Lesson 5 - Biomechanical properties of peripheral nerves

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This lesson contains 10 screens teaching text, 2 zoomable figures, and 4 videos. This lesson requires approximately 2 - 4 hours of study but can vary depending on the student.

Functionally the three main roles of the nervous system are sensation, integration, and response.

The **sensory functions** of the nervous system record and transmit the presence of a change from the body or in the environment, known as a stimulus.

Stimuli that are received by receptors are communicated to the central nervous system where that information is processed. Stimuli are compared with, or integrated with, other stimuli, memories of previous stimuli, or the state of a person. This is called **integration.**

The nervous system produces a **response** on the basis of the stimuli. The response would be the action of muscles or neural control of glands in the body (9).

This lesson focuses on the structure and the biomechanical properties of spinal peripheral nerves.

Please brush up your knowledge about the peripheral nervous system with this video:

https://www.youtube.com/watch?v=jaWrMYChc5A

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Composition, structure, and function of peripheral nerves

A peripheral nerve contains the **axon**s of multiple neurons bound together by connective tissue. Peripheral nerves, as complex structures, consist of nerve fibers, connective tissue layers and blood vessels (8).

Structure and function of nerve fibers

The nerve fibers serve as an anatomic connection between the nerve cell body and its end organs and provide impulse transmission between these items.

Most axons of the peripheral nervous system are surrounded by myelin sheaths. The myelin sheath is produced by Schwann cells arranged segmentally along the axon. Between the segments about 1 to 2 mm apart are unmyelinated gaps, the nodes of Ranvier increase the speed of impulses conduction. In saltatory conduction, the nerve impulse appears to jump from one node of Ranvier to the next. This kind of conductance is about 10-times faster than the continuous conductance in axons without a myelin sheath (1, 8). Nerve fibers are arranged in fascicles, which are further organized into bundles, as subunits of the nerve.

Structure and function of intraneural connective tissue

Nerve fibers are bundled into groups called nerve fascicles. Bundle of nerve fibers is protected by three main connective tissue layers, namely the endoneurium, the perineurium, and the epineurium (5, 8).

Epineurium is composed mostly of the collagenous extracellular matrix which surrounds the entire nerve and its individual fascicles. Several fascicles are held together by the epineurial connective tissue layer to form a peripheral nerve (10). From the mechanical point of view, the epineurium is a loose structure to keep the nerve soft and to protect the inner fascicles against external load and contributes to the tensile strength of the nerve. Where the nerves lie close to bone or joints, the epineurium is often more ample than elsewhere, to ensure greater protection in these locations (5, 8).

Perineurium is the thinnest but the densest layer of the three connective tissues. It protects the nerve fibers and maintains the inner pressure and stiffness of the fascicle. The perineurium is a lamellar sheath that encompasses each fascicle. This sheath has great mechanical strength and biomechanical barrier function to isolate the nerve fibers from their surroundings, thus preserving an ionic environment of the interior of the fascicles. Mechanically, the epineurium is a loose structure to keep the nerve soft and serves as a buffer barrier to protect the inner fascicles against external load (5, 8).

The **endoneurium**, the connective tissue inside the fascicles, is composed principally of fibroblasts, type I & II collagen fibrils. The collagen fibrils are arranged longitudinally and form an endoneurial tube that contains endoneurial fluid which provides the inner pressure of the fascicle. This pressure can make the fascicle stiffer (7).

Please watch this video about the intraneural connective tissue:

https://www.youtube.com/watch?v=WVBDnl9wAkM

Structure and function of microvascular system

The peripheral nerves are highly vascularized tissues. The blood supply to nerves is provided by curly segmental arteries that enter the epineurium repeatedly along the length of the nerve and form the vasa nervorum (11).

The intraneural connective tissues have an abundant anastomotic network, which provides adequate local oxygen supply to axonal transport and impulse propagation. Epineurial arterioles form a capillary plexus and run longitudinally within epineurium. These vessels perforate the perineurium and run an oblique angle through this layer. Within the endoneurium, the arterioles turn into longitudinally oriented capillaries (5). The intraneural vascular networks with several anastomoses allow the direction of blood flow to change in response to any local circulatory deficits. Due to the built-in safety system of longitudinal anastomoses to induce complete ischemia is extremely difficult (8).

Biomechanical behavior of peripheral nerves

Under normal physiological conditions applied by posture and movement, nerves are exposed to various mechanical stresses, stretching and compression are the most common loads on peripheral nerves.

Nerves are not homogenous materials. Since their biomechanical behavior depends on the biomechanical properties of each tissue component that builds the nerve, the discussion of biomechanical properties of the whole peripheral nerve is complex. Although, peripheral nerves also exhibit time-dependent viscoelastic behavior, including **creep** and **stress relaxation**. These viscoelastic properties help limit sudden, excessive elongation upon loading, or relieve the high degree of tension following stretch (6).

Effect of stretching on the peripheral nerve, tension injuries

Elongation of a nerve during joint movement will cause an increase in nerve strain. When a load is first applied to a resting nerve, the nerve lengthens markedly relative to the applied load, as you remember, it is the **toe region**. Structurally, the minimal longitudinal tensile load results in straightening of the wavy connective tissue and axons.

As the tensile load is increased, the nerve elongates consistently, which corresponds to the **linear region**. The ascent of the stress-strain curve (Fig. 1) represents the stiffness of the nerve. When the tensile stress has removed the elasticity of the connective tissues and pressure within the nerve will allow rebounding of the nerve to nearly the original length.

Once the nerve has reached ultimate strain, the structural integrity of the nerve is overcome, and the deformation is termed “plastic”, represented by the **plastic region** on the stress-strain curve. In the plastic region of the curve, the nerve reaches its ultimate elongation and undergoes mechanical **failure**. As the failure point is reached, the nerve fibers start to rupture inside the endoneurial tubes and inside the undamaged perineurium (8).

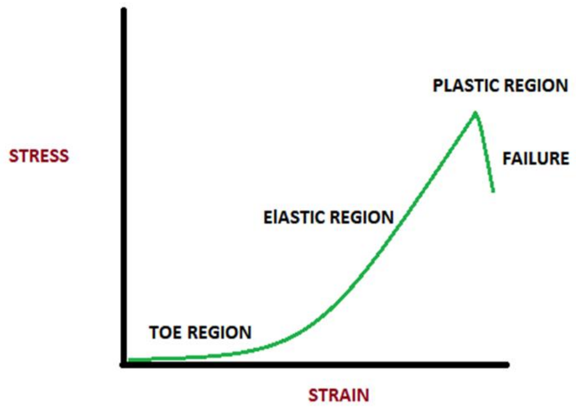

Fig. 1 Stress-strain curve for peripheral nerve.

The tissue that surrounds a nerve, termed **paraneurium** can have a profound influence on the ability of the nerve to move and adapt to changes in bodily positions. The composition of this tissue allows the nerve to move without causing excessive stress (4).

Injuries to peripheral nerves usually occur secondary to compression, tension or friction. Injury to nerves may also result from less traumatic mechanisms such as repetitive low-level forces resulting in a chronic overuse syndrome (4).

Changes in peripheral nerve due to elongation

Tensile stress applied longitudinally to peripheral nerve creates an elongation of the nerve. At the same time the elongation of peripheral nerve a transverse contraction occurs, that may create a change in intrafascicular pressure (2) (Fig.2).

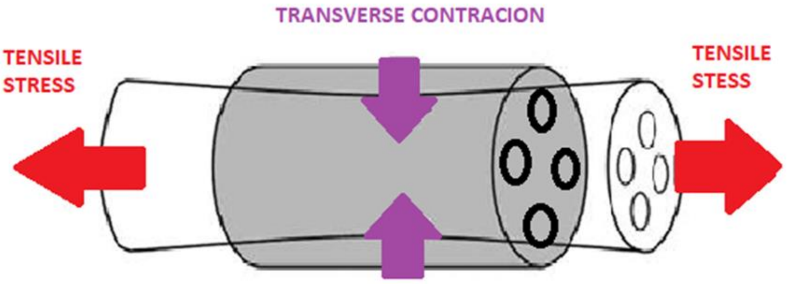

Fig.2 Tensile stress applied on peripheral nerve.

Additionally, during gradual elongation, the segmental blood vessels become firstly stretched, and the blood flow in them is decreased. Then the diameter of the nerve becomes reduced and the intraneural blood flow is further impaired. The complete cessation of the blood flow in the nerve generally occurs at about 15% elongation (8).

In physiological circumstances the mechanical requisition of the peripheral nerve remains in the elastic region, thus the structure and function of the nerve are unchanged.

Tensile injury occurs when high-energy tension is applied to the nerve, in association for example with a high-speed vehicular collision or a fall from a height. In these cases, in partial or total functional loss of the nerves may appear (8).

Effect of compression on the peripheral nerve, compression injuries

Compression of the nerve can cause several symptoms, such as numbness, pain, and muscle weakness.

Compression stress of a low magnitude and a short duration may result in reversible physiological and minor structural changes. The compressive stress of a high magnitude, however, may result in structural alterations in myelin sheaths and even disruption of axons. Low-magnitude compression applied over a long period of time can decrease intraneural microvascular flow, impair axonal transport, and alter nerve structure and function (8, 11).

Changes in peripheral nerve due to compression

There are two basic types of pressure application in pathologic conditions.

In case of a consistent circumferential compression the cross-section of the nerve tends to remain circular, but decreases, the intraneural pressure may increase and the blood flow may become impaired. Clinically, this type of compressive loading on a nerve may occur when the pressure on the nerve is elevated in an anatomic tunnel of the body (tunnels – soft or bony tissues may create tunnels the nerve must travel through, e.g. carpal tunnel).

In case of lateral compression two parallel loads effect on the nerve, squeeze the tissue, it may deform the cross section to more elliptical. Clinically, this type of compressive loading on a nerve may occur when a spinal nerve is compressed by a herniated intervertebral disc. Nerve deformation due to laterally compression can result in a sensation of pain (8).

Compression of a low magnitude and for a brief duration is well tolerated by nerves and constitutes normal stress. However, if compression is maintained and ischemia eventuates, then this high stress results in endoneurial edema and fibrotic changes of the nerve (11).

Regeneration of peripheral nerves

Compressive and tensile injuries can develop in numerous locations along the nerve. The symptoms are similar because both of these types of forces cause degeneration of the nerve.

Nerve injuries were classified into **neuropraxia**, **axonotmesis**, and **neurotmesis** by Seddon after World War 2, then Sunderland expanded on this classification according to histological diagnosis. (3).

Please watch the video below about the classification of peripheral nerve injury:

https://www.youtube.com/watch?v=KruZ4FCNlaM

Nerve regeneration processes vary according to the severity of the injury. For neurapraxic injuries, morphological and physiological changes are fully reversible with repair and restoration of function of the axon and surrounding Schwann cells. For axonotmetic injuries, the process is slower and relies upon the integrity of axonal regeneration. In neurotmesis, the axon and tissues surrounding the axon are disrupted (12).

Following a crush lesion or an intersection, the axon continuity is broken. The distal parts of the axon go through a degenerative process, named Wallerian degeneration. After the injury, the proximal part of the axon sending out a great number of sprouts, while the Schwann cells of the distal segment proliferate to form a longitudinal column. This column helps to guide the growing axon toward the distal end organ. The timing of nerve regeneration lasts for months to years, the maximum rate of axonal regeneration is around 1 mm per day (8).

Please watch the video below about the regeneration of nerve fiber:

https://www.youtube.com/watch?v=4009Nv4C4NY

Aging-related changes of peripheral nerves

Several structural and functional alteration occurs in the peripheral nervous system with aging. As people age, nerve conduction can slow generally because the myelin sheaths around nerves degenerate. Peripheral nerves may conduct impulses more slowly, resulting in decreased vibratory sensation, touch sensitivity, slower reflexes, motor dysfunctions and slightly elevated pain threshold (8).

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Study questions:

TRUE/FALSE questions

Read each statement below carefully. Choose the T if you think a statement is TRUE. Choose the F if you think the statement is FALSE.

1. Nerves are homogeneous materials. **T or F**
2. The peripheral nerves are highly vascularized tissues. **T or F**
3. The complete cessation of the blood flow in the nerve generally occurs at about 5% elongation. **T or F**
4. The pressure of the endoneurial fluid can make the fascicle stiffer. **T or F**
5. Nerve fascicles are protected by two main connective tissue layers. **T or F**
6. Epineurium is the thinnest but most dense layer of the intraneural connective tissues. **T or F**
7. Compression of the nerve can cause numbness, pain, and muscle weakness. **T or F**
8. The maximum rate of axonal regeneration is around 1 mm per day. **T or F**

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Matching questions

In this exercise, you have to match each word with a definition.

1. **Neuropraxia**
2. **Paraneurium**
3. **Sensory function of the nervous system**
4. **Neurotmesis**
5. **Perineurium**
6. **Axonotmesis**

A. It protects the nerve fibers and maintains the inner pressure and stiffness of the fascicle.

B. A peripheral nerve injury in which the nerve is completely disrupted by laceration or traction. It requires surgical approximation.

C. Axonal nerve damage that does not completely sever the surrounding endoneurial sheath.

D. An injury to a nerve that interrupts conduction causing temporary paralysis but not degeneration and that is followed by a complete and rapid recovery.

E. It records and transmits the presence of a change from the body or in the environment.

F. Tissue surrounding the nerve which allows nerve sliding without excessive stress during motion of the joint.

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