Muscle Function Testing – A Visual Guide

Karin Wieben
Bernd Falkenberg

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Muscle Function Testing—A Visual Guide

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Foreword

Nearly 80 years have passed since the first attempts to evaluate muscular deficits and record comparable results were undertaken (Daniels et al. 1962). In the development of muscle testing over the years, two things stand out: the key role these procedures play in daily physical therapy routine and the efforts by users to make muscle testing even more practical and functional. The testing methods are used to determine the status quo when patients are taken on for treatment. In addition, they are useful tools for monitoring therapy results through follow-up testing at regular intervals and for determining the final diagnosis. This provides physicians, physical therapists, occupational and sports therapists with information about treatment paths and any necessary modifications, recovery from paralysis, support required for patients to manage their activities of daily living by themselves, and their treatment needs following discharge. Testing allows patients to see their treatment progress, which reduces their anxiety, while therapists can adapt treatment methods to the individually determined functional circumstances. Test results provide coaches and athletic trainers working in sports for rehabilitation and for disabled participants with access to valuable documents for evaluating athletic performance ranges. Uniform principles at the national and international level allow for comparable tests when using medical, physical therapy, or occupational therapy treatment approaches.

The range of spinal cord injury symptoms is broad and includes both complete and partial paralysis. The tests presented in this book are especially well-suited for analyzing isolated deficits and for evaluating methods for testing these deficits, as well as possible compensatory mechanisms. While, in the 1950s, peripheral paralysis in patients with polio was the driving force behind the expansion of existing test methods, for many years it has been the improved treatment methods for spinal cord injuries that have driven this process.

Karin Wieben was head of the physical therapy department of the Spinal Cord Injury Center of the BUK Hospital in Hamburg for many years, and Bernd Falkenberg was one of her team members there. Together and in close collaboration with the rest of the team they developed the concepts presented in this book, which emerged from their daily work with spinal cord injured patients, starting from the days surrounding the accident through to the completion of comprehensive rehabilitation.

They have now added an additional grade to the tried and tested, internationally recognized evaluation system comprising muscle function grades 0 to 5. Adding grade 6 permits statements to be made about the endurance of a movement, which may allow residual weakness to be identified. The authors have added the usual symptoms related to paralysis to the functional descriptions, and have also described the impact of residual weaknesses on everyday movements. This provides an additional method for recognizing masked deficits and making therapeutic approaches accessible.

Pioneers who break new ground have to be prepared to receive both agreement and criticism. The outcome of debate is the decisive factor in whether or not new or complementary methods will enjoy broad application. No matter what, such debate offers to clarify a number of unanswered questions. This fuels progress, and there is no doubt that the material in this book will contribute to this progress.

Professor F.-W. Meinecke
Former Head of the Spinal Cord Injury Center of the BUK Hospital
Hamburg, Germany

Preface

"Keep what works and be open to new ideas."

The German version of this book, which has been published in six editions, has been part of the medical repertoire for over 20 years. The motto above has served as a guiding principle as we revised each edition.

Since the muscle testing in its current form has proven effective, we did not feel that any conceptual modifications were necessary. However, the changes to the sixth German edition, which is the basis for this first English edition, involved technical additions that have modified the layout. The chapter on the foundations of muscle testing has been expanded to include supplementary explanations and anatomical drawings. The chapter on testing of the muscles of facial expression and mastication is completely new. We have added these topics to provide guidelines for therapists working with muscles of the face and head.

The quick tests presented here allow examiners to obtain rapid initial insight into the muscular situation of the extremities or the trunk. Later on, a detailed muscle analysis using specific muscle tests can be performed.

Scientific progress is possible only if topics are dealt with critically. We sincerely hope that this book will provide a small contribution to this process and we welcome your feedback. We look forward to engaging with and building on your comments. We are especially pleased that this book will now be accessible to therapists in the United Kingdom, where muscle testing originated, and hope that the response there will be positive.

We would like to thank Eva Gruenewald and Fritz Koller of Georg Thieme Verlag for their valuable assistance with the realization of the new edition of the German book. Our gratitude also goes to Angelika Findgott and Joanne Stead of Thieme Publishers for the production of the English version. We are especially thankful to our photographer Christian Knospe for his unending patience and his professional standards. Our thanks go to Irina Schatz, my daughter Anne Falkenberg, and my son Max Falkenberg for kindly agreeing to pose as models for the photos.

Karin Wieben, Bernd Falkenberg

1
Fundamentals

Manual Muscle Testing

With manual muscle testing, the strength of a muscle group can be determined with minimal effort by using defined muscle movements.

In patients with neurological disorders, accurate statements about muscle function are helpful for performing differential diagnosis and for locating damage. They can also provide information to support a prognosis. Furthermore, muscle testing is a valuable tool for analyzing muscular imbalances as objectively as possible. By regularly repeating these tests, objective statements can be made about the course of physical therapy. The attainment of treatment objectives can be monitored and the treatment plan can be adjusted accordingly. Although using instruments or electromyography to measure muscle strength is more objective, these methods require significantly more effort. In addition, they can measure only certain muscle groups and cannot be used in all settings.

Prerequisites for Accurate Results of Muscle Testing

To evaluate the active range of motion in a joint, the examiner must have in-depth knowledge of joint mechanics as well as the muscle's anatomy and function. For the test to be reliable, it must be carried out accurately, precisely, and rigorously. Moreover, the examiner needs to have sufficient experience to come up with an objective assessment after weighing all the criteria.

Inaccurate muscle testing can create confusion because of false results and can result in incorrect conclusions being drawn.

The following points must be observed when performing muscle testing (Janda 2009, Montgomery and Hislop 2007):

- Muscle testing must always be performed with the patient in the correct starting position, while maintaining the proper planes of motion.
- If the patient needs to be stabilized in order to perform the test, the examiner should always do this proximal to the joint being moved.
- To keep individual variability to a minimum, muscle testing should always be performed by the same examiner. If possible, testing should not be performed by the patient's therapist, because he or she is usually unable to make an unbiased evaluation.
- Passive range of motion must be tested prior to determining the strength grade. The therapist must take any range-of-motion restrictions into account and note them in the evaluation. Restrictions may be related to the joints (ligament, capsule), bones, muscles, or nerves. Joint status, as measured by the neutral zero method, must be included if the normal range of motion cannot be achieved for these reasons.
- The examiner must adjust the level of resistance to the patient's constitution, age, and sex, and to the functions being tested. For instance, the examiner should apply more resistance with an active athlete than with an out-of-shape older adult. The examiner should apply less force when testing distal thumb extension than when examining elbow flexion. In case of doubt, the examiner can use the patient's healthy side to determine the individual's maximum strength.
- The examiner must record the final muscle testing results on a scoring sheet.
- This system cannot be used for testing patients with spasticity.

Evaluating Muscle Strength

0 = No visible or palpable contraction of a muscle involved in the movement.

1 = Visible or palpable contraction of a muscle that participates in the movement or the partially performed movement being tested, when the force of gravity is minimized.
The examiner can test the muscle's tension by palpating its origin, insertion, or muscle belly.
In some cases, it is easier to detect contraction when a muscle's insertion and origin are close together.
Images with palpation points for muscle testing are presented throughout this book.
If the examiner has doubts about the innervation of a muscle involved in a movement, the muscle must be tested while it is performing its primary action.
Some muscles cannot be palpated, owing to their anatomical position. These muscles are listed in the sections below.

2 = The muscle can complete the full range of motion when the force of gravity is minimized.
To reduce movement-related friction as much as possible, the examiner should place a cloth between the body part being tested and the testing surface.

3 = The muscle can complete the full range of motion against the resistance of gravity.

4 = The muscle can complete the full range of motion against the resistance of gravity and against moderate resistance (adjusted to the patient and movement being evaluated).

5 = The muscle can complete the full range of motion against the resistance of gravity and against maximum resistance (adjusted to the patient and to the movement being tested) (Janda 2009, Montgomery and Hislop 2007).

6 = The muscle can complete the full range of motion against the resistance of gravity and against maximum resistance and can perform the movement at least 10 times. By having the patient perform 10 repetitions, the examiner can make a fairly reliable statement about the muscle's strength endurance. "Strength endurance refers to the

neuromuscular system's ability to produce the greatest possible number of impulses in a defined time period (no longer than 2 minutes with maximal exertion) against higher loads (more than 30% of maximum strength) and, in so doing, keep the magnitude of the impulses as low as possible during the loading period" (Schmidtbleicher 1989).

In their everyday lives, patients generally need strength endurance rather than maximum strength. For this reason, it makes sense to add a grade to the existing grading scale for muscle testing, in order to take this muscle activity into consideration.

If the muscle tested falls within this strength grade, it is difficult to manually determine the transition to normal strength (the individual's maximum strength). This can be measured in more detail with isokinetic strength testing.

Manual resistance must be used for grades 3, 4, 5, and 6, if the examiner cannot use gravity for testing.

If the strength level is between two grades, the examiner should record the lower grade.

Documenting Muscle Function

A scoring sheet is required for clear and informative documentation (see pp. 6–16). Apart from the patient's personal data, the sheet must include the following information:

- Which muscles are innervated and therefore perform the movement? Place a cross on the line corresponding to the muscle in question.
- At what strength level is a movement performed? Do the muscles exhibit a certain level of endurance? Enter the grade on a scale of 0 to 6 on the movement line.
- The examiner should note which spinal cord segment innervates a muscle and which peripheral nerve is responsible for innervation.
- The examiner must also write down the test dates and the name of the examiner.

Name of patient: ____________________

Date of birth: ____________________

Diagnosis: ____________________

Name of examiner: ____________________

Right side							Left side					
Date:							Date:					
						Cervical spine extension						
						Cervical portion of autochthonous back muscles, C1–C8, dorsal branches of spinal nerves						
						Thoracic spine extension						
						Thoracic portion of autochthonous back muscles, T1–T12, dorsal branches of spinal nerves						
						Lumbar spine extension						
						Lumbar portion of autochthonous back muscles, L1–L5, dorsal branches of spinal nerves						
						Cervical spine flexion						
						Sternocleidomastoid muscle, accessory nerve, cervical plexus (C1–C2)						
						Rectus capitis anterior muscle, cervical plexus (C1–C4)						
						Longus capitis muscle, cervical plexus (C1–C4)						
						Longus colli muscle, brachial plexus, cervical plexus (C2–C8)						
						Trunk flexion						
						Rectus abdominis muscle, T5–T12, intercostal nerves						
						External and internal abdominal oblique muscles, T5–T12, intercostal nerves						
						Rotation of the trunk to the right						
						External abdominal oblique muscle, T5–T12, intercostal nerves						
						Internal abdominal oblique muscle, T10–T12, intercostal nerves and L1						

						Rotation of the trunk to the left						
						External abdominal oblique muscle, T5–T12, intercostal nerves						
						Internal abdominal oblique muscle, T10–T12, intercostal nerves and L1						
						Lateral bending of the trunk						
						Erector spinae muscles, C1–S4, dorsal branches of spinal nerves						
						External abdominal oblique muscle, T5–T12, intercostal nerves						
						Internal abdominal oblique muscle, T10–T12, intercostal nerves and L1						
						Rectus abdominis muscle, T5–T12, intercostal nerves						
						Latissimus dorsi muscle, C6–C8, thoracodorsal nerve						
						Quadratus lumborum muscle, T12, intercostal nerve, L1–L3, lumbar plexus						

Name of patient: ______________________________

Date of birth: ______________________________

Diagnosis: ______________________________

Name of examiner: ______________________________

Right side							Left side					
Date:							Date:					
						Shoulder blade, cranially						
						Trapezius muscle, descending part, accessory nerve, trapezius branch (C2–C4)						
						Levator scapulae muscle, C4–C5, dorsal scapular nerve						
						Shoulder blade, caudally						
						Trapezius muscle, ascending part, accessory nerve, trapezius branch (C2–C4)						
						Serratus anterior muscle, C5–C7, long thoracic nerve						
						Shoulder blade, dorsally and medially						
						Trapezius muscle, accessory nerve, trapezius branch (C2–C4)						
						Rhomboid muscles, C4–C5, dorsal scapular nerve						
						Latissimus dorsi muscle, C6–C8, thoracodorsal nerve						
						Shoulder blade, ventrally and laterally						
						Serratus anterior muscle, C5–C7, long thoracic nerve						
						Pectoralis major and minor muscles, C5–T1, pectoral nerves						
						Shoulder joint, elevation						
						Deltoid muscle, clavicular part, C4–C6, axillary nerve						
						Biceps brachii muscle, C5–C6, musculocutaneous nerve						

						Shoulder joint, extension						
						Teres major muscle, C6–C7, thoracodorsal nerve						
						Latissimus dorsi muscle, C6–C8, thoracodorsal nerve						
						Triceps brachii, long head, C6–C8, radial nerve						
						Deltoid muscle, spinal part, C4–C6, axillary nerve						
						Shoulder joint abduction						
						Deltoid muscle, C4–C6, axillary nerve						
						Supraspinatus muscle, C4–C6, suprascapular nerve						
						Shoulder joint adduction						
						Pectoralis major muscle, C5–T1, pectoral nerves						
						Triceps brachii, long head, C6–C8, radial nerve						
						Teres major muscle, C6–C7, thoracodorsal nerve						
						Latissimus dorsi muscle, C6–C8, thoracodorsal nerve						
						Shoulder joint, external rotation						
						Infraspinatus muscle, C4–C6, suprascapular nerve						
						Teres minor muscle, C5–C6, axillary nerve						
						Shoulder joint, internal rotation						
						Subscapularis muscle, C5–C8, subscapular nerve						
						Teres major muscle, C6–C7, thoracodorsal nerve						

						Elbow joint, flexion						
						Biceps brachii muscle, C5–C6, musculocutaneous nerve						
						Brachialis muscle, C5–C6, musculocutaneous nerve						
						Brachioradialis muscle, C5–C6, radial nerve						
						Elbow joint, extension						
						Triceps brachii muscle, C6–C8, radial nerve						
						Elbow joint, supination						
						Supinator muscle, C5–C6, radial nerve						
						Biceps brachii muscle, C5–C6, musculocutaneous nerve						
						Elbow joint, pronation						
						Pronator quadratus muscle, C8–T1, median nerve						
						Pronator teres muscle, C6–C7, median nerve						
						Wrist, extension						
						Extensor digitorum communis muscle, C6–C8, radial nerve						
						Extensor carpi radialis longus muscle, C5–C7, radial nerve						
						Extensor indicis muscle, C6–C8, radial nerve						
						Extensor carpi radialis brevis muscle, C5–C7, radial nerve						

						Wrist, flexion						
						Flexor digitorum superficialis muscle, C7–T1, median nerve						
						Flexor digitorum profundus muscle, C7–T1, median nerve, ulnar nerve						
						Flexor carpi ulnaris muscle, C7–C8, ulnar nerve						
						Flexor pollicis longus, C7–C8, median nerve						
						Flexor carpi radialis muscle, C6–C7, median nerve						
						Wrist joint, ulnar abduction						
						Extensor carpi ulnaris muscle, C7–C8, radial nerve						
						Flexor carpi ulnaris muscle, C7–C8, ulnar nerve						
						Finger flexion/metacarpophalangeal (MCP)						
						Dorsal and palmar interossei muscles, C8–T1, ulnar nerve						
						Lumbrical muscles, C8–T1, median nerve, ulnar nerve						
						Flexor digitorum superficialis muscle, C7–T1, median nerve						
						Flexor digitorum profundus muscle, C7–T1, median nerve, ulnar nerve						
						Finger flexion/proximal interphalangeal joint (PIP)						
						Flexor digitorum superficialis muscle, C7–T1, median nerve						
						Flexor digitorum profundus muscle, C7–T1, median nerve, ulnar nerve						
						Finger flexion/distal interphalangeal joint (DIP)						
						Flexor digitorum profundus muscle, C7–T1, median nerve, ulnar nerve						

						Finger extension/MCP						
						Extensor digitorum communis muscle, C6–C8, radial nerve						
						Extensor indicis muscle, C6–C8, radial nerve						
						Extensor digiti minimi muscle, C6–C8, radial nerve						
						Finger extension/PIP and DIP						
						Extensor digitorum communis muscle, C6–C8, radial nerve						
						Extensor indicis muscle, C6–C8, radial nerve						
						Extensor digiti minimi muscle, C6–C8, radial nerve						
						Dorsal and palmar interossei muscles, C8–T1, ulnar nerve						
						Finger spreading						
						Dorsal interossei muscles, C8–T1, ulnar nerve						
						Abductor digiti minimi muscle, C8–T1, ulnar nerve						
						Finger closing						
						Palmar interossei muscles, C8–T1, ulnar nerve						
						Thumb flexion, carpometacarpal joint						
						Flexor pollicis longus muscle, C7–C8, median nerve						
						Flexor pollicis brevis muscle, C8–T1, median nerve, ulnar nerve						
						Abductor pollicis brevis muscle, C8–T1, median nerve						
						Opponens pollicis muscle, C6–C7, median nerve						

						Thumb flexion, metacarpophalangeal joint						
						Flexor pollicis longus muscle, C7–C8, median nerve						
						Flexor pollicis brevis muscle, C8–T1, median nerve, ulnar nerve						
						Thumb flexion, interphalangeal joint						
						Flexor pollicis longus muscle, C7–C8, median nerve						
						Thumb extension, carpometacarpal joint						
						Extensor pollicis longus muscle, C7–C8, radial nerve						
						Extensor pollicis brevis muscle, C7–T1, radial nerve						
						Abductor pollicis longus muscle, C7–C8, radial nerve						
						Thumb extension, metacarpophalangeal joint						
						Extensor pollicis longus muscle, C7–C8, radial nerve						
						Extensor pollicis brevis muscle, C7–T1, radial nerve						
						Thumb extension, interphalangeal joint						
						Extensor pollicis longus muscle, C7–C8, radial nerve						
						Thumb adduction, carpometacarpal joint						
						Adductor pollicis muscle, C8–T1, ulnar nerve						
						Flexor pollicis brevis muscle, C8–T1, ulnar nerve						
						Thumb abduction, carpometacarpal joint						
						Abductor pollicis longus muscle, C7–C8, radial nerve						
						Abductor pollicis brevis muscle, C8–T1, median nerve						

Name of patient: ____________________

Date of birth: ____________________

Diagnosis: ____________________

Name of examiner: ____________________

Right side							Left side					
Date:							Date:					
						Hip joint flexion						
						Iliopsoas muscle, L1–L4, lumbar plexus, femoral nerve						
						Rectus femoris muscle, L2–L4, femoral nerve						
						Sartorius muscle, L1–L3, femoral nerve						
						Hip joint extension						
						Gluteus maximus muscle, L5–S2, inferior gluteal nerve						
						Semimembranosus and semitendinosus muscles, L5–S2, tibial nerve						
						Gluteus medius and minimus muscles, L4–S1, superior gluteal nerve						
						Adductor magnus muscle, L3–L5, obturator nerve, tibial nerve						
						Biceps femoris muscle, long head, L5–S2, tibial nerve						
						Hip joint adduction						
						Adductor muscles, L2–L5, obturator nerve, tibial nerve						
						Gluteus maximus muscle, L5–S2, inferior gluteal nerve						
						Semimembranosus and semitendinosus muscles, L5–S2, tibial nerve						

						Hip joint abduction						
						Gluteus medius and minimus muscles, L4–S1, superior gluteal nerve						
						Tensor of fascia lata muscle, L4–L5, superior gluteal nerve						
						Gluteus maximus muscle, L5–S2, inferior gluteal nerve						
						Hip joint, external rotation						
						Gluteus maximus muscle, L5–S2, inferior gluteal nerve						
						Gluteus medius and minimus muscles, dorsal portion, L4–S1, superior gluteal nerve						
						Short external rotators, L1–S2, obturator nerve, inferior gluteal nerve, sacral plexus						
						Hip joint, internal rotation						
						Gluteus medius and minimus muscles, L4–S1, superior gluteal nerve						
						Tensor of fascia lata muscle, L4–L5, superior gluteal nerve						
						Knee joint extension						
						Quadriceps femoris muscle, L2–L4, femoral nerve						
						Knee joint flexion						
						Semimembranosus and semitendinosus muscles, L5–S2, tibial nerve						
						Biceps femoris muscle, L5–S2, tibial nerve, and peroneal nerve						
						Foot, plantar flexion						
						Triceps surae muscle, S1–S2, tibial nerve						

						Foot, dorsal extension						
						Tibialis anterior muscle, L4–L5, deep peroneal nerve						
						Extensor digitorum longus muscle, L5–S1, deep peroneal nerve						
						Extensor hallucis longus muscle, L4–S1, deep peroneal nerve						
						Foot pronation						
						Peroneus longus and brevis muscles, L5–S1, superficial peroneal nerve						
						Extensor digitorum longus muscle, L5–S1, deep peroneal nerve						
						Foot supination						
						Triceps surae muscle, S1–S2, tibial nerve						
						Tibialis posterior muscle, L4–L5, tibial nerve						
						Tibialis anterior muscle, L4–L5, deep peroneal nerve						
						Toe flexion						
						Flexor digitorum longus muscle, S1–S3, tibial nerve						
						Flexor digitorum brevis muscle, L5–S1, medial plantar nerve						
						Big toe flexion						
						Flexor hallucis longus and brevis muscles, L5–S3, tibial nerve, medial plantar nerve						
						Toe extension						
						Extensor digitorum longus and brevis muscles, L5–S2, deep peroneal nerve						
						Big toe extension						
						Extensor hallucis longus and brevis muscles, L4–S2, deep peroneal nerve						

Diagnosis at the Neurological Level

When examining patients with neurological deficits, the damaged region must be precisely identified. A distinction is made between damage to the central nervous system and to the peripheral nervous system. For both types of damage, the injury site should be determined as accurately as possible.

Central efferent pathways are used to describe the pyramidal system (**Fig. 1**), which originates in the primary motor cortex of the brain. This system encompasses the lateral corticospinal tract, which supplies the hand and foot muscles and distal arm and leg muscles; the anterior corticospinal tract, which supplies the neck and trunk muscles and proximal arm and leg muscles; and the corticonuclear tract, which supplies the motor nuclei of the cranial nerves, except for those of the eye mus-

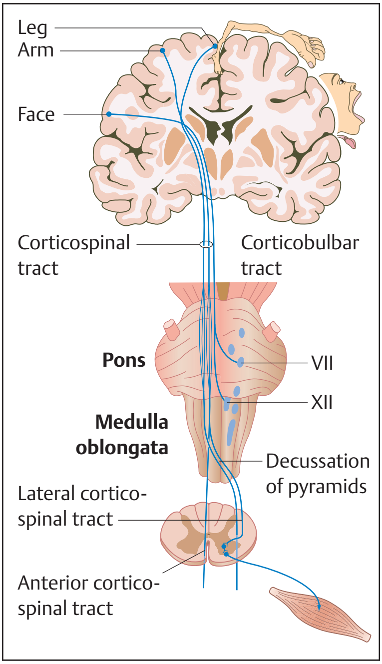


Fig. 1 Motor system: pyramidal tract and somatotropic representation of the skeletal musculature in the primary motor cortex (motor homunculus).

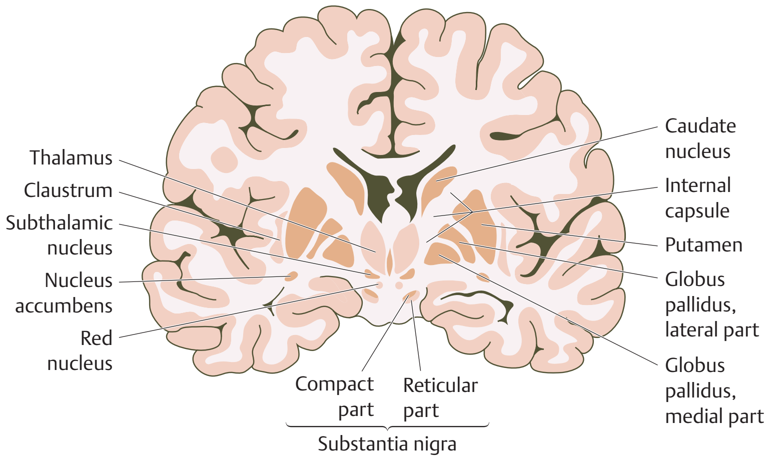


Fig. 2 The basal ganglia comprise subcortical nuclei in the telencephalon. They play a role in planning and performing movements.

cles. The three tracts have a common course through the internal capsule into the cerebral penduncles, where the corticonuclear tract branches off. The corticospinal tracts pass through the medulla oblongata. At the transition to the spinal cord, the lateral corticospinal tract crosses to the opposite side, while the anterior corticospinal tract does not switch to the other side until it reaches the level of the respective target segment. The lateral pyramidal tract is primarily responsible for the target motor function of the distal extremities, while the anterior pyramidal tract is responsible for postural reflexes and trunk movements, and for stabilizing body posture during arm and leg movements. Other systems, particularly the subcortical motor system, also impinge on these movement sequences controlled by the pyramidal system. The subcortical motor system comprises the striatum (caudate nucleus, putamen), the subthalamic nucleus, and the substantia nigra (**Fig. 2**). The subcortical centers are connected with each other in different ways and are also connected to the cerebral cortex, in order to inhibit or promote motor function (**Fig. 3**) (Rohen 2001). The peripheral motor system begins with the anterior horn motor neuron and its distal processes. Central and peripheral nervous system disorders can be manifested as a change in muscle tone and monosynaptic reflexes. Damage to the spinal cord or the peripheral nervous system is usually also manifested as sensory disorders (see **Figs. 5–8**).

Increased muscle tone is always a sign of a central nervous system disorder, except in the early stages of a stroke or quadriplegia. In these conditions, muscle tone is reduced but, later on, muscle tone increases as well.

Peripheral lesions are always manifested by reduced muscle tone, flaccid paralysis, and muscle atrophy (Duus 2012). In both cases, monosynaptic reflexes change in the same manner as muscle tone, that is, reflexes increase with increased muscle tone and decrease with reduced muscle tone. For disorders of the central nervous system, such as quadriplegia, as well as disorders of the peripheral nervous system, such as cervical or lumbar disk herniation, the lesion level must be determined. For peripheral disorders, a further distinction must be made between the nerve root and the peripheral nerve.

By testing
- *muscle strength* and the *key muscles*
- *sensitivity to pain* and *cutaneous sensitivity*
- as well as *monosynaptic reflexes,*

the damaged region can be located easily and accurately.

Muscle Strength and Key Muscles

Fig. 3 presents a schematic diagram of *motor innervation.* It clearly shows the topographic relationship of the spinal cord segments to the vertebral segments. In the upper part of the spinal column, the spinal cord segment and vertebrae are located at approximately the same level; in the lower part of the spinal column, this is not the case. For example, the fifth lumbar segment is located between the T11 and T12 vertebrae. This is the result of the vertebral column growing more rapidly and becoming longer than the spinal cord during development.

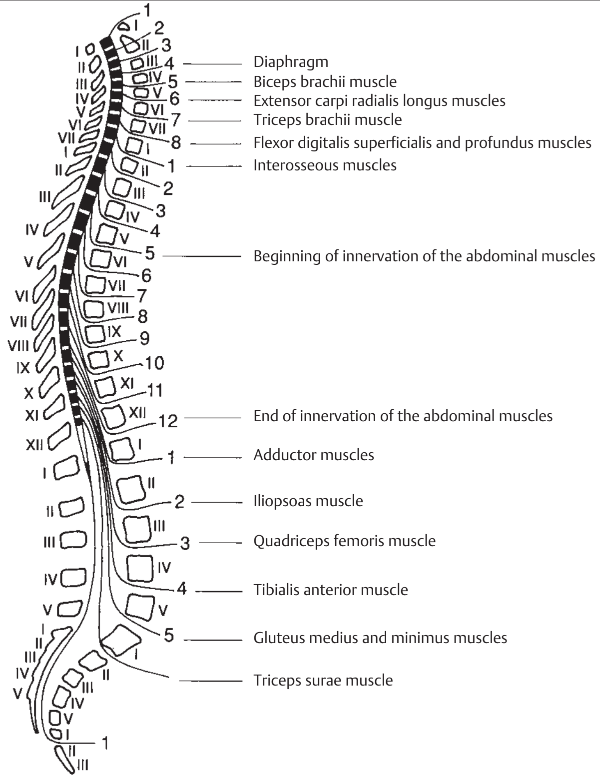
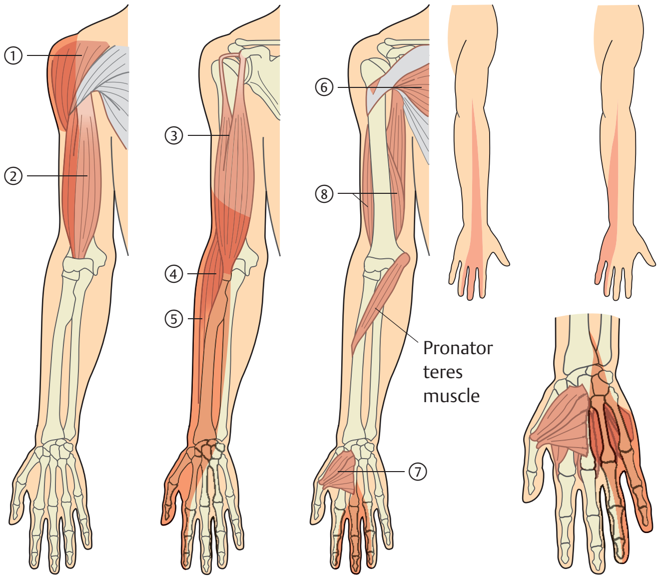


Fig. 3 Schematic diagram of segmental innervation with key muscles.

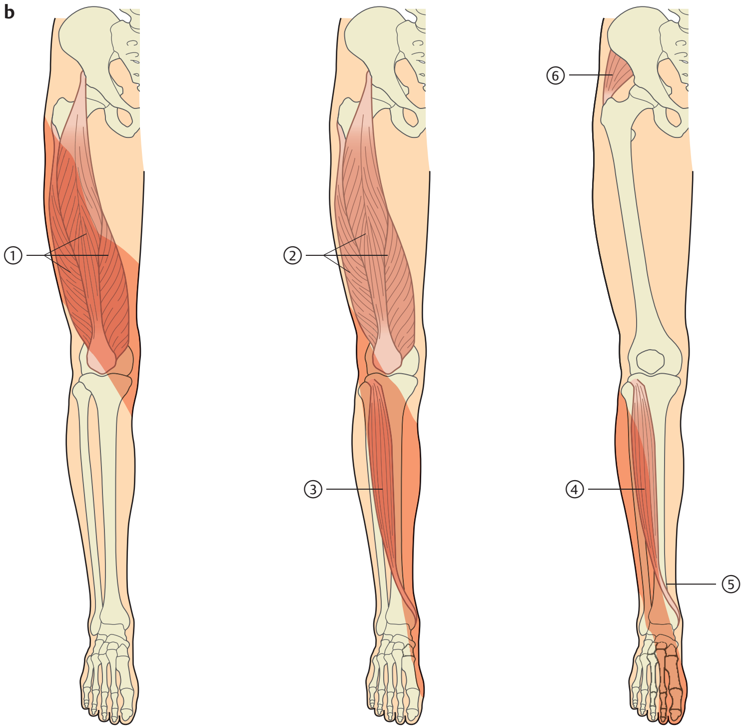
The muscles depicted in **Fig. 4 a, b** are referred to as *key muscles.* For the most part, their innervation can be assigned to a specific spinal cord segment. When these muscles are tested, they can be assigned to a segmental level. In a patient with spinal cord injury, if the triceps brachii is still innervated but the key muscles below the C7 level are no longer active, this is referred to as complete spinal cord injury below C7. When a patient with a lumbar disk herniation has a weak tibialis anterior muscle, the damage always affects the L4 nerve roots.

a



	C5	C6	C7	C8
Location of sensory disturbances	Lateral and posterior shoulder, anterior lateral proximal forearm	Dorsoradial upper arm, radial forearm, thumb	Posterior upper arm, extensor side of forearm, 2nd/3rd (4th) finger	Ulnar side of hand up to the little finger and ring finger
Key muscles	① Deltoid muscle ② (Biceps brachii muscle)	③ Biceps brachii muscle ④ (Brachio-radialis muscle) ⑤ Extensor carpi radialis longus and brevis muscles	⑥ Triceps brachii muscle, hand and finger flexors and extensors ⑦ Thenar muscles ⑧ Pectoralis major muscles (atrophy of the sternocostal head)	Tip of the little finger, ulnar long finger flexor (triceps brachii muscle, pectoralis major muscle—abdominal part)
Reflexes that are absent when the segment is damaged	Biceps reflex	Biceps reflex (brachio-radial reflex)	Triceps reflex (Trömner reflex)	Trömner reflex

Fig. 4 a Schematic diagram of segmental innervation of the upper extremity, with key muscles, reflexes, and sensations.



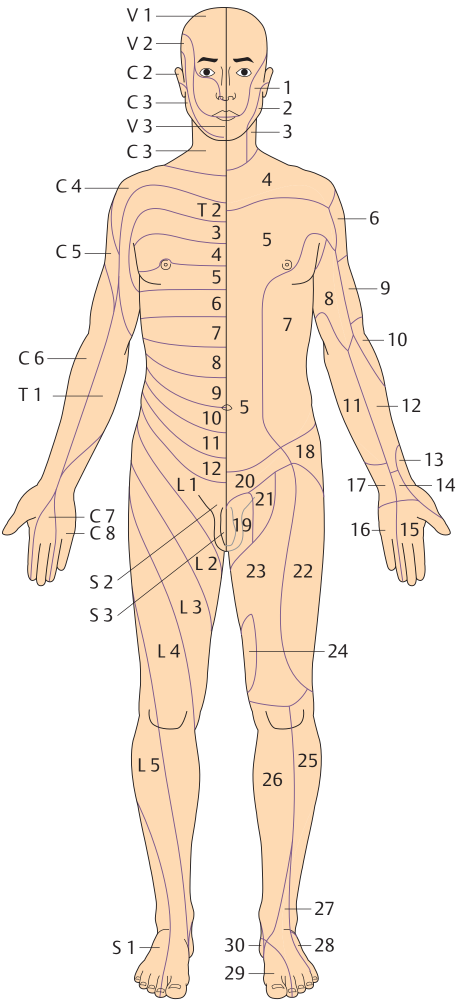
	L3	L4	L5
Location of sensory disturbances	Anterior thigh, slightly diagonally below the trochanter toward the lateral knee	Lateral thigh, extensor side of the knee up to the anterior medial aspect of the lower leg	Dorsolateral thigh, lateral knee, anterior lateral lower leg, dorsal foot up to the great toe
Key muscles	① Quadriceps femoris muscle (adductors)	② Quadriceps femoris muscle, especially its vastus medialis muscle ③ (Tibialis anterior muscle, adductors)	④ Extensor hallucis longus muscle ⑤ Tibialis anterior muscle ⑥ Gluteus medius muscle
Reflexes that are absent when the segment is damaged	Knee jerk reflex	Knee jerk reflex (adductor reflex)	Tibialis posterior reflex

Fig. 4 b Schematic diagram of segmental innervation of the lower extremity, with key muscles, reflexes, and sensations.

Sensitivity to Pain and Cutaneous Sensitivity

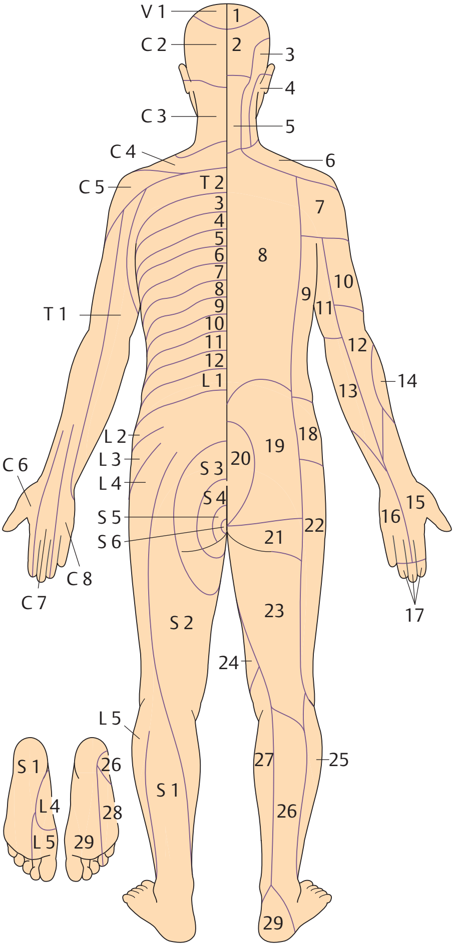
The *sensory innervation scheme* is also used to more precisely locate the lesion. **Figs. 5–8** depict segmental and peripheral sensory innervation. Sensitivity to touch and pain is the easiest to test. In patients with a central nervous system disorder where the cutaneous sensitivity pathways are also affected, the deficits (anesthesia and analgesia) are widespread below the lesion. In patients with hemiparesis, the entire contralateral half of the body can be affected, because the sensory tracts generally switch to the opposite side at the segmental level (**Fig. 9**). Patients with complete spinal cord injury are completely insensitive to touch and pain below the lesion. Disk herniation at the L5 nerve root is characterized by paresthesia or anesthesia in the L5 dermatome. In this case, testing for pain sensation, which is also reduced or eliminated in the corresponding dermatome, is more reliable than testing for tactile sensation (**Fig. 10**). If the lesion is more peripheral, which is the case with a compressed nerve, hypoesthesia and hypoalgesia (or anesthesia and analgesia) will be present in the dermatome innervated by the nerve. In this case, testing for tactile sensation is more accurate, since the individual cutaneous nerves are more sharply delineated than the dermatomes, which can greatly overlap for cutaneous sensitivity (Duus 2012). The examiner tests tactile sensation by lightly touching the skin with the fingertips, or with the brush from the reflex hammer. A pin prick is used to test pain sensation.

On the trunk, the examiner pricks the skin from top to bottom and on the extremities, in a circular pattern, to ensure that the dermatomes are compared.



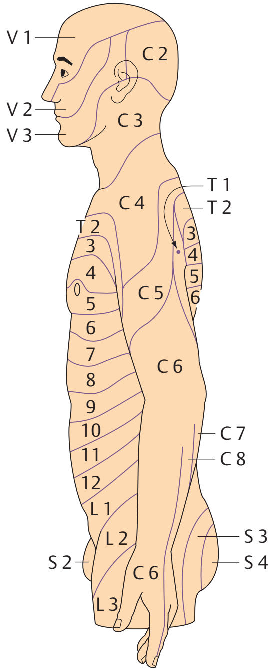
1 Trigeminal nerve
2 Great auricular nerve
3 Transverse cervical nerve
4 Supraclavicular nerves
5 Anterior cutaneous branches of intercostal nerves
6 Superior lateral brachial cutaneous nerve (axillary nerve)
7 Medial brachial cutaneous nerve
8 Lateral mammary branches of intercostal nerves
9 Posterior brachial cutaneous nerve
10 Posterior antebrachial cutaneous nerve
11 Medial antebrachial cutaneous nerve
12 Lateral antebrachial cutaneous nerve
13 Superficial branch of median nerve
14 Palmar branch of median nerve
15 Median nerve
16 Common palmar digital nerves
17 Palmar branch of ulnar nerve
18 Iliohypogastric nerve (lateral cutaneous branch)
19 Ilio-inguinal nerve (anterior scrotal nerves)
20 Iliohypogastric nerve (anterior cutaneous branch)
21 Genitofemoral nerve (femoral branch)
22 Lateral femoral cutaneous nerve
23 Femoral nerve (anterior cutaneous branches)
24 Obturator nerve (cutaneous branch)
25 Lateral sural cutaneous nerve
26 Saphenous nerve
27 Superficial peroneal nerve
28 Sural nerve
29 Deep peroneal nerve
30 Tibial nerve (calcaneal branches)

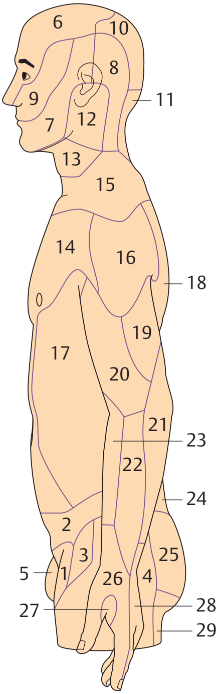
Fig. 5 Schematic diagram of sensory innervation, anterior view: right side, segmental innervation; left side, peripheral innervation.



1 Frontal nerve (V_1)
2 Greater occipital nerve
3 Lesser occipital nerve
4 Great auricular nerve
5 Dorsal rami of cervical nerves
6 Supraclavicular nerves
7 Superior lateral brachial cutaneous nerve (axillary nerve)
8 Dorsal rami of spinal, cervical, thoracic, lumbar nerves
9 Lateral cutaneous branches of intercostal nerves
10 Posterior brachial cutaneous nerve
11 Medial brachial cutaneous nerve
12 Posterior antebrachial cutaneous nerve
13 Medial antebrachial cutaneous nerve
14 Lateral antebrachial cutaneous nerve
15 Superficial branch of radial nerve
16 Dorsal ramus of ulnar nerve
17 Median nerve
18 Iliohypogastric nerve (lateral cutaneous branch)
19 Superior cluneal nerves
20 Medial cluneal nerves
21 Inferior cluneal nerves
22 Lateral femoral cutaneous nerve
23 Posterior femoral cutaneous nerve
24 Obturator nerve (cutaneous branch)
25 Lateral sural cutaneous nerve
26 Sural nerve
27 Saphenous nerve
28 Lateral plantar nerve
29 Medial plantar nerve

Fig. 6 Schematic diagram of sensory innervation, posterior view: right side, peripheral innervation; left side, segmental innervation.





1 Ilio-inguinal nerve
2 Iliohypogastric nerve
3 Genitofemoral nerve (femoral branch)
4 Lateral femoral cutaneous nerve
5 Dorsal nerve of penis (pudendal nerve)
6 Trigeminal nerve/1
7 Trigeminal nerve/3
8 Lesser occipital nerve
9 Trigeminal nerve/2
10 Greater occipital nerve
11 Dorsal rami of cervical nerves
12 Great auricular nerve
13 Transverse cervical nerve
14 Anterior cutaneous branches of intercostal nerves
15 Supraclavicular nerves
16 Superior lateral brachial cutaneous nerve (axillary nerve)
17 Intercostobrachial nerves (intercostal nerves)
18 Dorsal rami of thoracic nerves
19 Posterior brachial cutaneous nerve
20 Lateral brachial cutaneous nerve
21 Posterior antebrachial cutaneous nerve (radial nerve)
22 Superior lateral antebrachial cutaneous nerve
23 Medial antebrachial cutaneous nerve
24 Lateral cutaneous branch of iliohypogastric nerve
25 Superior cluneal nerves
26 Superficial branch of radial nerve
27 Autonomic region of the superficial branch radial nerve
28 Dorsal ramus of ulnar nerve
29 Inferior cluneal nerve
30 Median common digital palmar nerve

Fig. 7 Lateral view, segmental innervation.

Fig. 8 Lateral view, peripheral innervation.