Intensive Care Med (1998) 24: 808–814

ORIGINAL

G. Vivino
M. Antonelli
M. L. Moro
F. Cottini
G. Conti
M. Bufi
F. Cannata
A. Gasparetto

Risk factors for acute renal failure in trauma patients

Received: 22 September 1997
Accepted: 14 May 1998

G. Vivino · M. Antonelli (✉) · F. Cottini · G. Conti · M. Bufi · F. Cannata · A. Gasparetto
Istituto di Anestesiologia e Rianimazione, Università La Sapienza, Policlinico Umberto I, Viale del Policlinico, 155, 00161 Rome, Italy
Tel.: +39 (6) 44631 01/2
Fax: +39 (6) 4461967
email: max.antonelli@flashnet.it or manton@uniroma1.it

M. L. Moro
Laboratorio di Epidemiologia e Biostatistica, Istituto Superiore di Sanità, Rome, Italy

Abstract *Objective:* To elucidate the risk factors for the development of acute renal failure (ARF) in severe trauma.
Design: Prospective observational study.
Setting: A general intensive care unit (ICU) of a university hospital.
Patients: A cohort of 153 consecutive trauma patients admitted to the ICU over a period of 30 months.
Results: Forty-eight (31 %) patients developed ARF. They were older than the 105 patients without ARF ($p = 0.002$), had a higher Injury Severity Score (ISS) ($p < 0.001$), higher mortality ($p < 0.001$), a more compromised neurological condition ($p = 0.007$), and their arterial pressure at study entry was lower ($p = 0.0015$). In the univariate analysis, the risk of ARF increased by age, ISS > 17, the presence of hemoperitoneum, shock, hypotension, or bone fractures, rhabdomyolysis with creatine phosphokinase (CPK) > 10000 IU/l, presence of acute lung injury requiring mechanical ventilation, and Glasgow Coma Score < 10. Sepsis and use of nephrotoxic agents were not associated with an increased risk of ARF. In the logistic model, the need for mechanical ventilation with a positive end-expiratory pressure > 6 cm H_2O, rhabdomyolysis with CPK > 10000 IU/l, and hemoperitoneum were the three conditions most strongly associated with ARF.
Conclusions: The identified risk factors for post-traumatic acute renal failure may help the provision of future strategies.

Key words Acute renal failure · Trauma · Rhabdomiolysis · Mechanical ventilation · Hemoperitoneum

Introduction

Acute renal failure (ARF) is a serious complication of trauma and has a high mortality [1]. In large trauma populations a low incidence of ARF is generally reported (from 0.098 to 8.4 %) [1, 2]. Retrospective studies [3, 4] focused only on those trauma patients who developed ARF and required dialysis. Great importance for the development of ARF after trauma was attributed to pre-existing pathological conditions such as diabetes, hypertension, etc. [1, 4], but a prospective analysis of the risk factors, especially for the more severely ill patients admitted to the intensive care unit (ICU), is still lacking.

Although the etiology is not completely understood, the early literature suggested that ARF was primarily secondary to crush injuries and rhabdomyolysis [5], while more recent publications cite decreased renal perfusion as the most common cause of this complication [6, 7].

The alteration betwen oxygenation and energy demand, as seen during trauma, may induce damage to or death of tubular cells [8–10]. Moreover, improvements in treatment, including the introduction of dialysis, have not changed the mortality of ARF [11, 12]. The prospective characterization of risk factors of post-traumatic ARF remains crucial and could help to reduce the frequency of this complication with adequate early treatment.

We prospectively analyzed 153 multiple trauma patients admitted to a general ICU to identify these risk factors.

Patients and methods

Study population and data collection

All trauma patients consecutively admitted to the general ICU from December 1991 to May 1994 were prospectively enrolled in the study. The following information was collected for each patient: demographics, severity of trauma according to the Injury Severity Score (ISS) [13], severity of coma according to the Glasgow Coma Scale (GCS) [14], presence of head, thoracic, and abdominal trauma, rib and bone fractures, hemorrhagic shock, hypovolemic shock, rhabdomyolysis, hematological dysfunction [15], acute lung injury (ALI) [16] and use of mechanical ventilation with or without positive end-expiratory pressure (PEEP), and presence of pre-existing medical conditions such as diabetes, hypertension, ischemic heart disease, chronic obstructive pulmonary disease (COPD), and obesity [3].

During the stay in the ICU, patients were monitored daily for the onset of ARF, sepsis, sepsis syndrome, septic shock, circulatory failure, multiple organ failure (MOF) [15], and use of nephrotoxic agents (i.e., aminoglycosides and radiographic contrast agents).

Volume restoration was accomplished following guidelines for volume replacement and filling pressure monitoring reported elsewhere. Briefly, 3 l of crystalloid solution was infused for each liter of estimated blood loss. In the operating room, patients received 2 l of crystalloid solution for each liter of whole blood replacement and in the recovery room crystalloid solution was given to maintain vital signs and urine flow and blood to maintain hemoglobin level and adequate tissue oxygenation [17].

In order to prevent ventilator-induced disturbances in cardiac, renal, and pulmonary function, frequent monitoring of hemodynamic and oxygen transport parameters and appropriate adjustment of tidal volume, PEEP, fluid infusion rate, and inotropic therapy was carried out [17].

Aminoglycosides were administered in a single daily-dose regimen, instead of the equivalent dose given 3 times a day. For example, tobramycin administered at 5 mg/kg per day was injected in a single bolus instead of three divided doses. Antibiotic dosages were adjusted on the basis of calculated clearance of creatinine, when indicated.

All data were stored in a computer database using a standardized worksheet. All patients with chronic renal failure were excluded from the study.

Definitions

ARF was defined as an increase in serum creatinine to levels greater than 2 mg/dl (182 μmol/l) [6–15] or > 20 % with respect to basal values, if these values were already greater than 182 μmol/l. Early ARF was defined as the preselected rise in serum creatinine level in the first 6 days after admission [1].

Rhabdomyolysis was defined as an increased concentration of creatine phosphokinase (CPK) in serum at least 5 times the basal values, with the presence of compartmental syndrome [18]. Sepsis, sepsis syndrome, and septic shock were diagnosed following the criteria previously defined by the consensus conference on sepsis [19].

Circulatory shock (hemorrhagic and hypovolemic) was defined as hypotension lasting at least 1 h (systemic arterial pressure < 90 mm Hg or a drop > 40 mm Hg with respect to basal values) and not responding to conventional administration of fluids and/or requiring doses of dopamine > 6 μg/kg per min [15, 20]. Cardiac failure was diagnosed in accordance with Goris et al. [15].

ALI was diagnosed in accordance with the European-American consensus conference [16], taking into account the score assigned to the arterial oxygen tension/fractional inspired oxygen ratio < 300, evidence of diffused radiographic pulmonary infiltrates, and pulmonary capillary wedge pressure < 18 or lack of clinical evidence of left atrial hypertension.

Pneumonia and eventual bacteremia were defined as reported elsewhere [21].

Data analysis

Data were analyzed using the BMDP statistical package (BMDP statistical software, Los Angeles, 1990). Odds ratios (OR), confidence intervals, and a Pearson chi-square test with Yates' correction or a Fisher's exact test were calculated to identify which factors were most related to ARF. When confidence intervals for ORs were not reliable, exact limits were calculated. A multiple logistic regression was then performed to obtain an adjusted estimate of the ORs and to identify which factors were independently associated with ARF. All variables which showed a p value below 0.25 in the univariate analysis were entered in the model. A significant improvement in the log likelihood function was the main criterion for entering variables in the model. The effect of possible confounding factors was determined by introducing them in the final model and noting the change in the coefficients of the risk factors.

Results

During the study period, 153 patients were admitted for trauma to the ICU. These patients mainly consisted of men (79.7%), whose mean age was 37.6 ± 19.6 years. The average ISS for all patients was 28.1 ± 11, 77 patients (50.3%) presented a GCS < 10, and 28 (18.3%) had a GCS < 5. Fifty-nine patients (38.3%) died. Mean length of stay in the ICU was 17.8 ± 22.9 days.

Ninety-two patients (60.1%) with ALI required mechanical ventilation. Rhabdomyolysis was present in 67 (43%) patients. Fifty-eight patients had a CPK serum concentration < 10000 IU/l and 9 > 10000 IU/l. Sepsis, sepsis syndrome, or septic shock was observed in 46 patients (30%). The incidence of pre-existing medical conditions did not differ between the patients who developed ARF and those who did not: diabetes 2 (4%) and 7 (7%), hypertension 3 (6%) and 12 (11%), ischemic heart disease 2 (4%) and 5 (5%), COPD 3 (6%) and 3 (3%), obesity 4 (8%) and 9 (8%).

As shown in Table 1, 48 (31%) patients of the 153 developed ARF according to the definitions. These patients were older than the 105 (69%) patients without renal failure ($p = 0.002$), were more severely ill

Table 1 Characteristics and outcome for the whole population studied. Values are mean ± SD

	Without renal failure	Acute renal failure	p
Number of patients (%)	105 (69)	48 (31)	
Age (years)	34 ± 6	45 ± 17	0.002
GCS	11 ± 3	8 ± 4	0.007
ISS	26 ± 8	35 ± 9	< 0.001
Rescue time (min)	70 ± 16	68 ± 18	0.6
Patients transported by helicopter (%)[a]	4 (4)	1 (3)	0.5
MAP at admission (mm Hg)	101 ± 19	87 ± 23	0.0015
Fluids before ICU admission (ml/kg per h)[b]	17 ± 5	19 ± 6	0.3
Urine output at admission (ml/h)	108 ± 55	95 ± 76	0.2
Patients receiving PRBC or plasma (%)[c]	32 (30)	28 (58)	0.002
Male (%)	85 (81)	37 (77)	0.3
Died (%)	19 (18)	40 (83)	< 0.001
Length of ICU stay (days)	17 ± 19	16 ± 17	0.7
RRT (%)	None	12 (25)	< 0.001
Discharge with ARF	None	None	
Discharge with dialysis	None	None	
Nephrotoxic agents (%)	52 (49)	21 (44)	0.6
Surgical procedures (%)	26 (25)	15 (31)	0.5
Sepsis (%)	27 (26)	19 (40)	0.06

(*GCS* Glasgow Coma Score, *ISS* Injury Severity Score, *MAP* mean arterial pressure, *PRBC* packed red blood cells, *RRT* renal replacement therapy)

[a] The vast majority of patients (96 % of trauma patients without renal failure and 97 % of patients with renal failure) were transported by ambulance

[b] Fluids before ICU admission denotes the amount of fluid infused, not including PRBC and plasma

[c] Each patient received a minimum of 4 units PRBC and 5 units of plasma

($p = 0.001$), had a higher mortality ($p < 0.001$), had a more compromised neurological condition as assessed by GCS ($p = 0.007$), and their mean arterial pressure at study entry was lower ($p = 0.0015$). Fifty-two (49 %) patients without renal failure and 21 (44 %) with ARF received aminoglycosides as nephrotoxic agents ($p = 0.6$). The number of surgical procedures did not differ between the two groups, and the length of stay was similar as well as the amount of fluids infused before admission. Urine output at admission to the ICU was slightly higher for patients who did not develop ARF in comparison to those who did (108 ± 55 ml/h vs 95 ± 76, $p = 0.2$). ARF occurred in 8/11 (72 %) patients who had hemoperitoneum (5 splenic and 3 hepatic ruptures) (Table 3). Patients with ARF more frequently received packed red blood cells and plasma ($p = 0.002$).

Thirty-two (66 %) patients developed early renal failure. Seventeen (55 %) of these 32 were hypotensive at admission to the ICU (mean arterial pressure < 80 mm Hg) compared with only 3 (18 %) of the 16 patients who developed late renal failure ($p = 0.022$, Fisher's exact test).

Among the 48 patients with ARF, 21 (43 %) had a serum creatinine value > 2 mg/dl (182 µmol/l) and 27 (56 %) had a level ≥ 4 mg/dl (363 µmol/l). These two subgroups of patients with ARF had similar characteristics (Table 2). Mortality was higher for patients whose serum creatinine level was ≥ 4 mg/dl (363 µmol/l), but this difference was not significant ($p = 0.06$). Patients with ARF and higher creatinine values had a lower urine output at admission ($p = 0.003$), received a smaller amount of fluids before admission ($p = 0.0006$), and there were more who required renal replacement therapy ($p = 0.0004$) (Table 2).

All patients who received renal replacement therapy died due to severe MOF. No patient was discharged with the diagnosis of chronic renal failure or needed longterm chronic dialysis.

The factors significantly associated with ARF in the univariate and multivariate analyses are shown in Table 3. In the univariate analysis, the risk of onset of ARF was increased by increasing age, an ISS > 17, the presence of hemoperitoneum, shock, hypotension, and bone fractures, rhabdomyolysis with CPK > 10000 IU/l, ALI requiring mechanical ventilation, and a GCS < 10.

By contrast, sepsis, use of nephrotoxic agents (that is, nephrotoxic antibiotics), thoracic trauma, presence of pelvic fractures or ruptured kidney, and hematological dysfunction were not associated with an increased risk of ARF in either the univariate or the multivariate analysis. The variable MOF identified only 7 patients whose MOF occurred before ARF. Since all these patients developed ARF, it was impossible to include this variable in the model.

In the logistic regression model, the need for mechanical ventilation with PEEP > 6 cm H_2O, rhabdomyolysis with CPK > 10000 IU/l, and hemoperitoneum were the three conditions most strongly associated with ARF. Each of these conditions increased the risk by ARF at least 14-fold. The severity of coma, with a GCS < 5, emerged as another important factor capable of increasing five-fold the risk of ARF (Table 3). Long bone fractures were associated with ARF also after stratification by rhabdomyolysis (66.7 % of patients with bone fractures had a CPK > 10000 IU/l, $p = 0.0001$) or by shock (55 % of patients with bone fractures also were in shock, $p = 0.002$).

Table 2 Characteristics of the 48 patients with ARF stratified by serum creatinine values *CRE*. Values are mean ± SD or numbers (%)

	CRE > 2 (182 μmol/l)	CRE > 4 (363 μmol/l)	*p*
No. of patients	21	27	
Male (%)	13 (62)	23 (89)	0.10
Discharge (%)	6 (29)	2 (7)	0.05
Died (%)	15 (71)	25 (93)	0.06
Age (years)	44 ± 12	46 ± 10	0.3
ISS	37 ± 12	32 ± 10	0.2
GCS < 10 (%)	14 (67)	16 (60)	0.4
Hematological dysfunction (%)	2 (10)	5 (19)	0.3
Multiple fractures (%)	8 (38)	7 (27)	0.27
Long bone fractures (%)	10 (48)	10 (38)	0.32
Cardiac failure (%)	7 (33)	3 (11)	0.07
Acute lung injury (%)	19 (90)	25 (96)	0.4
Multiple organ failure (%)	7 (33)	14 (53)	0.2
Nephrotoxic agents (%)	7 (33)	15 (60)	0.1
Rhabdomyolysis (%)	11 (52)	11 (42)	0.3
Sepsis (%)	6 (29)	13 (50)	0.14
Hemorrhagic shock (%)	2 (10)	7 (27)	0.14
Abdominal trauma (%)	6 (29)	6 (23)	0.4
Head trauma (%)	14 (68)	16 (62)	0.23
Thoracic trauma (%)	6 (29)	14 (54)	0.09
MAP at admission (mm Hg)	88 ± 28	87 ± 27	0.9
Urine output at admission (ml/h)	132 ± 75	70 ± 60	0.003
Fluids before ICU admission (ml/kg per h)[a]	20 ± 6	15 ± 4	0.0006
RRT (%)	0	12 (46)	0.0004
Early renal failure (%)[b]	16 (76)	16 (59)	0.08
Patients receiving PRBC or plasma (%)[c]	9 (43)	19 (70)	0.1

(*GCS* Glasgow Coma Score, *ISS* Injury Severity Score, *MAP* mean arterial pressure, *PRBC* packed red blood cells, *RRT* renal replacement therapy)
[a] Fluids before ICU admission denotes the amount of fluid infused, not including PRBC and plasma
[b] Renal failure was defined as "early" if it occurred within the first 6 days after admission
[c] Each patient received a minimum of 4 units PRBC and 5 units of plasma

Discussion

In retrospective studies on large trauma populations, a low incidence of ARF is generally reported (from 0.098 to 8.4%) [1, 2]. In our population of patients, the incidence was higher (31%), probably due to different factors. First, the present study was prospective and concentrated only on more severe trauma patients admitted to intensive care, with no comparison with the general, less severe trauma population. Second, our definition of ARF was broader than in other studies [1] and included not only patients who needed dialysis. Definitions of ARF have often been very different. Notably, in a recent review [8, 22] of 26 studies on postoperative renal failure, no two studies used the same definition of ARF. Commonly used definitions of ARF [8] include an increase in serum creatinine of > 0.5 mg/dl (44 μmol) over baseline values, an increase of more than 50% over baseline values, a reduction in the calculated creatinine clearance of 50%, or a decrease in renal function that results in the need for dialysis. However, studies on the general intensive care population report an incidence of ARF similar to that in our trauma patients admitted to the ICU [23].

The major finding of the present sutdy was that an increased age, an ISS higher than 17, mean arterial pressure below 80 mm Hg, hemoperitoneum, circulatory shock, bone fractures, rhabdomyolysis with CPK > 10000 IU/l, ALI requiring mechanical ventilation, abdominal trauma, and a GCS < 5 were all important risk factors for the onset of ARF.

In the past, ARF in trauma patients was reported to be mainly secondary to crush injuries and rhabdomyolysis [5], whereas more recently decreased renal perfusion has emerged as the most common cause of ARF [1, 6, 7, 24–25].

Hemoperitoneum, bone fractures, and circulatory shock are all capable of inducing renal hypoperfusion, due to hypovolemia. It is noteworthy that 20 of the 48 patients who developed ARF had a lower mean arterial pressure, confirming the possibility of renal hypoperfusion.

In the logistic regression model, other factors such as rhabdomyoloysis with CPK > 10000 IU/l or hemoperitoneum were associated with ARF more strongly than hypotension. Sixty-seven patients developed rhabdomyolysis, and 23 of them developed ARF. The incidence of ARF rose when the CPK serum levels increased. When rhabdomyolysis was associated with bone fractures, the frequency of ARF increased proportionally with CPK serum levels. Another important association was that between bone fractures and shock. These three variables were strictly associated, confirming the importance of trauma extension as one of the major determinants for ARF. The importance of extensive injuries was previously stressed by Regel et al. [2] in a retrospective analysis of 3406 cases.

Abdominal trauma and hemoperitoneum were other risk factors for ARF. During trauma, the consequences of elevated intra-abdominal pressure are also significant determinants for the impairment of renal function [26, 27]. One limitation of the present study was the lack of measurements of intra-abdominal pressure, which could

Table 3 Risk factors for ARF: univariate and multivariate analysis (*OR* odds ratio, *95% CI* 95% confidence interval, *MV* mechanical ventilation)

Variables	Patients	ARF (%)	Univariate analysis		Multivariate analysis[a]	
			OR	95% CI	OR	95% CI
Age (years)[b]			2.82	1.36–5.84	1.61	1.22–2.13
Glasgow Coma Score						
> 10	76	23.7	1.00			
6–10	49	32.7	1.56	0.70–3.49	1.80	0.47–6.81
< 5	28	50.0	3.22	1.29–8.07	6.31	1.44–27.6
ISS						
< 16	28	7.1	1.00			
17–32	88	30.7	5.75	1.26–26.3	11.70	1.06–130
> 32	37	51.4	13.7	2.8–67.2	17.10	1.48–198
Mean arterial pressure (mm Hg)						
> 80	113	24.8	1.00			
< 80	40	50.0	3.04	1.42–6.48		
Respiratory failure						
No	44	13.6	1.00			
Yes, Venturi mask	17	17.6	1.36	0.30–6.25	1.00	0.14–7.01
Yes, MV, PEEP < 6 cm H_2O	77	36.4	3.62	1.35–9.70	2.89	0.63–13.2
Yes, MV, PEEP > 6 cm H_2O	15	73.3	17.4	4.11–73.8	20.70	2.53–169
Multiple organ failure (MOF)						
No or following ARF	146	28.1	Not calculable			
Yes	7	100.0				
Rhabdomyolysis						
No	86	29.1	1.00			
Yes, CPK < 10000 UI/l	58	29.3	1.01	0.46–2.24	1.44	0.47–4.35
Yes, CPK > 10000 UI/l	9	66.7	4.88	1.12–21.3	17.70	2.22–141
Shock						
No	126	27.8	1.00			
Yes	27	48.1	2.41	0.95–6.13		
Hemoperitoneum						
No	142	28.2	1.00			
Yes	11	72.7	6.80	1.70–27.2	11.90	1.73–81.6
Long bone fractures						
No	106	25.5	1.00			
Yes	47	44.7	2.36	1.14–4.89	4.08	1.37–12.1
Abdominal trauma						
No	126	27.8	1.00			
Yes	27	48.1	2.41	1.03–5.69		
No. of patients	153	48				

[a] Age has been analyzed as interval variable by decades
[b] Only variables indipendently associated with ARF, entered in the final model, are reported. Goodness of fit χ^2, $p = 0.953$; Goodness of fit χ^2 (Hosmer-Lemeshow), $p = 0.90$; Goodness of fit χ^2 (C. C. Brown), $p = 0.616$

have confirmed the hypothesis. Multiple logistic regression recognized only hemoperitoneum as an independent variable. ARF occurred in 72% of patients who had hemoperitoneum due to splenic and hepatic ruptures. This finding appears to be relevant, as the incidence of splenic or liver rupture with consequent hemoperitoneum is reported to be 36% in large trauma populations [2].

An important iatrogenic risk factor for the onset of ARF in our group of trauma patients was the need for mechanical ventilation for the treatment of ALI, which increased the relative risk at least three-fold. This risk increased dramatically when PEEP was > 6 cm H_2O, despite volume replacement, maintenance of normal filling pressures, and adequate oxygen delivery. In the general population, it has been clearly demonstrated [28] that mechanical ventilation requiring high airway pressure to maintain adequate gas exchange reduces renal perfusion, due to the increased hydrostatic pressure over the entire venous compartment.

Patients with more compromised neurological conditions (GCS < 5) were at major risk to develop ARF.

One explanation of this finding could be the longer requirement for artificial supports (as mechanical ventilation) for those patients neurologically more compromised, who stay longer in the unit and are more exposed to possible complications. Regel et al. [2] reported prolonged ICU stay for those patients with severe head injury.

The use of nephrotoxic antibiotics deserves a specific comment. The incidence of aminoglycoside nephrotoxicity has ranged from 5 to 36 % in most studies [29, 30]. Seventy-three patients received a single daily dose of aminoglycosides due to bacterial isolates, but the use of this nephrotoxic agent was not a risk factor for ARF. This contradicts the report of Hock and Anderson [29], who found that the use of nephrotoxic agents may favor the onset of ARF in the general population. This discrepancy can be explained by the attitude of our unit toward administering aminoglycosides in a single daily-dose regimen, rather than giving the equivalent dose in a three-times-a-day regimen. Recent studies showed the efficacy and safety of a single-dose regimen [29, 31].

Patients with a serum creatinine level greater than 2 mg/dl (182 μmol/l) and patients with levels equal to or greater than 4 mg/dl (363 μmol) had similar characteristics. Both groups of patients had a high mortality, despite differing severity of renal failure. Those patients with higher serum creatinine values had a lower urine output at admission and received a smaller amount of fluids. All trauma patients received an average of 1200 ml/h of fluids before ICU admission, not including plasma and blood transfusions. Other authors recommended larger amounts of fluids [2, 17]. This findings suggests that a suboptimal fluid replacement may have increased the risk for ARF in the hypotensive patients, stressing the need of a thorough policy of fluid infusion during the first few hours after trauma. Regel et al. [2] showed that, during recent decades, the dramatic increase in fluid administration to trauma patients in the first 24 h after injury has sensibly reduced the incidence of complications, including ARF, and improved outcome. Moreover, in that study, 74 % of the trauma population were transported by helicopter with a shorter rescue time. Our university hospital is located downtown and does not have a landing area close by for helicopters, so the vast majority of trauma patients (97 %) are transferred by ambulance after the rescue. This factor certainly prolonged the time interval before hospital admission and implied a delayed stabilization of clinical conditions.

Twelve patients (25 %) with a serum creatinine greater than 4 mg/dl (363 μmol) necessitated renal replacement therapy. All these patients died due to irreversible MOF. Although hemodialysis and hemofiltration can be used to correct the life-threatening metabolic complications of ARF, they do not reduce attributable mortality, reported in recent series at 42 to 88 % [12].

Therefore, prevention of ARF in severe trauma patients admitted to the intensive care unit remains crucial. The risk factors for post-traumatic ARF identified in the present study may help the provision of future strategies.

References

1. Morris JA, Mucha P, Ross SE et al (1991) Acute posttraumatic renal failure: a multicenter perspective. J Trauma 31: 1584–1590
2. Regel G, Lobenhoffer P, Grotz M, Pape HC, Lahmann, Tscherne H (1995) Treatment results of patients with multiple trauma: an analysis of 3406 cases treated between 1972 and 1991 at German level I trauma center. J Trauma 38: 70–77
3. Morris JA, MacKenzie EJ, Edelstein SL (1990) The effect of preexisting conditions on mortality in trauma patients. JAMA 262: 1942–1948
4. Tran DD, Cuesta MA (1994) Acute renal failure in patients with severe civilian trauma. Nephrol Dial Transplant 9: 121–125
5. Letteri JM (1987) Post-traumatic acute renal failure. Adv Exp Med Biol 212: 211–218
6. Menashe PI, Ross SA, Gottlieb JE (1988) Acquired renal insufficiency in critically ill patients. Crit Care Med 16: 1106–1109
7. Stene JK (1990) Renal failure in trauma patients. Crit Care Clin 6: 111
8. Thadani R, Pascual M, Bonventre JV (1996) Acute renal failure. N Engl J Med 30: 1448–1459
9. Mason JC, Joeris B, Welsch J, Kriz W (1989) Vascular congestion in ischemic renal failure: the role of cell swelling. Miner Electrolyte Metab 15: 114–124
10. Vetterlein F, Petho A, Schmidt G (1986) Distribution of capillary blood flow in the rat kidney during postischemic renal failure. Am J Physiol 215: H510–H519
11. Meyer AA (1988) Acute renal failure. In: Wilmore DW, Brennan MF, Harken AH et al (eds) American College of Surgeons care of the surgical patients. Scientific American: 2.6: 1–12
12. Levy EM, Viscoli CM, Horwitz RI (1996) The effect of acute renal failure on mortality – a cohort analysis. JAMA 275: 1489–1494
13. Baker SP, O'Neill B, Haddon W et al (1988) The Injury Severity Score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma 14: 187–196
14. Teasdale G, Jennet B (1974) Assessment of coma and impaired consciousness. A practical scale. Lancet II: 81–84
15. Goris RJA, Boekhorst TPA, Niytink JKS, Gimbrere JFS (1985) Multiple organ failure: generalized autodestructive inflammation? Arch Surg 120: 1109–1114
16. Bernard GR, Artigas A, Brigham J, Carlet J, Falke K, Hudson M, Lamy M, LeGall R, Morris A, Spragg R, Consensus Committee (1994) The American-European consensus conference on ARDS. Am J Respir Crit Care Med 149: 818–824

17. Lucas EC, Ledgerwood AM (1991) Hemodynamic Management of the Injured. In: Capan LM, Miller SM, Turndorf H (eds) Trauma: anesthesia and intensive care. Lippincott, Philadelphia, pp 83–113
18. Knochel JP (1981) Rhabdomyolysis and myoglobinuria. Semin Nephrol 1: 75
19. American College of Chest Physicians, Society of Critical Care Medicine (ACCP/SCCM) Consensus Conference (1992) Definitions for sepsis and organ failure and guidelines for the use of innovative therapies in sepsis. Crit Care Med 20: 864–874
20. Antonelli M, Moro ML, Capelli O, DeBlasi RA, D'Errico RR, Conti G, Bufi M, Gasparetto A (1994) Risk factors for early and late onset pneumonia in trauma patients. Chest 105: 224–228
21. Antonelli M, Moro ML, D'Errico RR, Conti G, Bufi M, Gasparetto A (1996) Early and late onset bacteremia and different risk factors in trauma patients. Intensive Care Med 22: 735–741
22. Novis BK, Roizen MF, Aroson S, Thisted RA (1994) Association of preoperative risk factors with postoperative acute renal failure. Anesth Analg 78: 143–149
23. Groeneveld ABJ, Tran DD, Ven der Meulen J, Nauta JJP, Thijs JG (1991) Acute renal failure in the medical intensive care unit: predisposing, complicating factors and outcome. Nephron 59: 602–610
24. Shustermann N, Strom BL, Murray TG (1987) The risk factors and outcome of hospital-acquired acute renal failure. Am J Med 83: 63–71
25. Hou SL, Bushinsky DA, Wish DB et al (1983) Hospital-acquired renal insufficiency: a prospective study. Am J Med 74: 243–248
26. Harmann PK, Kron IL, McLachaln HD et al (1982) Elevated intra-abdominal pressure and renal function. Ann Surg 196: 594–597
27. Antonelli M, Moro ML, Vivino G (1995) Bacteremia, pneumonia and acute renal failure in trauma patients. In Yearbook Intensive Care Emerg Med 834–842
28. Shinozaki M et al (1988) Hemodynamic relationship between renal venous pressure during positive and expiratory pressure. Crit Care Med 16: 144–147
29. Hock R, Anderson RJ (1995) Prevention of drug-induced nephrotoxicity in the intensive care unit. J Crit Care 10: 33–43
30. Bellomo R, Ronco C (eds) (1996) Drug induced acute renal failure. In: Acute renal failure in the critically ill, Springer, Berlin Heidelberg New York, pp 183–213
31. Prins JM, Buller HR, Kuijper EJ et al (1993) Once versus thrice daily gentamicin in patient with serious infection. Lancet 341: 335–339