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Renal replacement therapies in the aftermath of the catastrophic Marmara earthquake

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Background. Renal replacement therapy is of vital importance in the treatment of crush syndrome victims, who are frequently encountered after catastrophic earthquakes. The Marmara earthquake, which struck Northwestern Turkey in August 1999, was characterized by 477 victims who needed dialysis.

Method. Within the first week of the disaster, questionnaires containing 63 clinical and laboratory variables were sent to 35 reference hospitals that treated the victims. Information considering the features of dialyses obtained through these questionnaires was submitted to analysis.

Results. Overall, 639 casualties with renal complications were registered, 477 of whom (mean age 32.3 ± 13.7 years, 269 male) needed dialysis. Among these, 452 were treated by a single dialysis modality (437 intermittent hemodialysis, 11 continuous renal replacement therapy and 4 peritoneal dialysis), while 25 victims needed more than one type of dialysis. In total, 5137 hemodialysis sessions were performed (mean 11.1 ± 8.0 sessions per patient) and mean duration of hemodialysis support was 13.4 ± 9.0 days; this duration was shorter in the non-survivors (7.0 ± 8.7 vs. 10.0 ± 9.8 days, $P = 0.005$). Thirty-four victims who underwent continuous renal replacement therapy had higher mortality rates (41.2 vs. 13.7%, $P < 0.0001$). Only eight victims were treated by peritoneal dialysis, four of whom also required hemodialysis or continuous renal replacement therapy. The mortality rate in the dialyzed victims was 17.2%, a significantly higher figure compared to the mortality rate of the non-dialyzed patients with renal problems (9.3%; $P = 0.015$).

Conclusion. Substantial amounts of dialysis support may be necessary for treating the victims of mass disasters complicated with crush syndrome. Dialyzed patients are characterized by higher rates of morbidity and mortality.

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During catastrophic earthquakes, crush syndrome is the second most frequent cause of mortality after the direct impact of trauma [1], and calculated mortality rates up to 40% have been noted among the victims complicated with acute renal failure (ARF) and requiring renal replacement therapy (RRT) [2, 3]. Acute renal failure secondary to crush syndrome is unique because of frequent surgical and medical complications in addition to serious laboratory abnormalities such as fatal hyperkalemia and severe acidosis; therefore, RRT is of vital importance [3, 4].

During the treatment of crush victims of catastrophic disasters, RRT deserves special attention for several reasons: (*1*) emergency dialysis is frequently needed, mainly due to life-threatening hyperkalemia and volume overload [5, 6]; (*2*) capacities of local dialysis centers may be overwhelmed and stocked dialysis material can be insufficient to cope with such an "epidemic" of crush syndrome [7–9]; (*3*) the general infrastructure (such as water supply and electricity) as well as dialysis units can be damaged in the disaster area [10]; and (*4*) since dialysis personnel and their families are prone to be victims of the disaster themselves [10], available facilities may not always work efficiently.

All these matters were seriously considered by the Turkish nephrologists after the devastating Marmara earthquake that struck Northwestern Turkey on 17 August 1999, at 03.01 AM. The disaster was registered to be 7.4 on the Richter scale, lasted for 45 seconds, and caused more than 17,000 deaths and 43,000 injured according to official statistics [11], while the locally estimated mortality rate was even higher. One of the most critical features of the Marmara disaster was the registration of 639 casualties with renal complications of whom 477 needed dialysis support. Detailed descriptions considering these patients' epidemiological features as well as offered help have been provided in other publications [12, 13].

The present study aims to provide a comprehensive analysis of the demographic features, clinical and laboratory findings as well as the outcome of the victims who required at least one form of RRT, besides logistic aspects related to dialysis in the aftermath of the disaster.

METHODS

Patients

Within the first week of the disaster, the Turkish Society of Nephrology in collaboration with the Renal Disaster Relief Task Force (RDRTF) of the International Society of Nephrology (ISN) prepared questionnaires to analyze the extent of the nephrological problems. These questionnaires were sent to the nephrology units of 35 reference hospitals that treated the victims. A detailed outline of the questionnaire has been described previously [13].

In the questionnaires, crush syndrome was defined as the patients with crush injury and systemic manifestations, such as shock, acidosis and ARF [14]. The term "nephrological problems" was defined as the occurrence of oliguria (urinary output <400 mL/day), elevated levels of blood urea nitrogen (BUN; >40 mg/dL, that is, 14.3 mmol/L), serum creatinine (>2.0 mg/dL, 176.8 μmol/L), uric acid (>8 mg/dL, 475.8 μmol/L), potassium (K^+; >6 mEq/L), phosphorus (P; >8 mg/dL, 2.6 mmol/L) or decreased serum calcium (Ca^{2+}; <8 mg/dL, 2 mmol/L) at admission.

Such a broad definition of "nephrological problems," considering more than serum creatinine, urea and urinary volume alone, was ruled by our concern to include all victims in whom the kidneys could not cope with the metabolic derangements of crush injury at that particular time, as modeled on a previous study [15].

The percentage of patients meeting each of the criteria to be included in the analysis were as follows: 58% with oliguria, 79% high levels of BUN, 80% serum creatinine, 28% hyperkalemia, 24% hyperuricemia, 9% hyperphosphatemia; and 59% with hypocalcemia.

In the present study, considering the analyses related to admission parameters, only the data of the patients who were admitted to reference hospitals within the first three days of the disaster were taken into account. The rationale of this policy was that patients were admitted to the reference hospitals even one month after the disaster. Therefore, the admission data of the patients hospitalized later on might not have represented the clinical findings of an immediate disaster victim. On the other hand, for all other parameters including demographics, clinical and laboratory findings, the whole series (639 patients) were considered.

Statistical analysis

Descriptive statistics of all numeric variables, including means, standard deviations and minimum and maximum values, together with the proportions of all categorical variables were calculated. Two independent group means were compared by means of the Student *t* test for independent groups. If the group variances were not homogeneous as evidenced by Levene's test, the *P* values were adjusted. Correlations between numeric variables were examined by Pearson simple correlation coefficients. The correlation between all other variables and the number of traumatized extremities, the number of extremity fractures, the number of extremities with fasciotomies and the number of amputated extremities were examined by Spearman non-parametric correlation coefficients. *P* values were not adjusted when multiple statistical tests were performed.

For the analysis of the prediction of dialysis needs, first univariate tests (the Student *t* test for independent groups for numeric variables and chi-square test for categorical variables) were performed. Those variables that were found to be significant in univariate tests as well as some demographic findings were submitted to a multivariate logistic regression analysis.

Statistical significance was assigned to *P* values less than 0.05.

RESULTS

Overall demography

Taken as a whole, 9843 patients were admitted to reference hospitals; 5302 of whom were hospitalized and 425 died (overall mortality rate of 4.3%). Among the hospitalized victims, 639 were complicated with renal problems, and of these 477 (74.6%) were treated by dialysis. Accordingly, 12.0% of all hospitalized patients developed renal problems and 8.9% needed RRT.

The mean age of the victims with renal problems was 31.7 ± 14.7 (range 0.3 to 90) years, and most of them (69.3%) belonged to the age strata between 10 and 40 years. There were slightly more males than the females [348 (54%) vs. 291 (46%)]. Fifty (14.3%) deaths were noted among the male victims, while 47 (16.1%) of the female patients lost their lives ($P = 0.53$).

Demographic features of the victims related to RRT

Three RRT modalities, that is, intermittent hemodialysis (IHD), continuous renal replacement therapy (CRRT) or peritoneal dialysis (PD) were used for the treatment of the victims. Intermittent hemodialysis was the most commonly applied treatment modality; 437 and 462 of the dialyzed patients received IHD either solely or in combination with other dialysis modalities, respectively. CRRT was applied to 34 patients, whereas only 8 patients were treated with PD.

Of the 348 male victims, 269 (77.3%) were dialyzed, while 208 (71.5%) of the 291 female victims needed dialysis support ($P = 0.09$). Mean age of the patients who needed dialysis support (32.3 ± 13.7 years; range 2.5 to 87) was not significantly different from those who were not dialyzed (29.8 ± 17.4 years; range 0.3 to 90; $P = 0.068$). Considering age categories and dialysis needs, 85%, 79.5% and 77.8% of the patients within the 31 to 45, 16 to 30 and 61 to 75 age strata were dialyzed, respectively. The lowest dialysis needs (47.9%) were noted among the patients within the 0 to 15 age stratum, while elderly victims (aged more than 76) were also characterized by low dialysis needs ($P = 0.04$; Fig. 1A).

Dialyzed victims were characterized by a shorter time period under the rubble than the rest of the population (10.3 ± 9.5 vs. 15.9 ± 23.1 hours, $P < 0.001$). Considering time strata of 9 to 12, 13 to 16, 17 to 24, and 25 to 36 hours, the percentage of dialyzed victims was above 75%, while only 1 (14.3%) of the seven victims who were entrapped more than 72 hours needed dialysis support. Of the two victims who were rescued within the first hour of the disaster, one was dialyzed, while dialysis need was 60.8%, considering the victims who stayed under the rubble for one to four hours ($P = 0.03$; Fig. 1B).

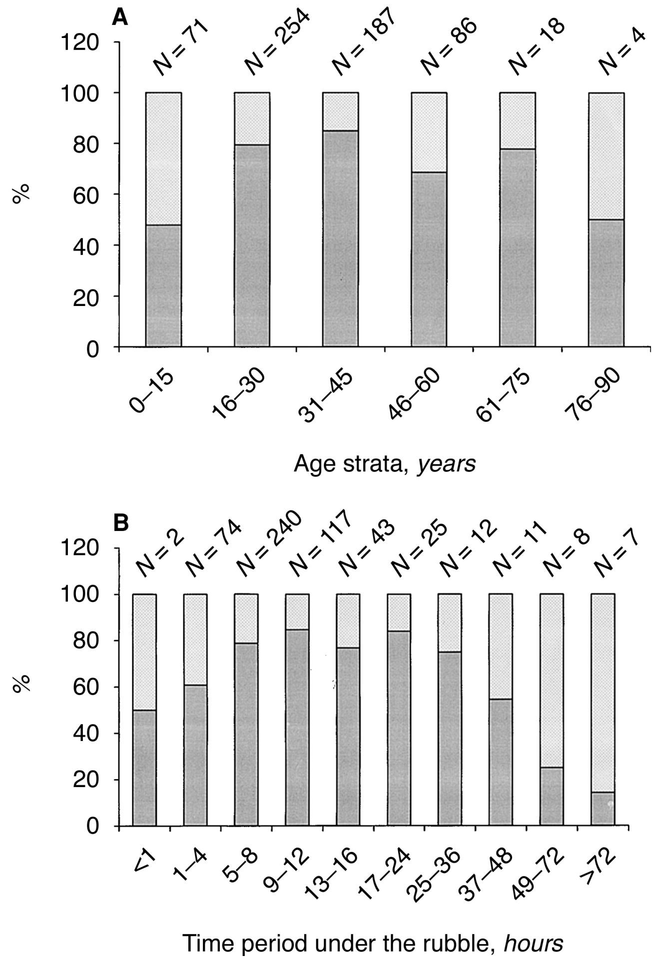

Fig. 1. Percentages of dialyzed victims in different age strata (*A*) as well as in various time strata spent under the rubble (*B*). Symbols are: (■) dialyzed; (□) non-dialyzed.

Clinical and laboratory features associated with RRT

Admission parameters both in dialyzed and non-dialyzed victims who were admitted within the first three days of the disaster are provided in Table 1. Urinary volume, platelet count and serum albumin levels were lower, while mean blood pressure, leukocyte count, BUN, serum creatinine, uric acid, potassium, phosphorus and creatinine kinase values were higher in the dialyzed victims.

Dialyzed patients were characterized by a higher number of traumatized (1.3 ± 0.9 vs. 0.9 ± 0.7, $P < 0.001$), and fasciotomized extremities (0.7 ± 0.7 vs. 0.4 ± 0.6, $P < 0.001$), longer durations of oliguria (10.2 ± 7.5 vs. 0.4 ± 1.2 days, $P < 0.001$), and polyuria (11.0 ± 7.8 vs. 7.7 ± 6.8 days, $P = 0.001$) and a higher serum creatinine value immediately before discharge (1.4 ± 1.1 vs. 0.9 ± 0.7, $P = 0.001$).

Dialysis was performed more frequently to the patients who suffered from extremity trauma, sepsis, pneumonia, acute respiratory distress syndrome (ARDS), disseminated intravascular coagulation (DIC) and hypertension and also to those who underwent fasciotomy. Also, the need for antibiotic treatment, blood, fresh frozen plasma (FFP) and human albumin transfusions were more frequent in the dialyzed victims (Table 2).

A multivariate logistic regression analysis (which included significant univariate variables related to dialysis needs as well as clinically relevant parameters such as age, gender, time period under the rubble, etc.) indicated that age, gender (male), time period under the rubble, abdominal trauma, fasciotomy, sepsis, pneumonia, and need for FFP transfusions were associated with dialysis needs (Table 3).

Types of dialysis therapy

Intermittent hemodialysis. Receiving IHD therapy was related to mortality at the borderline level of significance. Among the 437 patients who underwent IHD, 67 (15.3%) died, whereas the mortality rate was 9.3% (15/162) among the patients who did not need dialysis ($P = 0.055$).

Table 1. Admission laboratory findings of the patients who were admitted within the first three days of the disaster with regard to need of dialysis support

Parameters	Dialysis	*N*	Mean	SD	Minimum	Maximum	*P*
Urinary volume *mL/day*	(−)	97	1670	1455	0	7500	<0.001
	(+)	273	393	697	0	4600	
Mean blood pressure *mm Hg*	(−)	104	88	16	27	147	<0.001
	(+)	296	96	18	40	167	
Leukocyte count/*mm³*	(−)	91	13227	5692	4900	34600	=0.002
	(+)	282	15499	6803	3000	50100	
Platelet count/*mm³*	(−)	90	194596	91858	8600	653000	=0.006
	(+)	277	180525	145072	14500	2130000	
Blood urea nitrogen *mg/dL*	(−)	108	45.4	26.9	9	149	<0.001
	(+)	303	58.6	28.8	13	269	
Serum creatinine *mg/dL*	(−)	106	2.3	1.5	0.3	7.8	<0.001
	(+)	303	4.6	2.2	0.5	16.1	
Serum uric acid *mg/dL*	(−)	52	5.2	2.1	1.3	13	<0.001
	(+)	189	6.8	2.5	1.7	17.9	
Serum potassium *mEq/L*	(−)	106	4.7	0.9	2.7	8.91	<0.001
	(+)	295	5.7	1.3	2.4	13.3	
Serum phosphorus *mg/dL*	(−)	40	4.1	1.4	0.7	7.5	<0.001
	(+)	178	5.5	1.8	2	12.4	
Serum creatine kinase *IU/mL*	(−)	13	20901	22999	1384	85652	=0.018
	(+)	57	66713	83456	77	459800	
Serum albumin *g/dL*	(−)	58	2.7	0.7	1.1	4.2	=0.036
	(+)	221	2.5	0.7	1.3	4.8	

Table 2. Univariate analysis of clinical factors as well as therapeutic interventions related to dialysis support

Parameter	Presence/absence	Not dialyzed	Dialyzed	*P*
Extremity trauma	−	48 (37.8%)	79 (62.2%)	<0.001
	+	114 (22.3%)	398 (77.7%)	
Fasciotomy	−	110 (34.8%)	206 (65.2%)	<0.0001
	+	52 (16.1%)	271 (83.9%)	
Sepsis	−	150 (29.0%)	368 (71.0%)	<0.0001
	+	12 (9.9%)	109 (90.1%)	
Pneumonia	−	161 (26.9%)	437 (73.1%)	<0.0001
	+	1 (2.4%)	40 (97.6%)	
ARDS	−	156 (26.4%)	436 (73.6%)	=0.04
	+	6 (12.8%)	41 (87.2%)	
DIC	−	159 (26.7%)	436 (73.3%)	=0.003
	+	3 (6.8%)	41 (93.2%)	
Hypertension	−	160 (26.4%)	447 (73.6%)	=0.01
	+	2 (6.3%)	30 (93.8%)	
Antibiotic administration	−	92 (31.5%)	200 (68.5%)	=0.001
	+	70 (20.2%)	277 (79.8%)	
Blood transfusion	−	109 (39.1%)	170 (60.9%)	<0.0001
	+	53 (14.7%)	307 (85.3%)	
FFP transfusion	−	141 (32.8%)	289 (67.2%)	<0.0001
	+	21 (10.0%)	188 (90.0%)	
Human albumin transfusion	−	116 (33.7%)	228 (66.3%)	<0.0001
	+	46 (15.6%)	249 (84.4%)	

Abbreviations are: ARDS, acute respiratory distress syndrome; DIC, disseminated intravascular coagulation; FFP, fresh frozen plasma.

In total, 5137 hemodialysis sessions were applied to 462 patients. The mean number of sessions was 11.1 ± 8.0 (range 1 to 48) and 22 patients needed only one therapeutic session (Fig. 2). The survivors and non-survivors were treated by 8.3 ± 8.5 (range 0 to 48) and 6.6 ± 8.1 (0 to 36) hemodialysis sessions, respectively (P = 0.062). The number of hemodialysis sessions correlated with many admission parameters such as urinary volume ($P < 0.001$, $r = -0.365$, $N = 370$), mean blood pressure ($P < 0.001$, $r = 0.197$, $N = 400$), body temperature ($P = 0.010$, $r = 0.132$, $N = 377$), serum creatinine ($P < 0.001$, $r = 0.277$, $N = 409$), uric acid ($P = 0.003$, $r = 0.193$, $N = 241$), potassium ($P < 0.001$, $r = 0.243$, $N = 401$), phosphorus ($P < 0.001$, $r = 0.259$, $N = 218$) and albumin ($P = 0.030$, $r = -0.130$, $N = 279$). Other correlation analyses that dealt with clinical and therapeutic features versus the number of IHD sessions are provided in Table 4.

Mean duration of IHD support was 13.4 ± 9.0 (range 1 to 48) days. Non-survivors were dialyzed for significantly

Table 3. Multivariate logistic regression analysis of predictors of dialysis needs

Parameter	*P*	Odds ratio
Age	0.016	1.02
Gender	0.057	0.63
Time period under the rubble	0.005	0.97
Extremity trauma	0.311	1.36
Thoracic trauma	0.278	1.66
Abdominal trauma	0.013	0.29
Fasicotomy	0.006	2.13
Amputation	0.141	0.57
Sepsis	0.004	3.54
Pneumonia	0.026	10.88
ARDS	0.415	1.85
DIC	0.231	3.65
Hypertension	0.107	3.96
Antibiotic adminisration	0.623	0.88
Mechanical ventilation	0.799	0.79
Blood transfusion	0.092	1.60
FFP transfusion	0.025	2.26
Human albumin transfusion	0.258	1.35

Abbreviations are in Table 2.

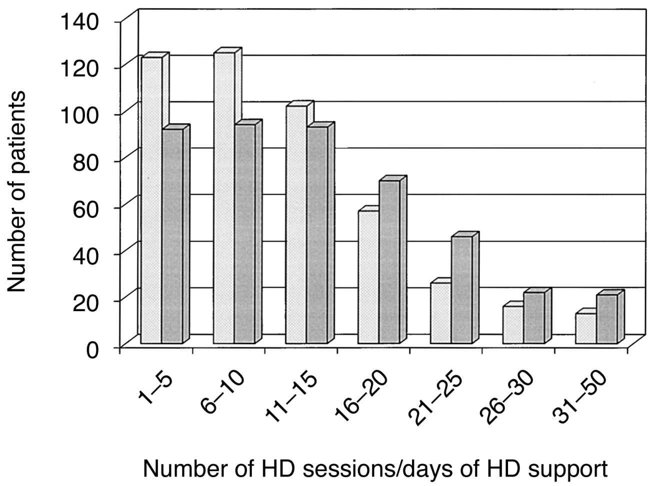

Fig. 2. Stratified number of hemodialysis sessions (▢) as well as number of days of hemodialysis support (▢) and corresponding number of patients.

shorter periods than the survivors (7.0 ± 8.7, range 0 to 36 days vs. 10.0 ± 9.8, range 0 to 48 days; $P = 0.005$). Days of hemodialysis support showed correlations with some of the admission parameters: urinary volume ($P < 0.001$, $r = -0.401$, $N = 358$), mean blood pressure ($P < 0.001$, $r = 0.213$, $N = 387$), serum creatinine ($P < 0.001$, $r = 0.356$, $N = 395$), uric acid ($P = 0.001$, $r = 0.214$, $N = 236$), potassium ($P < 0.001$, $r = 0.236$, $N = 395$) and phosphorus ($P < 0.001$, $r = 0.241$, $N = 211$). Other correlation analyses that concentrate on the duration of IHD versus clinical/therapeutic features are in Table 4.

Continuous renal replacement therapies. Among the 477 dialyzed victims, 34 (7.1%) received CRRT either as a sole therapy or in combination with other dialysis modalities. Mean number of hemofilters used per patient was 4.2 ± 4.7 (range 1 to 21) and the mean time period for CRRT support was 61.3 ± 68.9 (range 2 to 240) hours. Among the 34 patients to whom CRRT was applied, 14 (41.2%) died compared to in those receiving no RRT ($P < 0.0001$) (details are in the earlier section).

Duration of CRRT support correlated with admission body temperature ($P = 0.03$, $r = 0.110$, $N = 377$), corrected serum calcium ($P = 0.037$, $r = 0.140$, $N = 221$), number of blood ($P < 0.001$, $r = 0.151$, $N = 639$) and FFP transfusions ($P < 0.001$, $r = 0.173$, $N = 639$), duration of oliguria ($P = 0.001$, $r = 0.131$, $N = 594$) and mean last serum creatinine ($P = 0.009$, $r = 0.144$, $N = 329$).

Peritoneal dialysis. Only eight victims were treated by PD; four of them also required IHD or CRRT. The mean time period for PD was 4.9 ± 4.5 (range ¼ to 15) days. Among the patients who underwent PD, two died: one was treated solely by PD, whereas the other patient underwent CRRT and IHD as well.

Overall, of the 639 victims with nephrological problems, 97 (15.2%) died. Among the non-survivors, 82 received at least one form of RRT, thus giving rise to a mortality rate of 17.2% (82/477; $P = 0.015$ vs. those patients who received no RRT).

Intercenter variability

There was variability in the dialysis practices between the centers. Taking into account the 18 hospitals that treated more than 10 patients, the percentage of admitted patients with nephrological problems who were dialyzed varied between 100% and 23.5%; the latter percentage was obtained in a pediatric nephrology unit. As has been pointed out earlier, the most frequent dialysis modality was IHD; among the centers, 11 only applied IHD as renal replacement therapy, while five used IHD + CRRT and two IHD + CRRT and PD.

Considering the final outcome of the victims in various centers, the mortality rate differed between 31.6% and 4.2%. Four of the five centers with the highest mortality rates were university hospitals, most of which were very close to the disaster area. All but one of the hospitals located in Ankara (which is approximately 300 km from the epicenter) reported mortality rates lower than the general mortality rate of the present series. Interestingly, no deaths were recorded in the victims under the age of 10.

Logistic aspects

The largest fraction of the patients who received RRT (229/477; 48%) were treated in the reference hospitals located in Istanbul, which is a one hour drive to the epicenter. On the other hand, 110 (23%) patients were dialyzed in Ankara (three hour drive to the epicenter), 79 (17%) in Bursa (one hour drive to the epicenter) and the remaining 59 (12%) in other Turkish cities.

Table 4. Correlation analyses between number of hemodialysis sessions and days of hemodialysis support considering various clinical parameters and therapeutic interventions

	N of HD sessions			Duration of HD support		
Clinical/therapeutic features	*P*	*r*	*N*	*P*	*r*	*N*
Traumatized extremities	<0.001	0.182	639	<0.001	0.171	615
Fasciotomized extremities	<0.001	0.219	639	<0.001	0.213	615
Blood transfusions	<0.001	0.205	639	<0.001	0.246	615
FFP transfusions	<0.001	0.142	639	=0.001	0.131	615
Human albumin transfusions	<0.001	0.223	639	<0.001	0.283	615
Duration of oliguria	<0.001	0.773	594	<0.001	0.810	587
Duration of polyuria	=0.002	0.159	363	=0.021	0.122	360

Abbreviations are: HD, hemodialysis; FFP, fresh frozen plasma.

There were 561 hemodialysis machines in the reference hospitals that treated the victims. One hundred and fifty-eight doctors (nephrologists, internists or general practitioners) and 387 hemodialysis nurses took part in the treatment of nephrological problems of these victims.

Six nephrologists, 35 dialysis nurses as well as 20 members of Medecins sans Frontieres from various European countries came just after the disaster to contribute in the treatment of nephrological problems. Also, considerable amounts of dialysis material (more than 6000 dialyzers, 225 double-lumen catheters, 1040 dialysate concentrates, one water treatment system and 125 hemodialysis machines) were kindly donated mainly by ISN-RDRTF and other friends [16], while approximately 2000 dialyzers were donated by the Turkish Kidney Foundation.

Apart from the ones who worked at the disaster field, two doctors and 34 dialysis nurses from other cities of Turkey came to the reference centers to contribute to the treatment of casualties with renal complications.

Gigantic amounts of blood ($N = 2981$ units) and blood products (fresh frozen plasma, $N = 2837$ units) and human albumin ($N = 2594$ units)] of transfusions were required for the treatment of the victims.

DISCUSSION

Crush syndrome is a major cause of mortality after mass disasters [1], and the calculated mortality rate of the dialyzed victims suffering from ARF related to crush syndrome can reach up to 40% [2, 3]. On the other hand, long-term prognosis of the survivors is excellent with no permanent renal damage [5, 9, 17], emphasizing that RRT is of vital importance in the treatment and ultimate outcome of these victims. However, detailed descriptions of RRT during previous mass disasters are either lacking, or contain only small numbers of patients with incomplete data [5, 7, 18–20]. The present analysis offers as detailed as possible documentation of RRT applied to the highest number of (477) earthquake victims reported to date.

Retrospective gathering of data always has inherent limitations because many of the searched parameters might not have been recorded in the patient files, and not only the indications for a given diagnostic or therapeutic maneuver, but also the practical implementation of these may vary among the centers. Of course, these drawbacks are even further enhanced in disaster conditions since shock, panic and chaos early after the disaster as well as overload by the large number of victims usually result in incomplete files. On the other hand, despite these disadvantages, hopefully our data will be useful for both medical and logistic planning in order to improve the outcome of the victims at the occasion of future massive disasters.

During mass disasters there is no doubt that most of the deaths occur immediately after the earthquakes and for those still alive, rescue activities are of vital importance since short-term mortality dramatically increases as the time period under the rubble lengthens. Another pre-hospital concern in disaster victims is prevention of acute renal failure (ARF). Since ARF is a risk factor for mortality, prevention of this complication should contribute to improve the outcome of the victims. As fluid depletion is crucial in the pathogenesis of rhabdomyolysis, beginning of early and vigorous fluid replacement therapy (even before extrication from under the rubble) remains one of the mainstays of prophylaxis of ARF [4].

In the present series, 74.6% (477/639) of the casualties with renal complications needed dialysis support, while this rate was 61% (123/202) during the Hanshin-Awaji (Kobe) earthquake [20]. The dialyzed victims in this series were characterized by a higher number of traumatized and fasciotomized extremities, higher serum levels of admission creatinine kinase and nitrogenous waste products as well as the need for a higher number of blood and blood product transfusions. All these characteristics point to more severe trauma. After the Kobe earthquake, similar observations were reported [21].

The need for blood and blood product transfusions in the victims of the present series was very high. Several factors should have played a role in the need for these transfusions, such as bleeding from the traumatic and fasciotomy wounds as well as medical bleeding caused by hemorrhagic diathesis on the basis of disseminated intravascular coagulation, a frequent complication noted in these patients [6]. The latter complication also may necessitate high numbers of fresh frozen plasma transfusions, while oozing of plasma from the fasciotomy wounds contributes to hypoalbuminemia, and hence the need for human albumin transfusions. Therefore, during the dialysis procedure the fasciotomized patients should not be anticoagulated liberally, but rather should be dialyzed with controlled heparinization or no heparin administration at all, and regional heparinization should be discouraged because of differences in kinetics between heparin and protamine.

All forms of RRT (that is, IHD, PD and CRRT) can be effective in the treatment of crush syndrome victims, but IHD carries several advantages: (*1*) the high clearance rate of uremic solutes as well as potassium, phosphate and protons; (*2*) the possibility to dialyze these traumatized patients with high bleeding risk without anticoagulation; and (*3*) the opportunity to treat several patients per day at the same dialysis position [8, 22]. Considering these factors, in the present series, 462 of the 477 (96.8%) dialyzed victims received IHD.

The intensity of application of hemodialysis treatment is dependent on clinical and laboratory findings. Next to fatal hyperkalemia, severe metabolic acidosis and serious uremia due to high catabolism encountered in the crush syndrome patients necessitate higher doses of hemodialysis [9, 18, 23]. Furthermore, it has been suggested to start dialysis not only in the case of already established hyperkalemia, but also if the rate of rise of serum potassium level is fast [24]. Interestingly, both the number of hemodialysis sessions and the days of hemodialysis support were shorter in the non-survivors. This finding can be explained by the early death of the most severely affected victims, which obviously limited the opportunity to undergo dialysis for a long time.

In the present series, the total number of hemodialysis sessions was 5137. Therefore, to our knowledge, the Marmara disaster was the origin of the most extended dialytic intervention applied to casualties with renal complications of a disaster to date.

Continuous renal replacement therapies are gaining increasing popularity, especially in the intensive care units, mainly because they do not adversely affect blood pressure during fluid removal, hence allowing a better control of fluid status [25]. Gradual removal of solutes, thus avoiding disequilibrium syndrome and giving opportunity to freely feed the patients are other advantages of CRRT [8, 24, 25]. However, CRRT has some drawbacks such as low clearance rate, need for continuous heparinization and long periods of application time [8, 9, 26]. It has been suggested that this form of therapy would be more effective in removing myoglobin [27]; however, this effect has been found unremarkable by others, since the metabolic turnover of myoglobin is fast by itself [24], as well as in established ARF, the clearance of myoglobin is not affected by any of the blood purification methods [21]. In our series, the mortality rate of the patients treated with CRRT was higher, which can be explained by the choice for this modality in severely affected patients.

Peritoneal dialysis may offer some advantages, such as no need for vascular access, simpler technique, less hemodynamic instability and easy institution [8, 22, 26]. Abdominal traumas as well as pulmonary and cardiac complications together with the low clearance rate make PD less appropriate, however [7, 8, 22, 26, 28]. As a result, PD can only be used as a temporary rescue when hemodialysis is not available [9, 22]. In our case, only eight patients were treated with PD, four of whom were switched to IHD or CRRT. Crush patients on PD should be closely monitored for hyperkalemia, and if necessary, aggressive antihyperkalemic therapy should be administered for this complication.

Inter-hospital variability in the treatment strategies and outcome of disaster victims has been reported in previous disasters [2] and this was also the case during the Marmara earthquake. Regarding the therapeutic interventions and the fate of the victims, not only the percentage of dialyzed patients and the type of preferred dialysis modality, but also the final outcome of the patients varied between the centers. On the other hand, one should be careful in making straightforward conclusions based on these differences. A number of complex issues influenced the comparison of these centers. First, the patient demography was not the same for all centers from the beginning; more seriously injured victims were admitted to the centers that were closer to the epicenter, while distant centers (such as the 9 centers in Ankara) received somewhat more stable patients and this factor was probably the reason for the lower mortality rates. Second, during the clinical course, the victims who suffered from serious complications in state and social security hospitals were directed to the university hospitals by the suggestions of the local coordinator, which resulted in different patient and trauma demographics among the centers, even after admissions. Supporting this hypothesis, four of the five centers with the highest mortality rates were university hospitals. Considering the lower dialysis needs and mortality rate in the centers that treated pediatric victims, one may speculate that children with crush syndrome can have a more favorable outcome. This is probably related to a lower muscle mass, hence reducing the severity of the consequences of rhabdomyolysis.

During mass disasters, not only medical, but also logistic features of replacement therapies should be considered. CRRT and PD are problematic since large volumes of sterile replacement fluids are needed [19, 26], while PD is difficult to be used under non-hygienic field conditions [26]. Therefore, also from the logistic point of view, classical hemodialysis remains the most appropriate treatment, despite the need for an infrastructure and experienced personnel. On the other hand, even health care services in well-developed countries may be overwhelmed during disasters [29], while the situation is naturally worse in developing countries with inadequate dialysis facilities. These logistic problems were dramatically experienced during the Armenian earthquake [7], when gigantic amounts of dialysis equipment, as well as nephrologists, hemodialysis nurses and technicians were required for the treatment of the victims [19, 30, 31]. That particular disaster was the key event for ISN to develop RDRTF to support countries faced with mass disasters [26].

To conclude, the Marmara earthquake was characterized by the highest number of dialysis needs registered to date, and RRT enabled numerous lives to be saved that otherwise would be lost. On the other hand, although the Marmara region of Turkey had a well-developed dialysis infrastructure, many of the dialysis units were damaged and those remaining undamaged were overwhelmed because of the heavy patient load. Therefore, international help contributed to overcome these problems.

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