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Renal replacement therapy at the time of the Taiwan Chi-Chi earthquake

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Introduction

At 1:47 am on September 21st 1999, a devastating earthquake, measuring 7.3 on the Richter scale, struck central Taiwan. The epicentre was located in Central Taiwan near the Chi-Chi town, Nantou County. The most severely damaged area was found along the north–south Chelungpu fault that had ruptured southward for >80 km (Figure 1) [1]. Over the next few weeks, there were >10 000 aftershocks, with several of these of a magnitude of 6.0 of the Richter scale. The greatest destruction occurred in Nantou County, but also affected were towns along the Chelungpu fault in Yuenlin County, Taichung County and Taichung City, distributed from the south to the north. Other parts of the island were also damaged to a greater or lesser degree. In mountain areas of these counties a massive landslide buried people alive and turned the once-green mountain-side into a barren landscape. The collapsed buildings crushed bodies and trapped the wounded. This devastating earthquake resulted in 2405 dead, with 10 722 injured, and the collapse of >10 000 houses over the island [2]. Medical facilities (468) were damaged, including 79 hospitals, 199 clinics and various others [3]. Buildings, water pipes, electricity cables, telecommunication lines, bridges and roads were all severely damaged in the disaster areas, which caused almost complete paralysis of medical facilities and seriously hindered rescue efforts from outside. Although earthquakes occur frequently around Taiwan Island and its nearby Pacific Ocean, the Taiwan Chi-Chi great earthquake was the most devastating of the last century [4].

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Disastrous damage of public utilities and emergency relief

The earthquake destroyed an electric tower supplying the south-to-north super-high voltage electricity transmission. Thus, the power supply was cut-off over the entire island, except in the southern part of Taiwan. Communication equipment driven by electricity failed to work, which included most digital and cellular phones. This loss of communication capability resulted in informative isolation for some areas, thereby delaying the rescue action in the first days after the earthquake. Broken roads and bridges disrupted external connections, hindering rescue efforts further. As a result, alternative vehicles had to be used for rescue teams to gain entry into the disaster area. Helicopters efficiently transported the severely injured victims out of the shattered area; however, their transport capacity was limited. The tap water supply system also ran out after the power failure. The situation was further worsened by the severe damage to the Shinkang Dam, which supplied household water for the Taichung area. Thousands of houses collapsed, and several high-rise buildings fell over or collapsed into their basement. Residents were either crushed to death or trapped in the buildings and left waiting for relief. Domestic rescue organizations, medical teams and military task forces were immediately organized and rushed into the disaster areas. Later, international rescue teams from 21 different countries enthusiastically and actively participated in the disaster relief.

Emergency actions of the Taiwan Society of Nephrology

Data from the Annual National Dialysis Surveillance, conducted by the Taiwan Society of Nephrology (TSN), showed that we had 327 haemodialysis (HD) centres, treating ~26 000 HD patients, and

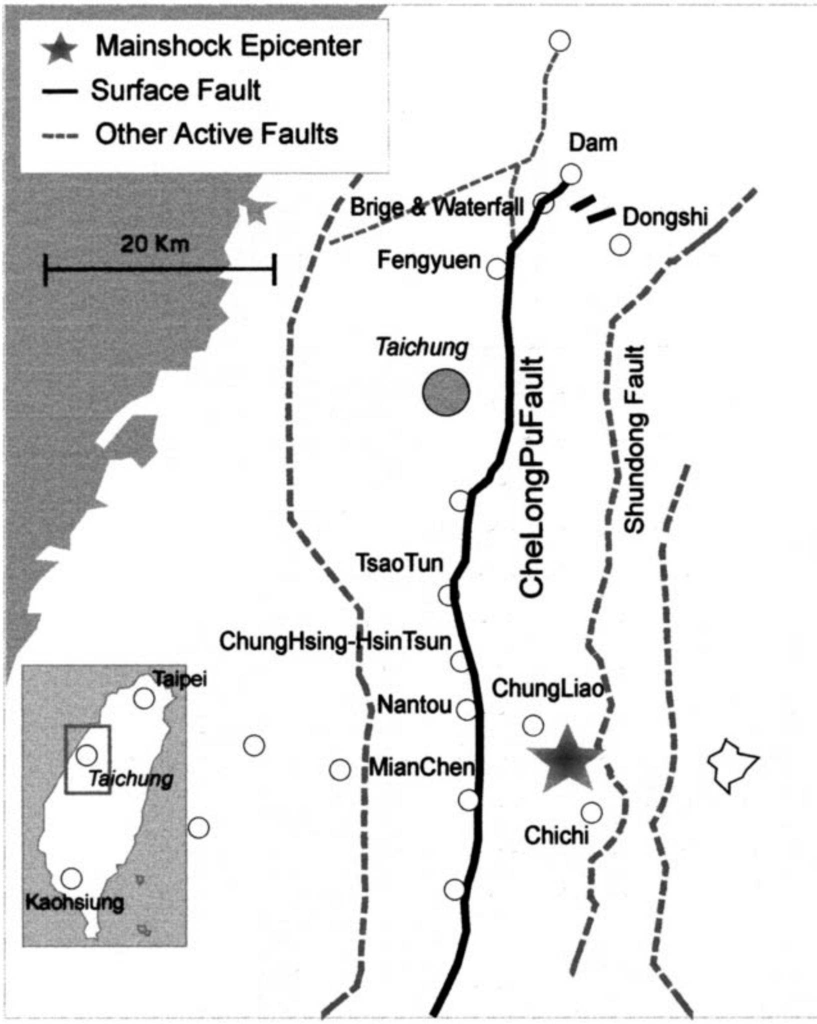

Fig. 1. The geographic location of the epicentre and distribution of the Chelungpu fault responsible for the Chi-Chi great earthquake in central Taiwan. The most severe damage occurred in towns surrounding the epicentre and in those along the Chelungpu fault. This figure has been reproduced courtesy of the Institute of Atmospheric Physics, National Central University, Taiwan.

36 peritoneal dialysis (PD) centres, treating ~1800 CAPD patients in Taiwan at that time. In the earthquake-stricken area of central Taiwan (one city and five counties), there were 78 HD centres, serving 5564 HD and 401 CAPD patients [5]. Over the days following the earthquake, TSN urged in the press, TV and radio media for the following urgent actions. First, victims of crushing injuries may have developed rhabdomyolysis, acidosis, hyperkalemia and acute renal failure (ARF); therefore resuscitation should have included sufficient fluid supply and mannitol-alkalization therapy without delay. Secondly, patients on maintenance HD should have been evacuated immediately or should have left the disaster area voluntarily if the dialysis facility failed to work. It was recommended, if possible, that the HD patients be moved to northern or southern Taiwan where sufficient resources for dialysis therapy could be provided. Patients were encouraged to stay there for a longer period to reduce the burden of unscheduled dialysis work imposed on HD centres in the affected areas. Thirdly, the less damaged nearby dialysis centres should have taken the evacuated HD patients. To ensure an efficient and coordinated plan of renal care, the Nephrology Division of the Taichung Veteran General Hospital took on the role of consultation, coordination and information collection for the victims with rhabdomyolysis and/or ARF following crushing injury. The TSN was in charge of managing and coordinating the emergency provision for those requiring maintenance dialysis. In the first week, each dialysis centre in the affected cities and counties was called daily by telephone and asked about the burden and capacity to serve the referred HD patients during the emergency period. This helped the TSN to obtain immediate and correct information for further planning, and to assist the dialysis centres in need to cope with the crisis.

To understand the extent of the damage to dialysis facilities and the ways in which the HD centres coped with the disaster, the TSN conducted a survey 6 weeks later by sending questionnaires to all 78 HD centres located in the earthquake-struck areas. It was expected that the collection of information would be helpful in organizing a future disaster provision plan for renal care in the areas of Taiwan frequently affected by earthquakes. The questionnaires included questions about personnel injuries, facility damages and emergency strategies on dialysis. The response rate was 100%. Two PD supply companies helped the data collection of CAPD, as because of their monthly delivery of dialysate they had direct access to patients or their families. For investigation of the incidence of rhabdomyolysis and ARF occurring in the earthquake zone, questionnaires designed to collect pertinent data were sent to the major medical centres located in central Taiwan.

Damage to HD centres in the earthquake-stricken area

Personnel injuries

At least three physicians were crushed and died during the earthquake; no medical staff in the nephrology centres were fatally injured. Three dialysis nurses suffered from minor injuries. However, among their family members three were dead and four injured. Among the 1500 HD patients who lived in the most severely damaged areas along the Chelungpu fault, six were crushed to death and seven were injured. Among the family members of the HD patients, 33 died and 11 were injured. Delay in dialysis treatment after the earthquake caused two patients to die, and six patients were hospitalized because of the resultant complications. Two other HD patients died of other medical causes not related to the earthquake injury.

Facility damages

All 78 HD centres in central Taiwan had various degrees of damage to their facilities, including damage to the hospital buildings (46.6%), HD facility (37.2%), electricity system (6.9%), telecommunication lines (59.5%), tap water supply systems (15.6%), and reverse osmosis (RO) systems (51.9%). The extent of facility damage was much higher in HD centres located along the Chelungpu fault, where most of the severe damage occurred. A total of 18 HD centres, including 11 in Nantou County and seven in Taichung County, were located in this area. One of them was completely destroyed.

Thirty-three HD centres in the earthquake-stricken area were unable to perform dialysis on the day after the earthquake. However, 12 centres restored their dialysis operations within 1 day, 12 within 3 days, four within 1 week, and three within 3 weeks. The first five leading causes for failure to work in the HD centres were failure of the RO system, interruption of the water supply, damage of HD facilities, failure of power supply and telecommunication failure.

Emergency management of the HD centres coping with the disaster

All the HD centres had emergency electricity generators, and this greatly helped the HD centres to restore their power supply. The shortage of tap water was overcome in different ways, including pumping underground water (41%) or by water-tank truck supply from public (33%) or private sources (20%). The rapid restoration of the RO systems and dialysis machines, performed by skilled technicians from the manufacturers, reflected the highly efficient and committed dialysis facility support system in Taiwan.

To cope with the inevitable chaos that existed in the aftermath of the earthquake, each HD centre automatically developed its own plan for establishing emergency command, execution, rescue and coordination of systems. Overall, the nephrologists in charge were responsible for commanding and executing the system in $\sim 75\%$ of these 78 HD centres. The nursing heads in the HD units also played an important role in assisting in-charge nephrologists in 56–68% of the centres. Although the army, local health units and other rescue teams made a huge and prompt contribution to the disaster relief task forces in the HD centres, the best people to deal with such a chaotic situation and to restore dialysis operation are the medical staff themselves. Medical staff acted as the main rescuers and coordinators in 82 and 59% of the centres, respectively.

As mentioned before, 54 of 78 HD centres had normal dialysis operation on the day of the earthquake, and another 12 restored their dialysis operation between the first day and the third day. Thus, the ways in which patients continued to receive dialysis therapy were dependent on the function of each HD centre. Most HD centres actively communicated with their patients by telephone (82.1%) or by direct access to the patient's residence (18.0%). Patients returned by themselves in 42.3% of the HD centres. More than 70% of the centres recommended that patients leave the earthquake-damaged area. Patients staying in the damaged area were either treated at their own HD centres or were referred to less damaged, nearby centres. Within the first three days of the earthquake, the less damaged nearby centres had taken on >800 patients who had been evacuated from the disaster area. Although the patients living in Pu-Li (one of the most severely damaged towns located at the centre of Taiwan) were evacuated by helicopter, most patients left their home by private vehicles (70%). Sixty per cent of HD centres assigned an appropriate HD unit for back-up dialysis for their patients, but patients chose the HD units for dialysis themselves in 30% of the centres.

In the disaster area, the major problems in the HD centres, where dialysis failed to work, were disrupted transferring systems (25%), loss of dialysis facilities (15%), and uncertainty with regard to the facility-repair time (15%). After restoration of the dialysis operations, fear from aftershocks (26%), shortage of water supply (21%), and post-traumatic syndrome of the patients and medical staff (18%) became the major concerns. The supportive measures undertaken by HD centres in less damaged nearby areas to provide back-up dialysis included an increase of dialysis shifts (18%) and machines (15%), an increase in the number of dialysis staff (38%), and a shortening of dialysis time (28%). Major difficulties imposed on these supportive HD centres included unawareness of the referred patients' medical condition (31%), and unknown dialysis prescription (21%) and medication (20%). Sharing medical staff and key personnel from the referred centres was helpful in this chaotic situation and reduced their workload. However, problems still remained, mainly regarding the insecurity (43%), and staff (17%) and patient complaints (13%).

Status of CAPD patients

According to the reports from two CAPD medical companies, there were a total of 401 CAPD patients living in central Taiwan. Most patients could be reached by telephone, except those living in the most severely damaged area. No patient was injured during the earthquake. The houses of seven patients were destroyed. The major fears of CAPD patients after the earthquake were those of aftershocks and their inability to contact CAPD nurses due to the failed telecommunications in the first few days. Since the stock of PD dialysate at the home of each patient was sufficient for several weeks to 1 month, there was no difficulty in continuing peritoneal dialysis. Most of the CAPD patients performed their exchanges at home, but went out thereafter and stayed outdoors for safety. Forty-five APD patients had to switch their dialysis to manual exchanges because the electricity failed, and APD was restarted again once the power supply was restored. Lack of dialysate was solved by supply from in-charge hospitals. No serious complications were reported except for the fact that two patients developed peritonitis in the month following the earthquake. Although most patients left their damaged houses and stayed in rescue tents or other safe places, the difficulty of delivery of the monthly dialysate supply to the patients was successfully realized by the efforts of the medical companies [6].

Rhabdomyolysis following crush injury

It is not known exactly how many people died of crushing injury-induced ARF after rescue from the rubble and during transport to the hospital, the so-called 'rescue death syndrome' [8]. The data shown here are collected via questionnaires from six major medical centres located in Central Taiwan. Dr K. H. Shu and his colleagues then reviewed their medical records. Rhabdomyolysis was defined by a peak serum creatine phosphokinase (CPK) level of >1000 IU/l, caused by crush injuries within 2 weeks following the earthquake. A total of 95 cases were collected. There were 60 males and 35 females with a mean ($\pm$SD) age of 37.6 ± 17.3 years. The median time from the earthquake to the time of rescue (T-rescue) was 6.0 h (range 0.1–31 h) and the time they were sent to emergency room (T-ER) was 11.0 h (range 2–144 h). The median CPK value was 20 000 IU/l (range 1040–351 540 IU/l). Fasciotomy was performed in 35 cases (36.8%) for compartment syndrome. Eighty-eight cases (92.6%) also suffered from at least one of the following injuries: fractures (41.5%), head injury (10.8%), motor or sensory neuropathy (29.8%), chest injury (7.5%), abdominal injury (7.4%) and thermal burns (1.1%). Acute renal failure, defined by a serum creatinine level of >1.3 mg/dl in a previously healthy subject, was found in 52 patients (54.7%). Dialysis, including HD and/or CAVH was necessary in 32 cases (33.7%). Among these, 29 (90.6%) were oliguric with a mean oliguric phase of 11.0 ± 9.5 days (median: 9; range: 1 to $\sim$36 days). The initial management at the emergency room included vigorous fluid supplementation (median: 5250 ml; range: 500–15 400 ml in 48 h) and the use of mannitol-alkaline therapy in various combinations (sodium bicarbonate, 43.2%; furosemide, 55.8%; mannitol, 18.9%; and dopamine, 36.8%). Oliguric patients were associated with a longer T-rescue (9.85 *vs* 5.04 h; $P<0.01$), higher CPK levels (79 204 *vs* 30 495 IU/l; $P<0.01$), higher lactate dehydrogenase (LDH) (4110 *vs* 1498 IU/l; $P<0.02$) and lower serum calcium levels (6.53 *vs* 7.46 mg/dl; $P<0.001$) as compared with non-oliguric patients. Serum CPK levels were correlated with urine volume in the first 24 h ($r=-0.27$; $P<0.05$), blood urea nitrogen ($r=0.33$; $P=0.001$), aspartate aminotransferase ($r=0.47$; $P<0.0001$), serum creatinine ($r=0.34$; $P=0.001$), LDH ($r=0.68$; $P<0.001$), serum phosphorous ($r=0.39$; $P<0.005$), serum calcium ($r=-0.46$; $P<0.0001$) and blood pH ($r=-0.29$; $P<0.02$). Although CPK levels were correlated with the presence of oliguria ($P<0.03$) and the requirement of dialysis ($P<0.0005$), they were not correlated with mortality. Mortality occurred in nine cases (9.5%) at a median duration of 7.0 days (range 1–32 days). Patients with ARF showed a higher mortality compared with those without ARF (17.3 *vs* 0%; $P<0.02$). Thus, the blood level of CPK seems to be a good prognostic indicator for renal outcome and correlates well with most of the abnormalities in the biochemical parameters in victims with crush injury. Those complicated by ARF carry a significantly higher mortality [6].

Lessons from the Taiwan Chi-Chi earthquake

Although earthquakes frequently happen around Taiwan Island and its nearby Pacific Ocean, we still faced a chaotic situation at the beginning of the local rescue actions during the Chi-Chi great earthquake. In contrast, the well organized, well equipped and well trained task force teams coming from foreign countries did embarrass the facility and capability of domestic emergency rescue system in Taiwan. Thus, there remains a lot for us to learn from this disaster. First, integrated renal care must be established as one of the essential roles of the disaster relief task force. Major earthquakes cause more injuries and casualties than wars [8]. Dialysis patients are more vulnerable during earthquakes owing to their need for continued dialysis therapy and their associated medical illness. Furthermore, hospitals or medical staff specializing in maintenance dialysis are more skilled in the prevention and treatment of patients with ARF [7].

Secondly, the loss of power supply and the subsequent telecommunication failure are very important causes of routine dialysis operation shutdown. It is strongly recommended that a satellite phone system for emergencies should be established without delay. Thirdly, both the Nephrology Society and the dialysis industry can be very helpful in the coordination and rescue of chaotic renal care in the disaster. Similar experiences were also found with the role of Japanese Society for Dialysis Therapy (JSDT) and industry in the 1995 Hanshin earthquake [7], and with the International Society of Nephrology Renal Disaster Relief Task Force and industry in the management of patients with crush injury-induced ARF during the 1999 Turkey earthquake [9].

Fourthly, a shelter HD centre may be needed in case of disaster. Because of the cultural difference, many dialysis patients would rather stay with their families in the earthquake-stricken area than be evacuated. Although HD centres in less damaged areas were already filled to their maximum capacity to accommodate referred patients from other centres, these referred patients had to go back and forth to other centres for dialysis every other day. This is why lack of security became their major concern, and unfamiliarity with their new environment made them anxious. Therefore, it would enhance efficiency if there was a provision plan to designate one or two HD centres to serve as shelter HD centres to treat referred patients. Fifthly, finding a 'clean' space to serve as a shelter PD centre may also be helpful for those PD patients who prefer to stay with their families in the disaster area. In the Chi-Chi earthquake it was dangerous for most CAPD patients to enter their homes, which were often partially damaged, to do their exchanges.

Finally, each HD centre should develop its own coordination plan with other facilities, such as other HD centres for back-up dialysis, and with miscellaneous companies for dialysis supply, and telephone, electricity and water supply. The recently published 'Planning for natural disasters and other types of emergencies' by the National Kidney Foundation, USA, should provide a practical guide for both renal facilities and renal patients [9,10]. With such comprehensive planning for disasters and emergency relief it is expected that the extent of loss and damage will be greatly reduced.

Dialysis therapy has been applied in Taiwan for near 40 years [5], and this is the first time that we have encountered such a chaotic situation with respect to renal care with an extensive national disaster. The prompt restoration of dialysis facilities and operations demonstrated the flexibility and capability of the renal supportive systems in Taiwan. However, from this experience we could still learn how to improve our emergency measures. A well organized disaster preparedness plan is needed to maximize the efficiency of renal care. It is essential that the government, the Nephrology Society, the dialysis centres and the medical supply companies work actively together to make such a plan.

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