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Monitoring somatosensory evoked potentials in spinal cord ischemia-reperfusion injury

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Research Highlights

(1) Intraoperative monitoring of somatosensory evoked potentials is regarded a new measure to avoid iatrogenic spinal cord injury.
(2) This study is characterized by that, through the changes of somatosensory evoked potential latency in the rabbit spinal cord ischemia-reperfusion injury, we can confirm the objective quantitative monitoring efficacy of somatosensory evoked potentials in the assessment of spinal functions.

Abstract

It remains unclear whether spinal cord ischemia-reperfusion injury caused by ischemia and other non-mechanical factors can be monitored by somatosensory evoked potentials. Therefore, we monitored spinal cord ischemia-reperfusion injury in rabbits using somatosensory evoked potential detection technology. The results showed that the somatosensory evoked potential latency was significantly prolonged and the amplitude significantly reduced until it disappeared during the period of spinal cord ischemia. After reperfusion for 30–180 minutes, the amplitude and latency began to gradually recover; at 360 minutes of reperfusion, the latency showed no significant difference compared with the pre-ischemic value, while the somatosensory evoked potential amplitude increased, and severe hindlimb motor dysfunctions were detected. Experimental findings suggest that changes in somatosensory evoked potential latency can reflect the degree of spinal cord ischemic injury, while the amplitude variations are indicators of the late spinal cord reperfusion injury, which provide evidence for the assessment of limb motor function and avoid iatrogenic spinal cord injury.

Key Words

neural regeneration; spinal cord injury; somatosensory evoked potentials; spinal cord; ischemia; reperfusion; iatrogenic spinal cord injury; histopathology; abdominal aorta occlusion model; latency; grants-supported paper; neuroregeneration

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INTRODUCTION

The rapid development of spinal surgery technologies and instruments allow for the surgical treatment of patients with spinal cord disorders, tumors and malformations, who have had no surgery for some time[1-4]. However, spinal surgery itself can cause damage through reperfusion injury, even if the surgery is very fine and delicate. Thus, the prevention of iatrogenic spinal cord reperfusion injury remains an urgent problem.

Somatosensory evoked potential is a response of the nervous system to outside specific stimuli and an indicator of detecting neural pathway integrity. In the middle of the 1980s, some scholars have successfully applied somatosensory evoked potentials for intraoperative monitoring of spinal cord functions[2]. In addition, the combination of somatosensory evoked potentials and motor evoked potentials significantly improved the prediction accuracy of spinal cord functions[3-4], thus greatly reducing the incidence of iatrogenic spinal cord injury.

Currently intraoperative monitoring using somatosensory evoked potentials has been widely recognized to prevent iatrogenic spinal cord injury[2] due to simple operation, stable signals of intraoperative monitoring, and no influence on operation. Previous studies only reported the monitoring effects of somatosensory evoked potentials after mechanical factors-caused spinal cord injury[1-4]. However, spinal cord injury is not only triggered by mechanical factors, biochemical factors and vascular factors may cause spinal cord ischemia-reperfusion injury. Spinal cord ischemia-reperfusion injury is the result of lipid peroxidation, excessive free radicals, leukocyte activation, release of inflammatory mediators and other pathophysiological mechanisms[5-8]. After the compression of spinal cord nerve cells during the ischemia-reperfusion period, some injury factors may lead to apparent limb dysfunction and even irreversible delayed neuronal death, ultimately leading to paralysis, even though the compressed nerve cells may regain blood reperfusion.

In summary, this study aims to observe the changes in somatosensory evoked potentials during spinal cord ischemia-reperfusion injury and to investigate the functions of somatosensory evoked potentials on monitoring spinal cord functions.

RESULTS

Quantitative analysis of experimental animals

Thirty New Zealand rabbits were used in this study. Twenty-four of the rabbits were randomly divided into three groups, in which the abdominal aorta was occluded for 20, 30, or 40 minutes, respectively, after spinal cord ischemia-reperfusion injury models were established. Subsequently, somatosensory evoked potential latency and amplitude were monitored and recorded before occlusion, during occlusion and at 30, 60, 120, 180, 240, 300, and 360 minutes after reperfusion. The remaining six rabbits served as the controls, three of which were used as the normal control group, while the remaining three were sacrificed at 40 minutes after abdominal aorta occlusion to observe histological changes in the spinal cord. Finally, all 30 rabbits were involved in the final analysis.

Changes of somatosensory evoked potentials during spinal cord ischemia-reperfusion injury in rabbits

Normal somatosensory evoked potential waveforms were detected immediately after the rabbit skin was sutured under anesthesia, including N-wave and P-wave in both positive and negative phases. After the rabbit abdominal aorta was occluded, the somatosensory evoked potential amplitude decreased gradually and the latency period gradually prolonged. After the abdominal aorta was occluded for 7–15 minutes, the amplitude reduced by approximately 50%, and somatosensory evoked potential waveforms disappeared at 20.0 ± 7.3 minutes. The potential disappearance occurred from 5–35 minutes after occlusion.

The reperfusion procedure refers to the occlusion, unclamping and reocclusion of the abdominal aorta in New Zealand white rabbits. Somatosensory evoked potentials may gradually restore after reperfusion, 3–11 minutes after the removal of the clamp. After reperfusion, the latency of somatosensory evoked potentials (N-wave peak time and P-wave trough time) gradually returned to near normal levels ($P < 0.05$; Figures 1, 2). At 360 minutes after reperfusion, the latency showed no significant difference compared with the normal levels before ischemia ($P > 0.05$). The amplitude of somatosensory evoked potentials began to decrease during the spinal cord ischemia period (data not shown, only changes were recorded), then gradually increased during the early reperfusion period (30–120 minutes), and began to decline during the late reperfusion period (180–360 minutes; Table 1).

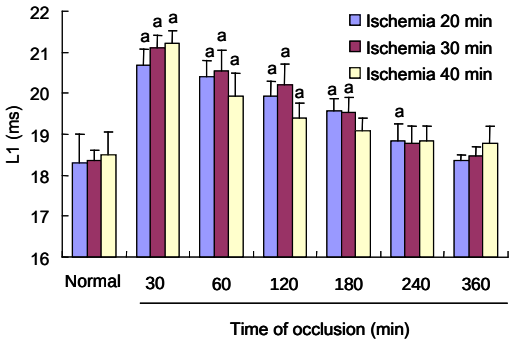

Figure 1 N-wave peak time (L1) of somatosensory evoked potential latency in rabbits with spinal cord ischemia-reperfusion injury.

[a]$P < 0.05$, *vs*. normal state before occlusion. Data are expressed as mean ± SD, *n* = eight rabbits per time point of occlusion, one-way analysis of variance and least significant difference test. min: Minutes.

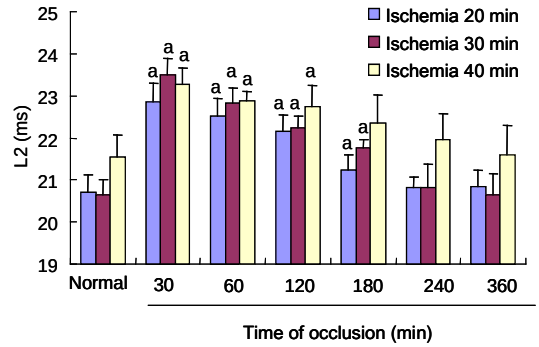

Figure 2 P-wave trough time (L2) of somatosensory evoked potential latency in rabbits with spinal cord ischemia-reperfusion injury.

[a]$P < 0.05$, *vs*. normal state before occlusion. Data are expressed as mean ± SD, *n* = eight rabbits per time point of occlusion, one-way analysis of variance and least significant difference test. min: Minutes.

Table 1 Changes of somatosensory evoked potential amplitudes (%) in rabbits with spinal cord ischemia-reperfusion injury

Group	20 min after occlusion	30 min after occlusion	40 min after occlusion
Normal	100	100	100
Reperfusion 30 min	51.3	46.5	43.3
Reperfusion 60 min	59.1	57.3	53.6
Reperfusion 120 min	66.5	63.4	65.7
Reperfusion 180 min	42.3	41.5	40.4
Reperfusion 240 min	40.3	39.1	38.5
Reperfusion 360 min	40.2	36.9	36.5

The variations of somatosensory evoked potential amplitudes are calculated as follows: amplitude after modeling/amplitude of normal rats × 100%, *n* = eight rabbits per time point of occlusion. Somatosensory evoked potential amplitudes of rabbits in each group began to increase at 30–120 minutes (min) after reperfusion, and then gradually decreased at reperfusion 180–360 min.

Correlation between somatosensory evoked potential latency, amplitude and hindlimb motor function after spinal cord ischemia-reperfusion

There were no statistically significant differences in somatosensory evoked potential latencies among groups after spinal cord ischemia-reperfusion. At 360 minutes after reperfusion, the rabbit hindlimbs exhibited severe motor dysfunction, where the amplitude decreased sharply.

Hindlimb motor dysfunction was not visible in rats with amplitude change > 44%, but became severe in rats with amplitude variation < 35% (Table 2). The N-wave peak time (L1) and P-wave trough time (L2) of rats in each group prolonged with increased severity of hindlimb dysfunction.

Spinal cord tissue pathological changes after spinal cord ischemia-reperfusion

Spinal nerve cells were complete, with clear nuclei, dendrites and axons in the normal control group (Figure 3A). At 40 minutes after abdominal aorta occlusion, spinal nerve cells were lightly stained, the nuclei dissolved and were absent, with perinuclear halos (Figure 3B). At 360 minutes after reperfusion, spinal nerve cell edema was visible, the gap between cells widened significantly, the polarity was blunt and there were unclear nuclei boundaries.

Furthermore, neutrophils were scattered within the tissues, some neurons had degenerated and became necrotic, with vacuolization and apparent hemorrhage, and a large number of neurons had abnormal morphologies (Figure 3C).

Table 2 Changes of somatosensory evoked potential latency, amplitude and hindlimb motor function at 360 minutes in rabbits with spinal cord ischemia/reperfusion injury

Group	Hindlimb motor function grade	*n*	N-wave peak time (L1, mean±SD, ms)	P-wave trough time (L2, mean±SD, ms)	Amplitude (%)
20 min occlusion	I	2	18.30±0.14	21.40±0.28	44.2
	II	6	18.37±0.15	20.63±0.20	40.2
	III	0	—	—	—
30 min occlusion	I	2	18.30±0.14	20.80±0.57	45.5
	II	3	18.60±0.20	20.87±0.61	39.7
	III	3	18.47±0.23	20.33±0.31	30.1
40 min occlusion	I	1	18.60±0.25	21.80±0.18	55
	II	0	—	—	—
	III	7	18.70±0.40	21.60±0.60	34.7

Somatosensory evoked potential latencies L1 and L2 are increased as the severity of hindlimb dysfunction. At 360 minutes (min) of reperfusion, the amplitude decreased sharply in the rabbit hindlimbs, where severe motor dysfunction was observed. There are eight rabbits per time point of occlusion. Hindlimb motor function evaluation criteria (self-made): level I: normal motor and sensory state (no spontaneous hindlimb activity, with activity in both hips and toes identifiable after stimulation); level II: moderate motor and sensory loss (flaccid paralysis on one side, or only ankle movement, or mild activity on one side after stimulation); level III: severe motor and sensory loss (no bilateral limb movement after stimulation).

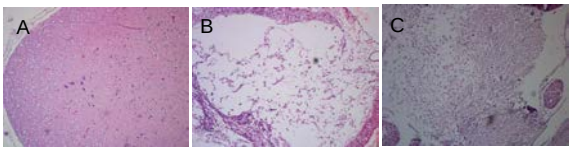

Figure 3 Spinal cord tissue at 360 minutes in rabbits with spinal cord ischemia-reperfusion injury (hematoxylin-eosin staining, optical microscopy, × 100).

(A) In the normal control group, spinal nerve cells showed a complete structure.

(B) At 40 minutes after abdominal aorta occlusion, the nuclei of spinal nerve cells had dissolved and disappeared.

(C) At 360 minutes after reperfusion, spinal nerve cell edema was observed, nuclear boundaries were unclear, and some cells degenerated and became necrotic, with apparent hemorrhage loci.

DISCUSSION

Somatosensory evoked potentials were first proposed by Tamaki and Nash[9-10] as an effective electrophysiological means for monitoring spinal cord functions, and has been widely used in various types of surgery involving neurological damage; however, few reports have been published in China. Somatosensory evoked potentials can record abnormal changes in skin around the surgical area through stimulating mixed peripheral nerves. Stimulating electrodes are often placed at the posterior tibial nerve, peroneal nerve, femoral nerve, and sural nerve. The stimulation can be given at 200–300 μs square wave, 4.1–4.7 stimuli per second. The stimuli intensity associated with the stimulation electrode is generally 10–25 mA. Recording electrodes are placed around the surgical incision, somatosensory cortex and subcortex. Somatosensory evoked potentials are usually evoked by peripheral sensory nerve fibers in the central nervous system under continuous stimulation; its variations may reflect the severity of spinal sensory nerve dysfunction, and it is an objective, quantitative and sensitive indicator for sensory dysfunction. The spinal cord dorsal funiculus and posterior lateral funiculus are the main pathway for somatosensory evoked potential conduction[10]. The occurrence of somatosensory evoked potentials depends on the integrity of the ipsilateral spinal cord dorsal funiculus and posterolateral funiculus, and it can reflect spinal sensory conduction pathway function, especially after spinal cord ischemia-reperfusion injury. Spinal cord anterior and posterior funiculi are adjacent to each other and can be entrapped by the same spinal pia mater, so somatosensory evoked potentials indirectly reflect the function of the anterior funiculus. This evidence indicates a correlation between somatosensory evoked potentials and hindlimb motor function, thus providing indirect demonstration for hindlimb motor function. Currently, the monitoring of somatosensory evoked potentials is regarded as an important means for the diagnosis of spinal cord injury and evaluation of spinal cord function.

The goals of intraoperative monitoring of evoked potentials are fivefold: first, to determine acute injury severity and location in the neural conduction pathway, thus promptly correcting induction factors; second, to quickly observe acute systemic changes, such as hypotension; third, to define nerve tissue around or within the tumor; fourth, to allow surgery in high-risk patients; and fifth, to ensure the implementation of more extensive surgical

procedures performed on patients[11]. Kai *et al* [12] proposed the main causes for spinal cord injuries as both structural and vascular injury. Somatosensory evoked potentials are the dominant means for detecting sensory pathways, but the surgeons focus their observations on motor function. Because the motor pathway is similar to the sensory pathway in anatomy, damage to motor function indirectly affects sensory responses after mechanical injury. As for spinal cord injury caused by vascular factors, the motor and sensory pathways have different blood supply sources, so no sensory dysfunction occurs even though motor dysfunction can be detected. In spinal surgery, surgeons often pay more attention to preventing structural damage, while potential vascular injury may be ignored. The goal of this study is to comprehensively reflect the changes of somatosensory evoked potentials after spinal cord ischemia and reperfusion. The results showed that, after the rabbit abdominal aorta was clamped, somatosensory evoked potential latencies gradually prolonged and the amplitude gradually decreased as time proceeded. After reperfusion, both the amplitude and latency gradually returned to normal levels, but the amplitude began to reduce during the late reperfusion period.

An evoked potential amplitude is determined by the number of neurons and the response synchronization, while the latency is closely associated with the conduction velocity[13-17]. Nerve conduction is affected by myelin function of myelinated nerve fibers. Ischemia can slow conduction velocity and produce a transient nerve block, resulting in a prolonged latency. After reperfusion, myelin functions and conduction velocity gradually restored, and accordingly the latency also returns to normal. The amplitude restored during early reperfusion and then decreased during the late reperfusion period, which corresponded with aggravated limb dysfunction, suggesting that changes in amplitude reflect the secondary injury after reperfusion. In this study, we found that one rabbit recovered motor function, which is possibly due to individual differences, where its spinal cord may not have been sensitive to ischemia.

Somatosensory evoked potentials can reflect the integrity of the spinal cord dorsal funiculus pathway[18-20]. Structural damage caused by mechanical factors directly affects the integrity of the posterior funiculus pathway, and thus somatosensory evoked potentials can be applied to monitor spinal cord functions and spinal cord injury caused by ischemia and other non-mechanical factors, with the following possible mechanisms: (1) After abdominal aorta is occluded, local blood supply redistributes to form a “steal blood” phenomenon. Abdominal aorta clamping results in severe blood supply insufficiency in the anterior spinal artery, also affecting blood supply in the posterior spinal artery, which compensatively transfers blood into the anterior spinal artery, resulting in changes in spinal cord dorsal funiculus function and somatosensory evoked potentials. After the abdominal aorta clamp was released, blood supply in the anterior spinal artery was restored, and no compensatory blood supply of the posterior spinal cord artery was required, the blood supply of the posterior spinal artery was then restored and somatosensory evoked potentials underwent a corresponding recovery. (2) It is generally recognized that the conduction of somatosensory evoked potentials is achieved through the posterior funiculus, where the dorsal root ganglia axons enter the spinal cord, travel along the ipsilateral fasciculus gracilis and fasciculus cuneatus, and cross into the medulla oblongata. This non-synaptic conduction pattern has been confirmed to be strongly tolerant against ischemia and can consume less energy. The labeling results of blood flow showed that short-term ischemia cannot induce loss of function in non-synaptic conduction pathways, and so the latency of somatosensory evoked potentials gradually returned to normal after blood supply was restored. (3) In contrast, synaptic conduction pathways require great energy and are sensitive to ischemia. Moreover, in sensory conduction pathways, both spinal cord posterior funiculus and gray matter second-grade neurons are involved in the conduction of somatosensory evoked potentials. These second-grade neurons are also sensitive to ischemia and may become necrotic after long-term ischemia. Somatosensory evoked potential amplitudes are largely dependent on the number of neurons and the response synchronization. The decline of neuronal number may trigger a reduction in amplitude. (4) After spinal cord ischemia-reperfusion, excitatory amino acids (glutamic acid, aspartic acid, folic acid) and intracellular Ca^{2+} content in spinal cord tissue increase, as well as their resultant cascade reactions, leading to axonal degeneration and neuronal necrosis, which play a decisive role on ischemia-reperfusion injury. This could also be explained by the amplitude increase at early reperfusion and decline at late reperfusion[21-24].

At 360 minutes after reperfusion, hindlimb function evaluation results showed that limb dysfunction had no apparent correlation with somatosensory evoked potential latency, and there was no significant difference in the latency compared with pre-ischemia levels, although loss of motor and sensory function was severe. This evidence

indicates that restoration of somatosensory evoked potential latency cannot represent the synchronous recovery of spinal cord function, in particular motor function, because the pyramidal tracts, which are responsible for the conduction of motor function, are located in the anterior spinal cord and supplied by the anterior spinal artery. Our findings are consistent with previous studies[25-26], which found that intraoperative somatosensory evoked potentials were normal in patients with the development of lower limb dysfunction after spinal surgery. This evidence also indicates that posterior spinal artery injury can be reversed, while anterior spinal artery injury is irreversible. In particular, the posterior funiculus itself has a strong tolerance against ischemia.

Myelin has the ability to regenerate and, as myelin function affects conduction velocity, it also affects somatosensory evoked potential latency. Moreover, as ischemia induces changes in myelin function, it also slows conduction velocity and prolongs the latency. After reperfusion, myelin functions and conduction velocity restore, and accordingly the latency also returns to normal; however, pathological changes caused by prolonged ischemia-induced neuronal necrosis are irreversible. In this study, when spinal cord ischemia caused neuronal necrosis, the number of neurons involved in the transduction and synchronization response reduced, resulting in a decrease in evoked potential amplitude. Moreover, at 6 hours after reperfusion, severe hindlimb motor disorders were observed in rats with amplitudes < 35%, while it was not present in rats with amplitudes > 44%. These discrepancies provide criteria for determining the severity of spinal cord ischemia following reperfusion and for assaying hindlimb motor function. After 2–3 hours of reperfusion, somatosensory evoked potential amplitudes reduced further, suggesting the potential occurrence of reperfusion injury. At this time some protective measures may reduce spinal cord injury. The representative images in Figure 3 appear as though the nerves are healthier at 360 minutes than at 40 minutes. This could be due to variations in the procedure.

In summary, we believe that somatosensory evoked potentials are a sensitive indicator for monitoring spinal cord ischemia-reperfusion injury, in which changes in latency reflect spinal cord ischemic insult, while changes in amplitude reflect late reperfusion injury. When the somatosensory evoked potential amplitude remains unchanged and the latency changes greatly, only myelin tissue is damaged; when both the amplitude and latency exhibit variations, the central nervous system is also affected. Therefore, somatosensory evoked potentials are an indirect means to determine the position of nerve tissue necrosis and to predict the prognosis following spinal cord injury. Our experimental findings indicate that there was no apparent correlation between the variations of somatosensory evoked potential latency and the restoration of spinal cord function. This evidence indicates that somatosensory evoked potentials and motor evoked potentials should be monitored simultaneously to comprehensively determine spinal cord function and reduce the incidence of intraoperative monitoring false negativities and false positives.

MATERIALS AND METHODS

Design

A randomized, controlled animal experiment.

Time and setting

The experiment was performed from January 2011 to January 2012 at Orthopedic Laboratory, the First Affiliated Hospital of Soochow University, China.

Materials

Thirty healthy New-Zealand white rabbits, of either gender, weighing 3 000 ± 500 g, were purchased from the Experimental Animal Center of Soochow University, China (license No. SYXK (Su) 2012-0045). Experimental disposals were in accordance with the *Guidance Suggestions for the Care and Use of Laboratory Animals*, issued by the Ministry of Science and Technology of China[27].

Methods

Establishment of spinal cord ischemia/reperfusion injury models

Spinal cord ischemia/reperfusion injury models were established as previously described[28-29]. In brief, rats were anesthetized with 25% urethane (4 mL/kg), injected into the auricular vein. Rabbits were fixed on the operating table under anesthesia, the skull hair was removed and the operating field was routinely disinfected. A left lateral incision was then made sterilely and somatosensory evoked potentials were monitored and recorded immediately. The skin and muscle were cut open along the paraspinal muscles. After the position of left renal artery was determined, the tissue was bluntly dissected *via* the retroperitoneal space. The abdominal aorta was exposed and blocked 0.5–1.0 cm below the left renal artery, until arterial pulsation below the blocking site completely disappeared, indicating the success of occlu-

sion. The blood flow was blocked for certain periods and then released, following which the incision was sutured. Somatosensory evoked potentials were continuously monitored during the occlusion procedure, and each rabbit was covered with warm saline gauze on organs and incisions. The room temperature was maintained at 20–25°C.

Implantation of somatosensory evoked potentials stimulating electrodes and recording electrodes and recording of stimulation parameters

The variations of somatosensory evoked potentials were observed with Viking IV type evoked potential apparatus (Thermo Nicolet Corporation, Madison, WI, USA). Electrical stimulation was at a pulse square wave of 0.2 ms width and 3.9 Hz frequency, and the stimuli intensity was permissible upon the symptoms of rabbit toe jogging. Recording electrodes were placed 17.5 mm above the sagittal suture on the skull surface and 3.5 mm lateral, which was close to hindlimb sensory projection area. Reference electrodes were placed below the scalp; signals were collected and analyzed through 500 superpositions with a sensitivity of 5 μV, and the filtering ranged from 30–3 000 Hz. The latency (L) refers to the period from the beginning of stimulation to the emergence of wave peak in milliseconds (ms) as a unit. The first upward wave was the N wave and the N-wave peak (L1) was recorded; and the second downward wave was P wave, and the P-wave trough (L2) was recorded. The amplitude was measured as the distance from N-wave peak or P-wave trough to the baseline, in millivolts (mV) as a unit. Variations of amplitude were calculated as follows: amplitude after modeling/amplitude in normal rats × 100%. The somatosensory evoked potentials were monitored before occlusion, during occlusion, and at 30, 60, 120, 180, 240, 300, and 360 minutes after reperfusion.

Evaluation of hindlimb motor function after spinal cord ischemia-reperfusion

The hindlimb motor function of New Zealand white rabbits was assayed after ischemia (20, 30, 40 minutes) and reperfusion (360 minutes) according to the self-made limb movement function criteria as follows: level I: normal motor and sensory state (no spontaneous hindlimb activity, and activities of both hips and toes are identifiable after stimulation); level II: moderate motor and sensory loss (flaccid paralysis on one side, or only ankle movement, or mild activity on one side after stimulation); level III: severe motor and sensory loss (no bilateral limb movement after stimulation).

Histological changes of spinal cord after spinal cord ischemia-reperfusion

After 40-minute occlusion and 360-minute reperfusion, the rabbits were sacrificed and spinal cord specimens were harvested. Then specimens were fixed in 10% neutral formalin solution for 72 hours, paraffin-embedded, sliced into continuous cross-sections for hematoxylin-eosin staining. The pathological changes of spinal cord specimens were observed under an upright optical microscope (Axio Imager M1, Carl Zeiss Company, Germany). In comparison to the spinal cord tissue of normal rabbits in the control group, the histological changes of injured spinal cord specimens were observed to determine the effect of ischemia .

Statistical analysis

Measurement data were expressed as mean ± SD and data were expressed as the percentage. All data were analyzed using SPSS 18.0 software (SPSS, Chicago, IL, USA). The data between groups were compared using one-way analysis of variance and least significant difference test, a $P < 0.05$ value was considered statistically significant.

Research background: Intraoperative monitoring using somatosensory evoked potentials has been widely recognized as one of effective measures for avoiding iatrogenic spinal cord injury, and somatosensory evoked potentials can directly reflect the integrity of spinal cord dorsal funiculus pathway after mechanical-induced structural damage. Thus, we speculated that somatosensory evoked potentials can be applied to monitor spinal cord function.

Research frontiers: Previous studies mainly focused on the variations of somatosensory evoked potentials after spinal cord injured caused by mechanical factors; however, little evidence is available regarding spinal cord ischemia-reperfusion injury caused by ischemia and other non-mechanical factors.

Clinical significance: Intraoperative monitoring using somatosensory evoked potentials can improve the prediction accuracy of spinal cord function and reduce the incidence of iatrogenic spinal cord injury.

Academic terminology: Somatosensory evoked potentials – a group of comprehensive potential activities evoked by peripheral sensory nerve fibers in the central nervous system. Following continuous stimulation, changes in somatosensory evoked potentials can reflect the severity of spinal sensory nerve dysfunction. They are an objective, quantified and sensitive indicator for the evaluation of sensory functional disorders and neural pathway integrity.

Peer review: Our experimental findings provide evidence for the care of patients undergoing clinical surgery to minimize the incidence of iatrogenic spinal cord injury, indicating that monitoring of somatosensory evoked potentials can detect early

accidental spinal cord injury in orthopedic surgery, and thus help avoid irreversible damage.

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