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Original Article

Effect of traction force during surgery on physical integrity and histological changes in peripheral nerves: experimental study on rabbits

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Abstract

Sensory and motor nerve damage is a common complication of maxillofacial surgery and trauma. Procedures such as orthognathic surgery, tumor resection, and salivary gland interventions can damage peripheral nerves when the surrounding soft tissue or the nerve itself is manipulated. The purpose of this study was to evaluate the histological changes in the sciatic and median nerves of albino rabbits following traction-induced nerve injury. Nine albino rabbits were included in the study and divided equally into three groups, with three rabbits per group. In each rabbit, four peripheral nerves were exposed: the right and left sciatic nerves and the right and left median nerves. In Group A, varying traction forces (0.5 N, 1 N, 1.5 N, and a control of 0 N) were applied to each nerve for 5 minutes. The same traction forces used in Group A were applied to Groups B and C for 10 minutes and 15 minutes, respectively. Nerve fiber abnormalities, as well as damage to the axons, myelin sheath, and connective tissue layers, were assessed through histological examination. Histopathological evaluation of the injured nerves revealed Grade I and Grade II nerve injuries in Group A, while Grade IV and Grade V nerve injuries were noted in Groups B and C, respectively, based on the criteria established by the histopathologist.

Keywords: Axon, Injury, Median nerve, Peripheral nerve, Sciatic nerve, Stretch, Traction force.

1. Introduction

Traction is an integral element of any surgery, serving to facilitate exposure and access to the surgical site. However, excessive traction force can potentially compromise the physical integrity of peripheral nerves, resulting in complications such as numbness, weakness, and pain. The degree of injury resulting from traction force during surgery varies, contingent upon numerous factors, including the type of procedure and the location of the surgical site. In some instances, the use of specific retractors can aid in minimizing the required amount of traction force; conversely, certain situations may necessitate increased traction force [1].

Traction nerve damage is a common complication in maxillofacial surgeries such as fracture reduction [2], orthognathic surgery [3], tumor resection [2], and salivary gland procedures [4], as well as nerve repositioning during implant placement for patients with an edentulous posterior atrophic mandible [5]. During these procedures, peripheral nerves may sustain damage when the soft tissue surrounding the nerve or the nerve itself is manipulated.

In 1943, Seddon classified nerve injuries into three categories: neurapraxia, characterized by temporary interruption of conduction without loss of axonal continuity; axonotmesis, involving loss of relative continuity of the axon and its myelin covering while preserving the endoneurium, epineurium, and perineurium; and neurotmesis, which entails total severance or disruption of the entire nerve fiber [6,7].

Following Seddon's classification, Sunderland expanded upon it by introducing five grades of peripheral nerve injury: Grade I (demyelination), Grade II (demyelination and axon loss), Grade III (Grade II with involvement of the endoneurium), Grade IV (Grade III with involvement of the perineurium), and Grade V (Grade IV with involvement of the epineurium) [7,8].

Traction nerve injuries cause histological changes, mechanical failure, ischemia, and conduction problems in peripheral nerves. Histological changes include axonal damage, demyelination, elongation of nerve fibers, and reduced fiber width, often accompanied by marked disintegration of axons and surrounding tissue.

Regarding mechanical failure, traction nerve injury leads to damage of both motor and sensory functions. The

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extent of nerve injury depends on the magnitude and duration of the traction force, as well as the direction and location of the force [9].

The rate of recovery and surgical repair after nerve injury varies depending on the severity of the injury. For patients with neuropraxia, surgical repair is unnecessary, and recovery is typically rapid and complete within a few days to weeks. In cases of axonotmesis, where axonal regeneration occurs, recovery is possible without surgical treatment. However, in cases of neurotmesis, recovery is not possible without appropriate surgical intervention [8].

To prevent nerve damage caused by traction pressure during surgery, surgeons can employ techniques such as gentle traction or the use of retraction tools with minimal force, such as retraction rubber. These methods can help prevent nerve injury during surgery, leading to improved patient outcomes and reduced long-term complications [10].

The aim of this study was to evaluate the effect of traction with different force magnitudes and durations on the histological aspects of the median and sciatic nerves in albino rabbits.

2.Materials and methods

The study included nine albino rabbits, divided into three groups, each comprising three rabbits. In each rabbit, four peripheral nerves were exposed: the left and right sciatic nerves and the left and right median nerves.

In Group A, various traction forces (0.5 N, 1 N, and 1.5 N) were applied to the right sciatic nerve, left median nerve, and left sciatic nerve, respectively, for a duration of 5 minutes. The right median nerve of each rabbit in each group served as the control nerve, with no traction force applied.

Groups B and C underwent similar procedures with different durations of traction forces applied to the nerves. Each traction force in Group B was applied for 10 minutes, while in Group C, each traction force lasted 15 minutes.

2.1. Surgical procedure

The rabbits were anesthetized with ketamine (5–10 mg/kg) and xylazine (1 mg/kg) [11]. The surgical site was shaved and cleaned with povidone-iodine. The rabbits' limbs were secured to the experimental plate, and surgical landmarks were identified. For the sciatic nerve, palpation was performed at the lateral condyle of the knee and the greater trochanter, followed by a linear posterolateral incision [11]. After incising the fascia and dissecting between the anterior and posterior muscular compartments, a 10–20 mm segment of the nerve was exposed.

The median nerve originates from the ventral rami of C8, C7, and T1. This nerve, along with the musculocutaneous nerve, forms a loop in which the axillary artery is suspended. It descends alongside the ulnar nerve near the distal humerus and continues distally to the medial elbow [12]. The nerve was exposed through a skin incision along the humerus on the medial aspect of the forelimb. Traction force was then applied using a spring balance device according to the times set in the methodology [9] (Figure 1).

After removing the weight scale, a stretched nerve segment was sharply cut with a #11 surgical blade [11]. The sampled nerve was immersed in a tube containing formalin, labeled accordingly, and sent for histological evaluation. Throughout the experiments, the nerves were kept moist with saline irrigation. Histological damage to the axons, myelin sheath, and connective tissue layers was examined under a light microscope [9]. The animals were euthanized following the protocol of the Universitat Autònoma de Barcelona (UAB) [13]. This animal experiment was approved by the ethics committee on the experimental use of laboratory animals of the Asan Medical Center Animal Research Committee.

2.2. Histopathological evaluation

The nerves were sectioned and fixed for 24 hours in a 10% paraformaldehyde solution in 0.1 M phosphate buffer (PB) and embedded in paraffin wax. Hematoxylin and eosin (H&E) staining was used to detect abnormalities in nerve fibers. Each section or slide was examined under a microscope at 20–400× magnification by two pathologists blinded to the study. Sample slices were analyzed using computer-assisted image analysis software (AmScope™, Japan) and a traditional light microscope (Leica, Germany). The grading system proposed by Schaeren et al. (14) was adapted to assess IAN damage as follows: Grade 0 indicated no nerve injury with intact connective tissue organization; Grade 1 showed damage to the perineurium with intact nerve fibers; Grade 2 indicated 20–25% axonal degeneration; Grade 3 included 26–50% axonal degeneration; Grade 4 represented ≥75% axonal degeneration; and Grade 5 signified total axon disruption (axonotmesis) with partial endoneurial injury.

2.3. Statistical analysis

Statistical analyses were conducted using Fisher's exact test, chi-square tests, and Kruskal-Wallis tests to evaluate differences among the groups. A statistically significant p-value (<0.001) indicated a significant difference in nerve injury grades among Groups A, B, and C following the traction procedures.

Group A exhibited a higher incidence of Grade I injuries compared to Groups B and C, reflecting milder outcomes. In contrast, Groups B and C showed more severe injuries, with a notable occurrence of Grade IV and Grade V injuries, respectively.

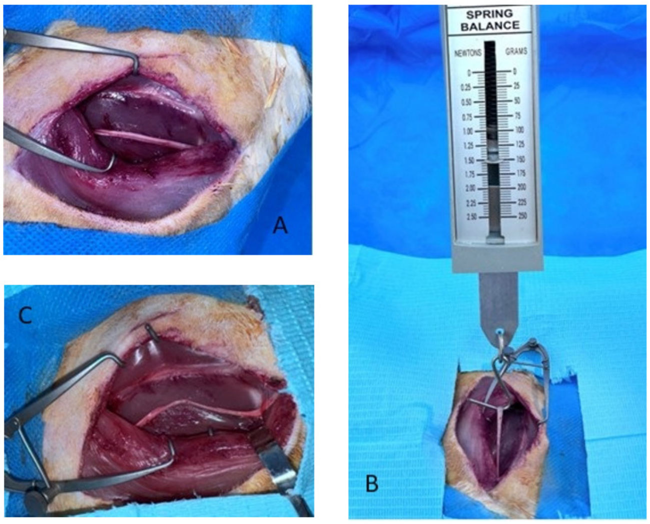

Fig. 1. Surgical Procedure and Nerve Exposure: A) Sciatic Nerve Exposure, B). The tractor used is visible, with the nerve in a traction status. C) This figure demonstrates the stretching that occurred due to the nerve's longer course compared to its pre-stretched state.

In the control groups, Group A showed no nerve injuries, Group B had mild injuries (Grade I), and Group C exhibited moderate injuries (Grade II).

3. Results

Applying a traction force of 0.5 N for 5 minutes resulted in a Grade I nerve injury, characterized by sloughing of the epineurium and perineurium while maintaining intact individual nerve fibers, which were enveloped by the endoneurium and displayed normal axons surrounded by myelin sheaths. Increasing the force to 1 N and 1.5 N for the same duration caused a slight increase in the severity of nerve injuries, which were classified as Grade I and Grade II injuries, respectively.

Prolonging the application duration to 10 and 15 minutes at the same force levels led to a significant increase in nerve injury, involving the epineurium and perineurium, along with moderate to severe degeneration of nerve fibers and focal damage to the endoneurium and axon.

In the control groups, Control Group A (nerve exposed without traction force for 5 minutes) showed no nerve injuries. Control Group B (nerve exposed for 10 minutes) exhibited mild injuries (Grade I), while Control Group C (nerve exposed for 15 minutes) demonstrated moderate injuries (Grade II) (Table 1).

In Group A, where the right sciatic nerve was exposed to a 0.5 N traction force, it exhibited a Grade 1 nerve injury. Microscopic examination (Figure 2a–c) revealed sloughing of the epineurium and perineurium covering the nerve bundles, with well-organized nerve fibers displaying a wavy appearance and mild congestion. Individual nerve fibers were intact, surrounded by the endoneurium, and exhibited normal axons enveloped by myelin sheaths, along with the formation of nodes of Ranvier. Schwann cells showed normal histologic features with oval nuclei participating in multiple fibers.

In the same group, the left median nerve, exposed to a 1 N traction force, also exhibited a Grade 1 nerve injury, characterized by disruption of the epineurium and perineurium, loss of the normal wavy appearance of nerve fibers, and mild loss of the myelin sheath. However, individual nerve fibers maintained an intact endoneurium, axons, nodes of Ranvier, and Schwann cells (Figure 2d–f).

The left sciatic nerve in the same group, which was exposed to a 1.5 N traction force for 5 minutes, exhibited a Grade 2 nerve injury. Pathological features included complete damage to the epineurium and perineurium, moderate vacuolar degeneration of nerve fibers or axons, and moderate loss of the myelin sheath. However, the histological features of Schwann cells and the endoneurium remained normal (Figure 2g–i).

The right median nerve in the same group, where no traction force was applied, showed a Grade 0 nerve injury. It presented a normal appearance of wavy, well-organized peripheral nerve fibers with slight sloughing of the perineurium and mild congestion. Individual nerve fibers were surrounded by intact endoneurium, exhibited normal structures of axons enveloped by myelin sheaths, and dis-

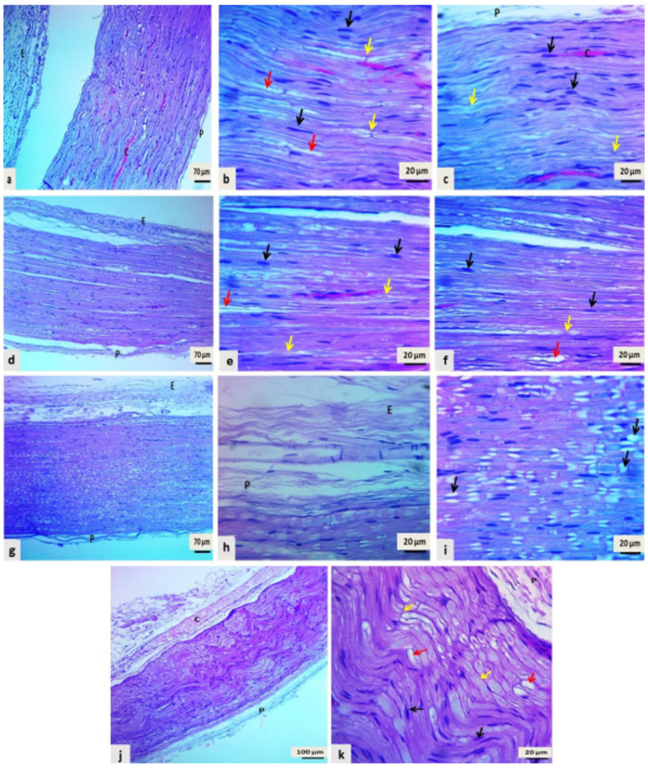

Fig. 2. Light microscopic longitudinal sections of a right sciatic nerve fiber in Group A. (a) Damage to the epineurium (E) and perineurium (P) with well-arranged nerve fibers and mild congestion (C). (b, c) Normal features of axons enveloped by myelin sheaths (red arrows), and a node of Ranvier (yellow arrows) with Schwan cells as indicated by black arrows. d: Disruption of the epineurium and perineurium, e, and f: Mild loss of the myelin sheath (red arrows). g: Complete damage to the epineurium and perineurium, h and i: moderate vacuolar degeneration of nerve fibers or axons (black arrows), and moderate loss of the myelin sheath with normal histological features of Schwan cells and the endoneurium, j: Slightly sloughing of perineurium with wavy well organized nerve fibers with mild congestion (C), l: Intact histologic individual nerve fibers surrounded by intact endoneurium with normal features of axon that enwrapped by myelin sheath (red arrows), and nodes of Ranvier (yellow arrows) with Schwan cells as indicated by black arrows, (H&E stain).

Table 1. Distribution of nerve injury grades across experimental and control groups following traction procedures.

Groups	Grade									
	0		1		2		4		5	
	No.	%	No.	%	No.	%	No.	%	No.	%
Group A	0	0.0%	6	66.7%	3	33.3%	0	0.0%	0	0.0%
Group B	0	0.0%	0	0.0%	0	0.0%	3	33.3%	6	66.7%
Group C	0	0.0%	0	0.0%	0	0.0%	3	33.3%	6	66.7%
Control Group A	3	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Control Group B	0	0.0%	3	100.0%	0	0.0%	0	0.0%	0	0.0%
Control Group C	0	0.0%	0	0.0%	3	100.0%	0	0.0%	0	0.0%

played nodes of Ranvier formation (Figure 2j, k).

In Group B, the severity of lesions in the peripheral nerves increased compared to Group A. For example, the right sciatic nerve exposed to a 0.5 N traction force for 10 minutes exhibited a Grade 5 nerve injury. This included complete disruption of the epineurium and perineurium, moderate to severe degeneration or vacuolization of nerve fibers, intact elongated Schwann cells, and focal disruption of the endoneurium, with axons displaying a swollen or dilated pattern (Figure 3a–c).

Similarly, in the same group, Grade 5 nerve injury occurred when the left median nerve was exposed to a 1 N traction force for 10 minutes. This was characterized by complete damage to the epineurium, marked disruption of the perineurium, moderate to severe degeneration of nerve fibers, diminished Schwann cells, and multiple focal areas of damage to the endoneurium and axons (Figure 3d–f).

However, the left sciatic nerve in the same group, which was exposed to a 1.5 N traction force for 10 minutes, exhibited a Grade 4 nerve injury. Pathological features included complete damage or sloughing of the epineurium and perineurium, severe vacuolar degeneration of nerve fibers, and a decrease in the number of Schwann cells and myelin sheaths (Figure 3g–i).

In comparison, the right median nerve in this group, where no traction force was applied, displayed the lowest-grade lesion (Grade 1 nerve injury). Complete sloughing of the perineurium, mild vacuolar degeneration of nerve fibers, and normal histological features of Schwann cells and the endoneurium were observed (Figure 3j, k).

The nerves in Group C exhibited various microscopic abnormalities and grades. For instance, the right sciatic nerve and left median nerve, which were exposed to 0.5 N and 1 N traction forces for 15 minutes, respectively, presented Grade 5 nerve injuries. These nerves showed destruction of the perineurium, marked vacuolar degeneration of nerve fibers, focal damage to axons, loss of the endoneurium, severe congestion of vessels, and a decrease in the number of Schwann cells with myelin sheaths (Figure 4a–f).

Moreover, the left sciatic nerve in the same group, which was exposed to a 1.5 N traction force, exhibited complete damage or sloughing of the epineurium and perineurium with severe vacuolar degeneration of nerve fibers.

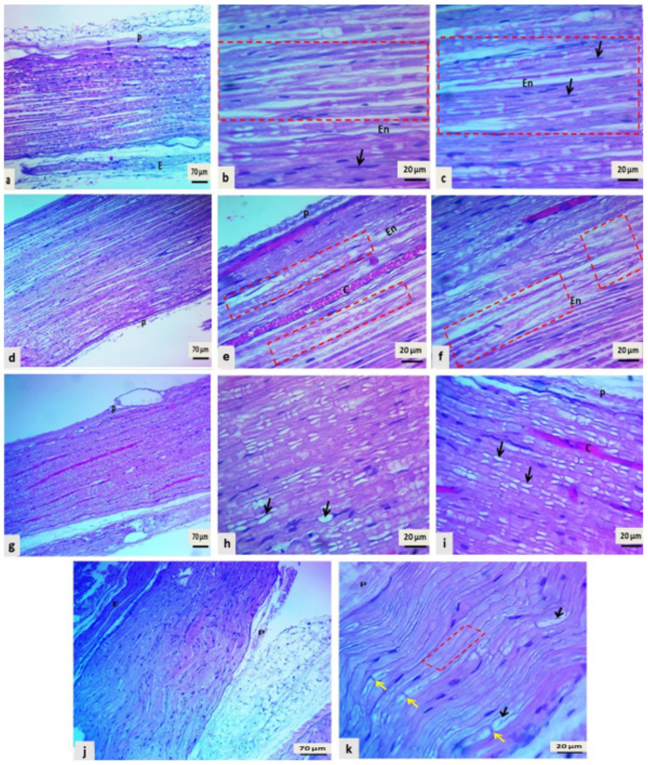

Fig. 3. Light microscopic longitudinal sections of the right sciatic nerve fiber in Group B. (a) Complete disruption of the epineurium and perineurium. (b, c) Moderate to severe vacuolization of the nerve fibers with intact elongated Schwann cells (black arrows) and focal damage to the endoneurium (En) and axons, indicated by the red dashed line. (d) Complete damage to the epineurium and marked disruption of the perineurium. (e, f) Moderate to severe degeneration of the nerve fibers with multiple areas of focal damage to the endoneurium (En) and axons, indicated by the red dashed line. (g) Complete damage to the epineurium and severe sloughing of the perineurium. (h, i) Severe degeneration of the nerve fibers. (j) Sloughing of the epineurium and perineurium with a slightly wavy appearance of the nerve fibers. (k) Intact endoneurium with mild degeneration of the nerve fibers (red dashed line), wrapped by a few myelin sheaths (black arrows), and nodes of Ranvier (yellow arrows) with Schwann cells. (H&E stain).

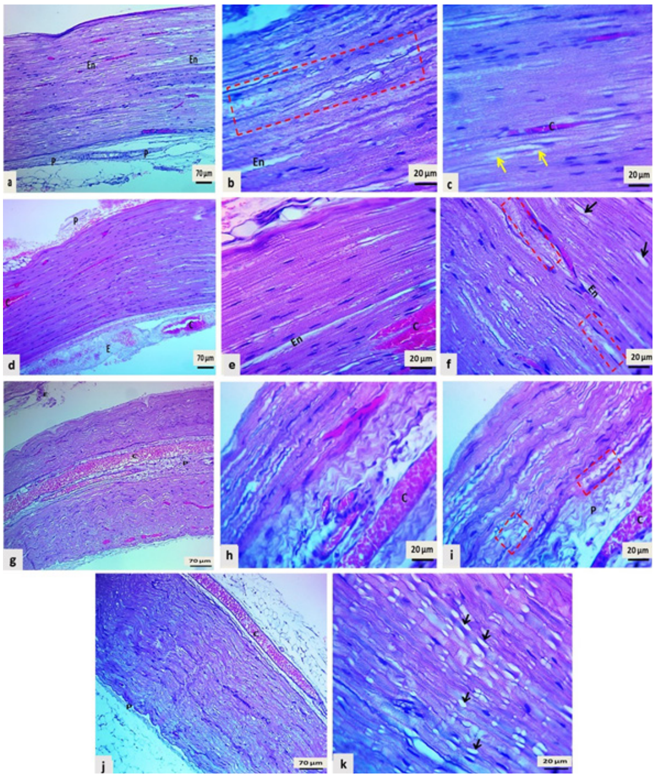

Fig. 4. Light microscopic longitudinal section of a right sciatic nerve fiber in GC; a: Complete damage to the epineurium and partial damage to the perineurium, b and c: Severe degeneration of the nerve fiber, damage to the endoneurium, and severe damage to the axon as indicated by the red dashed line. d: Complete damage to the epineurium and perineurium with severe vessel congestion (C), e and f: severe degeneration of the nerve fiber, damage to the endoneurium, and focal disruption of the axon as indicated by the red dashed line. g: Complete damage to the epineurium and sloughing of the perineurium with severe congestion and edema of the perineurium, h and i: severe degeneration of the nerve fiber (red dashed line). j: complete sloughing of the perineurium, k: Moderate vacuolar degeneration of nerve fibers or axons (black arrows), mild loss of a wavy appearance with normal histological features of Schwan cells and the endoneurium, (H&E staining).

It also caused mild damage to the endoneurium, while the axons remained histologically intact, corresponding to a Grade 4 nerve injury (Figure 4g–i).

The right median nerve in this group, where no traction force was applied, exhibited the lowest-grade lesion compared to the other studied nerves in Group C. Complete sloughing of the perineurium, moderate vacuolar degeneration of nerve fibers, and mild loss of the wavy appearance were observed, along with normal histological features of Schwann cells and the endoneurium, corresponding to a Grade 2 nerve injury (Figure 4j, k).

4. Discussion

After a peripheral nerve injury, there may be partial loss of function in the innervated region, leading to motor and sensory dysfunction. If the nerve is completely severed, it can result in more extensive nerve damage and structural changes, potentially causing motor neurological deficits in affected muscles (if a motor nerve is involved) or sensory issues such as numbness (if a sensory nerve is affected). This can permanently impact the patient's quality of life [15]. Therefore, it is crucial to minimize nerve injury, given its significant impact on both the patient and the clinician.

The layers of peripheral nerves (endoneurium, perineurium, and epineurium) are vital components that provide support, protection, and aid in conduction. Damage to the myelin sheath can lead to a decrease in conduction velocity, while injuries to the axon, endoneurium, and perineurium may cause partial or complete conduction blocks. In cases where the epineurium is affected during a nerve injury, it can contribute to a complete conduction block.

In the present study, applying a traction force of 0.5 N for 5 minutes resulted in a Grade I nerve injury. Microscopic examination revealed sloughing of the epineurium and perineurium covering the nerve fiber bundles, with intact individual nerve fibers surrounded by the endoneurium and featuring normal axons enveloped by myelin sheaths. Increasing the force to 1 N and 1.5 N for the same duration led to a slight increase in the severity of nerve injury, which was classified as Grade I and Grade II injury. When the same forces of 0.5 N, 1 N, and 1.5 N were applied for 10 and 15 minutes, the severity of nerve injury increased, resulting in Grade IV and Grade V injuries. These severe grades showed complete disruption of the epineurium and perineurium, along with moderate to severe degeneration of nerve fibers and focal damage to the endoneurium and axon (neurotmesis).

The impact of traction force has been investigated by Soo-Hwan Byun and Kang-Min Ahn [9], who reported that the duration of application is as important as the magnitude of the force. They suggested that forces ranging from 0.5–2 N may have different effects on nerve tissue, but the duration factor should also be considered [9].

In his book “The Recurrent and Superior Laryngeal Nerves,” Gregory W. Randolph explains that there are three main mechanisms of nerve injury: visible structural trauma, which occurs with transection or thermal injury; compression, which can occur with a ligature; and stretch/traction injury. According to Randolph, traction applies a stretch force to the nerve, and its impact is influenced by three parameters: the degree of traction (how forcefully the surgeon pulls), the duration of traction (how long the pull lasts), and the direction of traction. He also emphasized that the duration of traction has a direct impact on nerve injury because traction injury is a gradual stretch injury that occurs over time, unlike compression or direct trauma [16].

Randolph further explains that when traction is applied, the fibers closest to the point of maximal traction should break first. As traction continues, additional fibers break in an anterior-to-posterior direction within the nerve, resulting in sufficient disruption of fibers or sheaths to cause a motor or sensory deficit. Awareness during surgery is critical for preventing traction injury, which can be achieved by keeping the traction force minimal, periodically releasing the traction, and altering the direction of traction [16].

This study demonstrated that duration is a crucial factor in determining the severity of nerve injury. This finding aligns with Randolph’s theory, which suggests that the longer the duration of traction, the greater the potential for injury.

Various techniques for nerve retraction have been described in the literature. In 1987, Nock and Jensen performed the first nerve repositioning procedure for dental implant insertion in the posterior mandibular areas, utilizing a looped suture as a nerve retractor to distance the nerve from the surgical site [17]. In 1992, Rosenquist pioneered a case series involving 10 patients and 26 implants [18]. Subsequently, Rosenquist [18, 19], Kan et al. [20], Del Castillo-Pardo et al. [21], and Bovi et al. [22, 23] employed vessel loops as nerve retractors during their surgeries. Other alternatives have been suggested, such as Babbush's use of umbilical tapes [24, 25], Hashemi's various suggestions, including green cloths, sections of suture covers, and rubber pistons [26, 27], and Vasconcelos et al.'s use of delicate spatulas [28].

When applying traction force to a peripheral nerve, it is important to consider the number of nerve fascicles and the thickness of the epineurium. Nerves with fewer fascicles and thicker epineurium are more resilient to pressure, whereas those with more fascicles and thinner epineurium are more susceptible to damage [29, 30]. Therefore, minimizing pressure on the nerve is essential. Increasing the contact area between the retractor and the nerve can help achieve this goal. According to the principles of physics, there is an inverse relationship between pressure and contact area. By increasing the contact area, the pressure on the nerve decreases. Using wide elastic tape as a retractor can effectively increase the contact area, transforming the contact point into a contact surface. This reduces pressure on the nerve and lowers the risk of ischemia and damage during surgery [5].

In contrast, using a looped suture, vessel loop, or any fine retractor creates point contact, concentrating pressure on the nerve and potentially leading to ischemia, nerve damage, and sensory and motor disturbances. A wider retractor, however, distributes pressure over a larger area, minimizing the risk of ischemia and nerve damage post-surgery. Additionally, the elastic properties of the retractor should be considered. A nonelastic retractor directs the entire traction force onto the nerve, increasing the risk of ischemia. In contrast, wide elastic tape absorbs some of the traction force, reducing pressure on the nerve. The glossy surface of elastic tape remains consistently wet during application, ensuring the nerve is in contact with a smooth surface, further reducing the risk of damage [5].

Maintaining vigilance during surgery is crucial in preventing traction injuries. This involves minimizing the traction force, periodically releasing traction, and adjusting the direction of traction. The use of wide retractors with elastic properties can help reduce the risk of nerve damage during retraction.

The results of the current study align with those of Soo-Hwan Byun and Kang-Min Ahn [9], who demonstrated that applying traction force to peripheral nerves can lead to nerve damage and impact physical integrity. Their study suggested that the severity of nerve injury depends primarily on the amount of traction force applied. However, the current study reveals that both the amount of applied traction force and the duration of force application contribute to the severity of nerve injury.

In the previous study, the sample size was smaller, with traction forces of 0.7 N and 1.5 N applied for a fixed duration of 10 minutes. In contrast, the current study used a larger sample size and applied forces of 0.5 N, 1 N, and 1.5 N for durations of 5, 10, and 15 minutes. This expanded approach offers more precise insights into the effects of varying traction forces and application times on nerve injury. The current study showed that applying a traction force of 0.5 N to the nerve for 5 minutes resulted in a minor, Grade I nerve injury. When the traction force was increased to 1 N and 1.5 N, the injury level escalated to Grade II. Furthermore, as the duration of traction increased to 10 and 15 minutes, the severity of injury progressed to Grades IV and V. These findings emphasize the combined influence of traction force magnitude and duration on the extent of nerve injury.

5. Conclusion

This study highlighted the impact of traction force on the sciatic and median nerves of albino rabbits, leading to histological changes. The severity of nerve injury is influenced by factors such as the degree and duration of traction force, as well as the direction and location of its application. Importantly, the study emphasized that the duration of traction force application is the most critical factor in determining the severity of nerve injury. Additionally, prolonged exposure of nerves to air, even without traction force, can cause damage due to nerve dryness. Therefore, it is crucial to keep any nerve exposed during surgery moist and hydrated with normal saline or continuously covered with gauze soaked in normal saline.

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