofen L：**Clinical analysis of 176 patients suffered from upper gastrointestinal bleeding in intensive care unit**．Chinese Journal of Digest 2004，24：179-180．

37. Deborah LC，Monte SW，White DJ， Horton JW， Brett PG：**Tumor necrosis factor -α - induced caspase activation mediates endotoxin – related cardiac dysfunction**. Crit Care Med 2005，33：1021-1028.

38. Werman HA，Jaynes C，Blevins G：**Impact of a triage tool on air versus ground transport of cardiac patients to a tertiary center**. Air Med J 2004 ，23： 40-47.

39. Kreimeier U， Prueckner S：**Small volume resuscitation from hemorrhagic shock by hypertonic saline dextran conceptional basis and historical background**．Eur Surg Res 2002，34：138-144.

40. Hachimi Idrissi S，Yang X，Nguyen DN，Huyghens L：**Combination of therapeutic mild hypothermia and delayed fluid resuscitation improved survival after uncontrolled haemorrhagic shock in mechanically ventilated rats**．Resuscitation 2004，62：303-310．

41. Katzenelson R，Perel A，Berkenstadt H，Preisman S，Kogan S，Sternik L， Segal E：Accuracy of transpulmonary therm odilution versus gravimetric measurement of extravascular lung water ．Crit Care Med 2004，32：1550-1554．

Table 1: Clinical details of the 32 patients in our group

Patient No.	Primary injury	Admitting time	Dark urine	Urine volume（ml)	Protei-nuria	Entrapment time
1	Chest trauma, left humerus fracture and right radius fracture	2008/5/13	√	150	++	3.5
2	Brain trauma and left femur fracture	2008/5/13	√	350	+++	3
3	Fracture of shaft of right femur, pelvic fracture, and splenic rupture	2008/5/13	√	70	++++	5
4	Brain trauma, pelvis fracture, fracture of hypomere of left femur, and right fibula fracture	2008/5/13	√	470	34UY	6
5	Chest trauma, left humeral fracture, right ulna fracture, splenic rupture	2008/5/13		630	++	2.5
6	Left shaft of femur fracture and left tibiofibula fracture	2008/5/13		560	++	4
7	Right femur fracture	2008/5/13	√	480	++	3
8	Brain trauma, pelvic fracture, left femoral neck fracture, and right sprained knee	2008/5/13	√	540	++	4.5
9	Chest trauma, fracture of shaft of left humerus, right ulna and radius fractures	2008/5/13	√	560	++	2.5
10	Brain trauma, hemopneumothorax, left shoulder blade fracture, and sprain of left shoulder joint	2008/5/13		750	++	2
11	Epimere fracture of right shin and sprain of right knee	2008/5/13	√	630	++	3
12	Pelvic fracture, compression fracture of lumber vertebral body, splenic rupture, retroperitoneal hematoma, and left femoral neck fracture	2008/5/13	√	40	++++	5
13	Chest trauma and fractures of shaft of left humerus	2008/5/13	√	450	++	4
14	Pelvic fracture, splenic rupture, perirenal hematoma, fracture of shaft of left femur, and right tibial plateau fracture	2008/5/13	√	90	+++	3.5
15	Brain trauma, splenic rupture, fracture of right shoulder blade, right shoulder joint sprain	2008/5/13		870	++	2
16	Left tibiofibula fractures, compression fractures of	2008/5/13	√	430	++	4

	lumber vertebral body, and retroperitoneal hematoma					
17	Pelvic fracture, fracture of shaft of right femur, and left tibial fracture	2008/5/13		740	++	5.5
18	Chest trauma, and fracture of shaft of left humerus, and right clavicular fracture	2008/5/13	√	510	++	7
19	Pelvic fracture, splenic rupture, right femoral neck fracture, and fracture of left tibial plateau	2008/5/14	√	470	++	6
20	Brain trauma, fracture of lower shaft of femur, and right fibula fracture	2008/5/14	√	540	++	3.5
21	Pelvic fracture, left femoral neck fracture, and right fibula fracture	2008/5/14	√	390	+++	3
22	Chest trauma, fracture of shaft of left humerus, and right ulna fracture	2008/5/14	√	730	++	5
23	Brain trauma, compression fracture of lumber vertebral body, pelvic fracture, and right tibiofibula fracture	2008/5/14	√	70	++++	18
24	Chest trauma, fracture of shaft of left humerus, and right radius fracture	2008/5/14		830	++	9.5
25	Right tibiofibula fracture	2008/5/14	√	460	+++	11
26	Pelvic fracture, compression fracture of choracic12\lumber1 vertabral body, splenic rupture, retroperitoneal hematoma, fracture of shaft of right femur, and left tibiofibula fracture	2008/5/15	√	60	++++	16
27	Chest trauma, fracture of shaft of right femerus, and left ulna fracture	2008/5/15		850	++	6
28	Chest trauma and fracture of shaft left femerus	2008/5/15		780	++	13
29	Pelvic fracture, splenic rupture, and fracture of right femerus shaft	2008/5/16	√	70	++++	32
30	Brain trauma, pelvic fracture, left inferior femur fracture, and right fibula fracture	2008/5/16	√	490	++	12
31	Fracture of right femur shaft	2008/5/17		670	++	9
32	Chest trauma, fracture of shaft of left femur, and right olecroanon fracture	2008/5/19	√	50	++++	121

Table 2: Improvement of laboratory parameters after treatment in 32 patients with crush injury

	Pre-intervention	Post-intervention	P
LDH(u/L)	5725±1859	736±1182	0.000
ALT(u/L)	258±164	69±25	0.000
Pottasium(mmol/L)	5.4±2.4	3.8±1.2	0.000
Creatinine(umol/L)	794±85	261±67	0.000
CK(u/L)	4697±359	2281±263	0.000
BUN(mmol/L)	32.6±12.8	12.7±8.7	0.000
Severity of urine protein	++ ～ ++++	±～ +	0.000

LDH: lactate dehydrogenase；ALT：alanine aminotransferase；CK：creatine kinase；BUN：blood urea nitrogen