Survey and analysis of peripheral nerve injuries caused by the earthquake

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Abstract
Many victims of earthquakes experience nerve injury with dysfunction. To observe earthquake-caused nerve injuries and recovery after the earthquake in Wenchuan. Methods: Earthquake-caused nerve injuries were examined 5 to 16 weeks after the trauma and over 2 years for the injury course and nerve recovery. Type I injuries were nerve transection injuries, type II injuries were nerve compression injuries, and type III injuries exhibited no direct neurological dysfunction due to trauma. 31 patients had type I injuries involving 41 nerves, 419 had type II injuries involving 823 nerves, and 73 had type III injuries involving 150 nerves. Among the 22 patients with open-transection nerve injury, 13 had infections around the wound. Closed-nerve injury was associated with soft injury. With calf compartment syndrome, tibial nerves were compressed by the tendinous arch of the soleus. Surgical decompression favorably affected nerve recovery. Physiotherapy was effective for type I and II nerve injury but not much for type III nerve injury. Pharmacotherapy had little effect on type II and III nerve injury. The Louisiana State University Health Sciences Center (LSUHSC) score for nerve injury severity was decreased with duration of being trapped. In the first year, the LSUHSC score for grade 3 to 5 nerve injury increased from 28.2% to 81.8%. If scores were still poor (0 or 1) after 1-year treatment, further treatment was not effective. Nerve injury in victims of earthquakes is directly related to the crush and indirectly to soft-tissue damage. Targeted decompression surgery and physiotherapy is effective for nerve transection and compression injury.

Key Words: nerve regeneration; earthquake; nerve injury; LSUHSC score; compartment syndrome

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injury factors and in reference to other surveys,20,21,26 we classified the peripheral nerve injuries into 3 major types.

Type I: nerve transection injuries, a complete severing of nerve continuity.

Type II: nerve compression injuries, with nerve continuity was present, but with a history of direct peripheral nerve injury.

Type III: no direct neurological dysfunction due to trauma. No limb fractures, dislocations, or localized soft-tissue wounds but nerve injuries in certain innervated areas.

Survey of patients
Experienced clinicians performed physical examinations to determine the condition of the peripheral nerve injury. We analyzed and graded the injuries according to the Louisiana State University Health Sciences Center (LSUHSC) Nerve Grading System27. All patients underwent electromyography, and a database of nerve injuries was constructed. Then patients were surveyed to determine the context of the earthquake injury, including the injury location, soft-tissue condition at the time of injury, the time between the injury and rescue, and the treatment (surgery, physical therapy, and vitamin B12). The follow-up was 1 to 2 years after the initial information collection (Figure 1).

Medical Ethics
This study was approved by the Medical Ethics Committees of the hospital. All patients gave their written informed consent to participate in this study.

Statistical analysis
Data are reported as number (%). Chi-square test was used for data analysis. Correlation was analyzed by Spearman correlation coefficient (rho). P < 0.05 was considered statistically significant.

Results
Incidence of nerve injury
Disease distribution
We surveyed 8,626 patients with confirmed earthquake injuries: 571 had peripheral nerve injuries (257 males [45%]). At 2 years, 12% of the patients were lost to follow-up. We obtained continuous data for 503 patients, and their nerve injury characteristics are in Table 1 and Figure 2. Among them, 31 patients had type I injuries involving 41 nerves, 419 had type II injuries involving 823 nerves, and 73 had type III injuries involving 150 nerves.

Soft-tissue injury and nerve injury
According to the medical records of patients and the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification of soft-tissue injury, we analysed soft-tissue injury28 to determine the predictive value of severity of closed injury on nerve injury, evaluated by LSUHSC nerve-injury score and found closed injury associated with LSUHSC nerve-injury score (P < 0.05). Similarly, we determined whether open-transection nerve injury, muscle and tissue injury and nerve and vessel injury were independent predictors of nerve injury. Muscle and tissue injury as well as nerve and vessel injury were associated with nerve injury score (P < 0.05), with no association with open injury (P > 0.05).

Compartment syndrome and nerve crush injury
For type II nerve injury, we determined whether compartment syndrome and crush injury were associated with nerve injury score and found both factors were associated with nerve injury score (P < 0.05).

Passive position, time and positional nerve injury
In all, 73 patients had movement disorder and sensory dysfunction in certain innervated areas when they were rescued, but these patients were not harmed directly by external forces. A few similar injuries have been described in other reports19, 38. All patients had been trapped in a passive body position for a long time. The hip joint of patients with sciatic nerve injury was in the flexion position when they were trapped. Overall, 38 patients were in a squatting position; the hip joint was in the flexion position and the knee joint was in the extension position for 12 patients; 3 had their legs spread apart in a split position.

Nerve injury rehabilitation
Nerve injury recovery trend analysis
The nerve injury scores from screening to year 1 and from year 1 to 2 are in Table 2. If scores were still poor (0 or 1) after a year of treatment, further treatment was not effective and the nerve scores did not improve. However, if the scores increased (4 or 5) after 1 year, further treatment would be more effective and the possibility of recovery became higher33,34.

Infection and nerve injury recovery
Among the 22 patients with open-transection injury, 13 had infections around the wound. Patients with infections had their dressings changed (Table 3). After the soft tissue was stabilized, surgery was performed. One patient underwent direct nerve anastomosis. Five patients had nerve graft repair.

Calf compartment syndrome and nerve injury recovery
We studied whether the calf compartment syndrome was related to the injury recovery. We calculated the difference in LSUHSC score during the treatment and found an association of compartment syndrome and recovery.

Trauma and other factors can cause the tendinous arch of the soleus muscle to compress the tibial nerve29,30. Mascaglia31 reported 9 patients with tibial nerves compressed by the tendinous arch of the soleus. The compartment syndrome caused by the earthquake also featured this injury-causing course (Figure 3).19,30

Positional nerve-injury recovery analysis
During the second year, all of the type I patients showed full recovery, except for one patient who had been trapped for 38 h with hip flexion and knee extension. This patient underwent ultrasonography, MRI, and electromyography. At
the end of year 2, her whole sciatic nerve had thickened, for injury of the entire nerve and all branches. Imaging showed the internal blood supply was greater on the injured than opposite side, and electromyography revealed persistent left sciatic-nerve injury (Figure 4).

**Therapeutic intervention and nerve injury recovery**
*Physiotherapy and pharmacotherapy*
Neurologic recovery was decided by the difference in LSUH-SC score between 2008 and 2010. Recovery was considered an ordinal categorical variable.
In all, 229 patients received physiotherapy. In type I and type II nerve injuries, patients with or without physiotherapy differed in recovery \((P = 0.034\) and \(P = 0.001\)). Physiotherapy was effective for recovery of type II \((P < 0.05)\) but not type III nerve injury \((P = 0.511)\).

A total of 346 patients received pharmacotherapy (vitamin B12, 500 μg/day, for about 12 weeks). Recovery significantly differed with and without pharmacotherapy \((P = 0.003)\). For patients with type II nerve injury, pharmacotherapy was negatively correlated with recovery \((\rho = -0.076)\). For type III nerve injury, pharmacotherapy was not effective \((P > 0.05)\).

**Surgery and compartment incision decompression**

In total, 262 nerves underwent surgery, and 186 nerves were rehabilitated. Surgery was weakly correlated with nerve rehabilitation \((\rho = 0.092)\). Cutting open the compartment for decompression affected nerve recovery. In the first year, 75% of nerves (27 nerves) with a screening score of 0 that did not undergo nerve decompression did not improve, and only 33.3% of nerves with a score of 0 (5 nerves) that underwent decompression did not improve. Similarly, nerves with a screening score of 2 or 3 undergoing nerve decompression improved more than those not undergoing decompression.

In the second year, all nerves with an LSUHSC screening score of 0 showed no recovery, but nerves with higher initial scores undergoing decompression improved more than those that did not undergo decompression.

During follow-up, some patients with calf compartment syndrome showed a delay in tibial nerve recovery. Physical examination revealed some patients with Tinel signs of irritated nerves in the upper part of the calf. Ultrasonography and MRI revealed signs of nerve compression where the tibial nerve passes through the tendinous arch of the soleus muscle (Figure 3). Six patients underwent incision of the tendinous arch for decompression, for better recovery.

**Discussion**

In recent years, there has been a frequent occurrence of large earthquakes. In the past, earthquake surveys mainly focused on acute or fatal traumas and on-site rescue procedures and strategies. In contrast, not much attention has been paid to disabling injuries caused by disasters. In the aftermath, society’s attention shifts, and these patients receive even less social concern than they received at the earthquake rescue site.

A large number of cases showed that earthquake compression injuries were mostly caused by direct compression on the deformed nerve site. Injury in this portion of patients could be at any location in the nerve and could be due to the direct compression on the local nerve by a foreign object or to the compression or twisting of the nerve by a fractured bone. Other than the localized compression injuries caused by direct nerve compression, we also found many patients at...
the earthquake site who suffered from crush syndrome and compartment syndrome. They both have diffuse external force directly interacting with the nerves, causing a relative large range of nerve injuries. From electromyographic, ultrasonic, and MRI examinations, we found that three factors were involved in nerve injuries. First, diffuse force directly interacted with nerve bundles. Second, a large amount of soft tissue injuries caused damage to the nerve vascular bed, affecting blood supply to the nerve. Third, due to the existence of extensive compression, a large number of scars formed within and around nerves, further aggravating the nerve injury and affecting nerve function recovery.

Nerve injury without direct trauma is a special class of injury. After scrutinizing the literature, we found that a few similar injuries have been described unsystematically in different reports19, 38. For example, in the Hanshin-Awaji earthquake in Japan, Takeshi reported some patients with orthostatic nerve injuries.19 Patients with this kind of nerve injury normally did not have a direct injury history or soft tissue and bone tissue injuries where nerves are located. However, further investigation showed that patients normally had a longer period in a passive body position. The analysis of patient body positions and injured nerves showed that sciatic nerve injuries occurred most often if the patients were trapped in a squatting position. The sciatic nerve is in the hip extensor side; when the hip joint bends, the sciatic nerve is under tension. The femoral nerve is in the hip flexor side; when the hip joint is in hyperextension, the femoral nerve is under tension. When the patients were trapped in a squatting position, the sciatic nerve was under tension, and the femoral nerve was relaxed. The tensed state of the sciatic nerve resulted in injury when it continued for a long period of time, and the relaxed femoral nerve did not have any abnormality. Such relationship between injury and body position existed in all of the nerve injuries without direct trauma; the injured nerves were different only because the positions of joint hyperextension or flexion were different.

Further analysis suggested that the injuries were related
to the duration of entrapment. We use ordered logistic regression and found a significant association of length of time being trapped and LSUHSC nerve injury score. The intensity of injury could also to be related to the intensity of the stretch. We found that the hip joint of most patients with sciatic-nerve injuries was in the flexion position and the knee joint was in the flexion position. However, in some patients, the hip joint was in the flexion position and the knee joint was in the hyperextension position. When the hip joint is flexed, the sciatic nerve is stretched, but if the knee is flexed at the joint, the intensity of stretching can be alleviated to some extent, so the nerve is relatively thicker in the sciatic nerve segment. In addition to hip joint flexion, these patients also had knee joint hyperextension. When trapped for the same or shorter time, the nerve injuries of these patients were more severe than that of others.

Among the 22 patients with open-transection injury, 13 had infections around the wound. Nerve repair of transection injuries by nerve anastomosis showed significantly poorer results than those of similar nerve injuries. Infection and the on-site anastomosis technique are the core factors. We think that for this type of nerve transection injury, immediate anastomosis on-site or at frontline emergency treatment centers may not be the best option. Therefore, we propose that, when conditions permit, the damage should first be marked and secondary anastomosis subsequently conducted.

Limitations
Data were collected 4 weeks after the earthquake and mainly covered the information for the patients treated in the core area of the earthquake aid center. However, under most circumstances, the nerve injury was not life-threatening, so patients with minor injuries would not seek health care in our aid center. In addition, some had fully recovered before they were approached. Therefore, our data on nerve injury after the earthquake are incomplete. Also, because of the complexities of injury types and locations caused by the earthquake, the observation and analysis of nerve recovery was limited with the current methods for statistical analysis.

Conclusions
Earthquake nerve injury may not be life-threatening, but it can affect long-term quality of life. Effective treatment depends on careful observation and targeted interventions. Closed soft-tissue injury was significantly associated with severity of nerve injury, as were both compartment and crush syndrome. The position of entrapment was an important factor in the nerve injury. The severity of positional nerve injury

Figure 4 A: Injured left sciatic nerve shows larger diameter than the right nerve (12.9×5.7 vs. 6.8×5.0 mm) on axial T1 weighted MRI image. B: Left sciatic nerve shows hyperintense signals and right sciatic nerve shows isointense signals on axial diffusion weighted MRI image. C: A large part of the left sciatic nerve demonstrating hyperintense signals and thickness on reconstruction diffusion weighted MRI image. D and E: After contrast media administration, the left sciatic nerve shows greater enhancement than the right (77% vs. 53%).
References


