Guide to Paraplegia

Evaluation of the Orthotic Treatment of the Lower Extremity following Paraplegia

2nd edition

Introduction

"I want to be able to walk again." That, or something very similar, is the dream of many patients when they are first diagnosed with paraplegia. This goal can only be reached if rehabilitation is initiated without delay, as the period immediately after disruption of the neural pathways is extremely important for the recovery of motor skills.

The rehabilitation of patients with paraplegia also places greater requirements on the entire interdisciplinary team, the patient's relatives and the patient himself. Nowadays, goal-oriented gait training is the treatment of choice in most SCI centres and draws on a wide variety of technically advanced procedures. Modern orthoses can also adopt a fundamental role in an advanced rehabilitation process.

Nevertheless, many patients still report that they are merely offered a wheelchair, without the possibility of orthotic treatment ever being assessed sufficiently. As such, it would appear that many healthcare professionals still have plenty of reservations about the efficacy of orthoses. Even though said reservations are most likely founded on an antiquated view of orthoses, misconceptions unfortunately still appear to be present in many people's minds.

In this guide, we shall be introducing to you a concept which describes the potential of a modern orthotic treatment in case of paraplegia to the affected persons and to professionals. Assessment of the possibility for orthotic treatment is a fundamental requirement for the correct tapping of this potential. Classification of the patient's remaining motor skills and sensory functions using the ASIA impairment scale provides a solid basis for this.

In addition, the guide presents the different system knee and system ankle joints available, with which the orthotic treatment can be customised to suit the individual patient's requirements. The guide is intended to provide an overview of the possibilities for orthotic treatment in the case of paraplegia.

Dare to accompany your patient a stretch on the journey to their goal!

Your FIOR & GENTZ team

Content

Cover: Patient (incomplete SCI below L3), supplied with a KAFO
(NEURO TRONIC system knee joint and NEURO SWING system ankle joint)

Paraplegia

Paraplegia is a complete or incomplete severance of the spinal cord resulting in organic and/or muscular deficits. The form and level of the injury are decisive for which deficits arise. Paraplegia can have traumatic or atraumatic causes, with traumatic causes being more common among younger patients and the incidence of atraumatic causes increasing respective to the age of those afflicted [McD].

Traumatic causes:

- traffic accidents, occupational accidents and sports injuries
- falls
- suicide attempts
- violent crime

Atraumatic causes:

- congenital (spina bifida)
- degenerative (spinal muscular atrophy)
- metabolic (gangliosidoses)
- inflammatory (multiple sclerosis)
- infectious (neuroborreliosis)
- ischaemic (aortic dissections, embolisms)
- rheumatological (rheumatoid arthritis)
- toxic (methrotrexate)
- tumour-related (compressing tumours)

In addition to the primary deterioration in the sensory and motor functions of the skeletal muscle, the failure of certain organs and the loss of bladder, bowel and sexual function is observed. Furthermore, spasticities often develop once the spinal shock subsides [Ber], which can result in further limitations (e.g. contractures).

If both legs are paralysed due to an injury below the cervical vertebrae but there is no impingement of arm function, the condition is referred to as paraplegia. It is entirely possible for the left and right legs to be affected to different extents. The loss of the use of both arms and both legs due to an injury in the cervical spine is referred to as tetraplegia or quadriplegia.

Treatment Goal

Acute care is followed by rehabilitation drawing on a wide range of therapeutic measures and provision of treatment appliances which are as customised to the patient as possible with the aim of restoring their independence. Many patients hope to regain or improve their ability to walk. The aim is to achieve the greatest possible mobility so that the patient can return to normal life in society without severe restrictions or assistance from others. The requirements placed on rehabilitation are high, as the better the success of the treatment, the simpler it is for patients to be included again.

In the case of SCI rehabilitation, these requirements are realised by an interdisciplinary team comprising doctors, care staff, physiotherapists and occupational therapists, orthotists, biomechanists and health insurance/cost bearers as well as relatives and patients themselves, all of whom participate in the continued development and implementation of a treatment plan [Kir].

Mobilisation

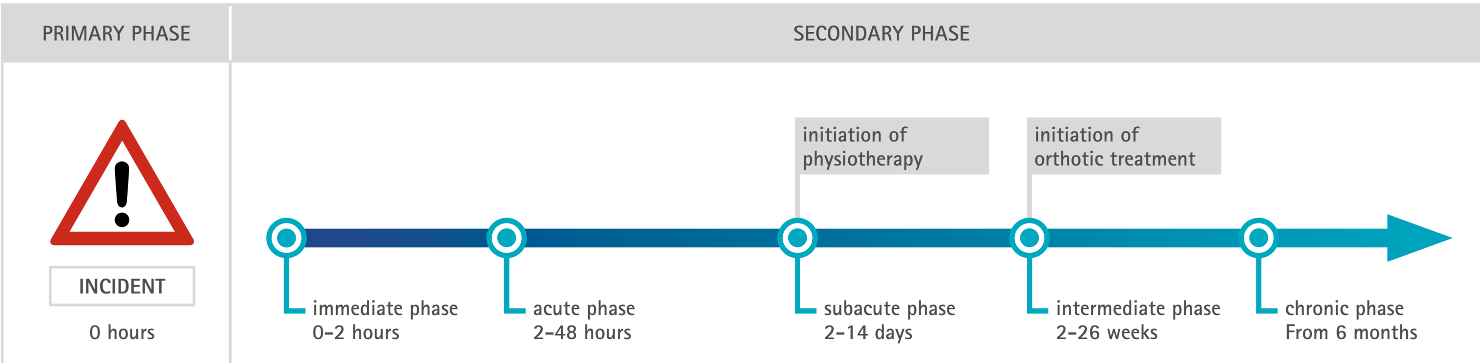
The progress of rehabilitation is aligned to the phases of a traumatic paraplegia (see below) [Row]. Spontaneous improvements in the clinical condition may occur within the first year following the trauma [Bur], which is why specialists recommend that gait training and corresponding appliances be integrated in the treatment as early as possible [Cur2].

Whilst physiotherapy is already commenced in the subacute phase, patients should be provided with orthotic appliances as early as possible in the intermediate phase, so as to allow the patient to benefit from the orthosis' rehabilitative potential through intensive gait training.

This training should be initiated as soon as possible after the spinal shock subsides, as rehabilitation of the lost spinal connections is possible in the secondary phase. At the same time, the frequency of the gait training is decisive for the success of rehabilitation [Cur2, Kir].

Modern SCI rehabilitation employs partially weight-supported treadmill training and robot-assisted gait training. The patient's first attempts to walk between parallel bars with orthoses are usually the first step towards independent walking. Whilst therapy devices such as exoskeletons and treadmills are predominantly employed in inpatient settings due to their size and costs, orthoses can be employed anywhere and accompany the patient throughout the course of their intensive rehabilitation as well as after returning home. Unfortunately, however, they are often provided to the patient too late, meaning they cannot be used in parallel to the treatment.

Course of a Traumatic Paraplegia



Orthotics from a Historical Perspective

Until just a few years ago, orthoses were still commonly referred to using the term “caliper(s)” and were viewed more as restrictive apparatus with only a minimal therapeutic benefit. A well-known example of the gait with a historical orthosis can be found in the film Forrest Gump (see p. 9). Due to their features, these medical appliances sometimes caused serious secondary damages for the patients.

The countless failures of orthotic treatments can primarily be traced back to the poor functionality of the components employed, which resulted in the poor functionality of the orthosis as a whole. This was exacerbated by the fact that traditional construction materials such as leather and steel resulted in heavy orthoses.

In addition, in the past there were no intelligent calculation systems available for determining the loads to be expected, which made it very difficult to plan orthotic treatments precisely. Without such systems, it is not possible to perform the complex calculation of orthoses. As a result, the functionalities displayed by such orthoses were often inadequate or not coordinated to the respective patients. Underestimated loads often resulted in breakages or the orthosis proved too heavy.

A lack of knowledge concerning the optimal use of new materials and innovative components as well as the employment of intelligent calculation systems is one reason why failures can unfortunately still occur among the orthoses produced and supplied to patients today. Taking the prerequisites outlined above into account, wheelchairs represent the only available and effective alternative for mobilisation. As a result of negative experiences with inadequate and faulty orthoses, wheelchairs are unfortunately still the recommended treatment in many hospitals.

The potential for orthotic treatment is not always investigated, meaning that patients who in principle might be capable of walking are hastily confined to wheelchairs instead. In addition, effective gait training demands increased therapeutic and technical efforts during rehabilitation and is thus far too often ignored. Unfortunately, this often results in a missed opportunity to restore the ability to walk of patients with that potential.

An example of the use of a historical orthosis can be found in Robert Zemeckis’ film Forrest Gump (Paramount Pictures 1994).

Requirements on Orthoses for the Treatment of Spinal Cord Injuries

The aim of treating SCIs with orthoses is to achieve the greatest possible extent of mobilisation for the patient. This goal requires both the orthosis as a whole and its individual components to possess a high functionality. As the orthosis is often subject to extreme loads, a stable construction is essential. Alongside high resilience, low weight is equally important for a successful orthotic treatment and the acceptance of this appliance.

The varied usability of an orthosis plays an important role in SCI rehabilitation. The appliance should already be integrated as a support within the scope of gait training, e.g. on a treadmill or parallel bars. Once the patient is ready to take the first steps on their own, it can help to increase the range of mobility and manage activities of daily living (ADL) as part of everyday rehabilitation. Even before the ability to walk is regained, the verticalisation achieved through the use of the orthosis can be advantageous [Nen].

As medical appliances, orthoses must provide a therapeutic benefit. Even though an improvement in stance stability is the most important requirement on an orthosis during rehabilitation, it must also not limit the movements that the patient is able to perform actively, or only do so to the smallest extent possible. This is the only means of ensuring that the success achieved during gait training is maintained beyond rehabilitation.

Modern Orthotics in the Rehabilitation of Paraplegia

Basic requirements for innovative orthotics
Modern technical orthopaedics offers not only technologically advanced knee and ankle joints (e.g. mechanical, electronic and hydraulic knee joints, as well as different types of sensors for detecting stance phase and swing phase) but also new, light but stable materials such as carbon and titanium at its disposal. Continually improved techniques and tools such as e-Cast allow efficient working. Intelligent calculation systems such as the FIOR & GENTZ Orthosis Configurator can be used to determine the loads to be expected and the ability of the orthosis to withstand them in a simple, transparent and precise manner resulting in the selection of adequately dimensioned components.

Modern gait analysis methods can make the treatment's success visible immediately and make it easier to identify and localise the demand for necessary adjustments and improvements.

When planning an orthotic treatment, the requirement for stance stability must be weighed up precisely against the maximum possible freedom of movement. The biomechanical tasks of orthoses comprise:

1. establishing a stable balance when the patient is standing. Secondary effect: verticalisation has a wide range of positive effects [Nen];
2. supporting lost functions during dynamic movement: in combination with physiotherapy, the right motor impulses can establish new cerebral connections [Hor]. This mechanism is termed neuro plasticity [Cur1].

e-Cast = digital casting aid; was developed in order to check and, if necessary, correct the joint angles while making the negative cast.

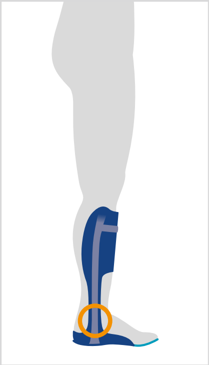
Function of Modern Orthoses

The muscles involved in walking are no longer controlled correctly by the damaged neural pathways. Modern orthoses can replace a large proportion of these lost muscle functions or even restore them. For this reason, it is important to initiate the orthotic treatment early. Different orthosis types and joints are employed depending on the severity of the deficits (see pp.12-13).

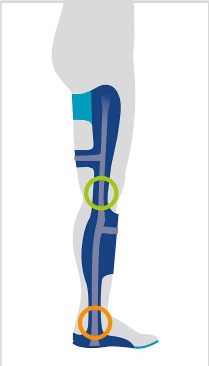
The orthosis type and the joints used must be determined individually for each patient. The FIOR & GENTZ Orthosis Configurator is able to assist with precise determination of the required orthosis components.

Function using an orthosis with stance phase control as an example
During stance phase – when the supporting leg bears the entire weight of the body – the orthosis locks the knee joint in order to guarantee stance control and avoid falls. In swing phase, it allows the leg to swing through completely, as the automatic knee joint of the orthosis permits flexion of the knee. The beginning and end of stance phase are detected either mechanically or electronically by different sensors.

Types of Orthoses



Ankle-foot orthosis (AFO):
AFOs can be produced in different versions and with different ankle joints. They are employed when primarily the plantar flexors and dorsal flexors are affected. Depending on the ankle joint used, AFOs have an integrated foot lifter and/or prevent excessive dorsiflexion by means of a dorsiflexion stop [Plo].

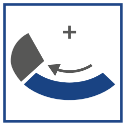


Knee-ankle-foot orthosis (KAFO):
KAFOs are produced with an ankle joint and depending on the muscle strength with free moving, automatic (with stance phase control) or locked knee joints. They are employed mainly in cases of a pronounced weakness of the quadriceps femoris. The patient placing a hand on his thigh when walking so as to support knee extension is an indication of this deficit. The compensation of the knee in hyperextension and excessive forward inclination of the torso can also be early warning signs indicating the need for a KAFO [Nol].

AFO = ankle-foot orthosis – an orthosis encompassing both the ankle joint and the foot

KAFO = knee-ankle-foot orthosis – an orthosis encompassing the knee, the ankle joint and the foot

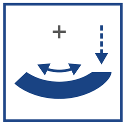
Ankle joint functions (in AFOs and KAFOs):



dorsiflexion stop

- establishing a stable balance when the patient is standing
- physiological knee extension and heel lift starting at terminal stance
- ankle joints with static or dynamic dorsiflexion stop;

example: NEURO VARIO or NEURO SWING system ankle joint



foot lifter

- foot is held in slight dorsiflexion during swing phase
- adjustability of controlled dynamic lowering of the foot
- adjustability of the knee flexion moment and controlled forward progression of the lower leg

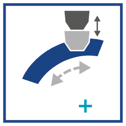
example: NEURO CLASSIC-SPRING system ankle joint

Knee joint functions (in KAFOs):

free moving

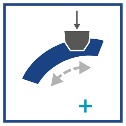
- movement of the knee joint stays unimpeded
- limitation of range of motion in extension (by use of extension stops)
- lateral guidance and stability
- increased safety in mid stance due to posterior offset of joints

example: NEURO CLASSIC system knee joint



automatic

- knee flexion is locked in stance phase and released again in swing phase
- mechanical (NEURO MATIC system knee joint) or electronic (NEURO TRONIC system knee joint) locking and releasing
- optimal safety with excellent freedom of movement
- also suitable as a training device in rehabilitation



locked

- completely locked during walking (no knee flexion possible)
- greatest possible safety in stance phase
- manual release possible (e.g. when sitting down)
- disadvantage: development of compensatory mechanisms to compensate the missing knee flexion in swing phase

example: NEURO FLEX MAX system knee joint

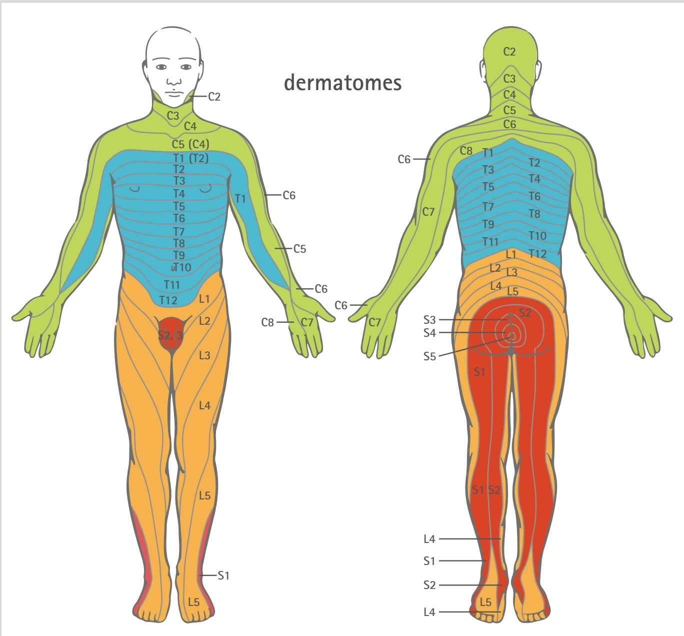
Classification

To be able to estimate the potential for orthotic treatment, the interdisciplinary team requires information on the extent of the paraplegia. The most important data include the level of injury and whether the incident involves a complete or an incomplete paraplegia. With the aim of designating and communicating this information precisely, the ASIA Impairment Scale was developed to establish an international standard for the classification of paraplegia [May]. The first step involves determining the level of injury by identifying the section of the spine in which neither motor nor sensory deficits are observed (neurological height). This is done by determining the motoric height of selected reference muscles by testing the muscle grade and the sensory height at defined key points on the skin, known as dermatomes, by light touching and a pin prick test. The sensitivity at these key points provides information on the position on the spine at which sensory signals are still transmitted (see pp. 14–15 below).

Motoric height: determination of grade of reference muscles

Upper Extremities				Lower Extremities			
	L	R	Key Muscles Involved		L	R	Key Muscles Involved
C5			elbow flexors	L2			hip flexors
C6			wrist extensors	L3			knee extensors
C7			elbow extensors	L4			dorsal flexors
C8			finger flexors	L5			long toe extensors
T1			finger abductors	S1			plantar flexors

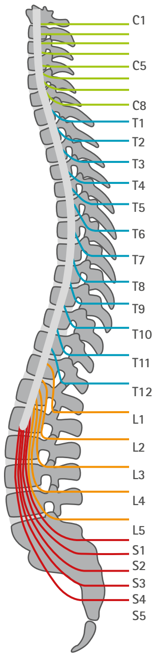
Sensory height: sensitivity of certain key points



Levels of injuries according to the *ASIA Impairment Scale:*

- cervical injuries (C1-C8) injuries on the level of the cervical spine
- thoracic injuries (T1-T12) injuries on the level of the thoracic spine
- lumbar injuries (L1-L5) injuries on the level of the lumbar spine
- sacral injuries (S1-S5) injuries on the level of the sacrum

The following step employs a specific evaluation scale to determine whether the respective case involves a complete (ASIA A) or an incomplete paraplegia (ASIA B-D) (see box below).



A = Complete
No sensory or motor function is preserved in sacral segments S4-S5.

B = Incomplete
Sensory but no motor function is preserved below the neurological level and extends through sacral segments S4-S5.

C = Incomplete
Motor function is preserved below the neurological level and the majority of the key muscles have a muscle grade of less than 3 (according to Janda).

D = Incomplete
Motor function is preserved below the neurological level and the majority of the key muscles have a muscle grade that is greater than or equal to 3 (according to Janda).

E = Normal
Sensory and motor functions are normal.

Complete Paraplegia

Complete paraplegia is referred to as ASIA A according to the ASIA Impairment Scale. All of the neural pathways below the level of the injury are completely destroyed and neither sensory nor motor functions are preserved in the S4 and S5 segments of the spine. The prognoses for complete rehabilitation of essential bodily functions are comparatively poor.

With complete paraplegia below T12, the remaining active musculature of the pelvis (quadratus lumborum muscle) allows forward movement of the affected leg, which represents the minimum requirement for walking with an orthosis [Mic]. In addition, coordinative and sensorimotor factors, which influence the muscle strength of the muscle groups, are important for a precise control of the muscle groups.

In the case of injuries in the lumbar and sacral regions, motor and sensory functions are still present even in the case of complete paraplegia. These functions can be utilised to operate an orthosis. Depending on the evaluation of the potential for orthotic treatment, different orthosis and joint functions are required to achieve the necessary stability in stance phase.

Despite poor prognoses [Cur1], early orthotic treatment within the first year can contribute to an improvement in the patient's ability to walk and the motoric height.

ASIA = **American Spinal Injury Association;** North American association for treatment, training and research in the field of paraplegia, based in Richmond, Virginia.

Incomplete Paraplegia

Incomplete paraplegia is classified with ASIA B-D. The spinal cord is only partially damaged below the level of injury. Both sensory and motor functions of the dermatomes and key muscles activated by the S4 and S5 segments of the spine are preserved. The chances of rehabilitation of important bodily functions and thus also the ability to walk are good.

The affected bodily functions and the permanence of the damage to the spinal cord depend both on the severity of the injury and on the particular spinal cord syndrome [Ber]. The spinal cord syndrome refers to the damaged section of the spinal cord.

Due to these spinal cord syndromes, incomplete paraplegia do not always display the same motoric deficits at identical neurological heights, unlike complete paraplegia. It can be assumed that control of some muscle groups is possible without any limitations. However, it is very difficult to estimate the exact extent.

Orthotic treatment is possible in cases of incomplete paraplegia in the lumbar and sacral regions – and even for injuries above T12 if the corresponding muscle strength is confirmed. In the early phase of rehabilitation, orthoses can be used as practical complements to physiotherapeutically assisted gait training. It is even possible that early orthotic treatment may contribute to an improvement in the patient's ability to walk and the motoric height. This potential for improvement is higher in patients classified as ASIA D than in patients classified as ASIA C or even ASIA B [Cur1].

Classification of Different Spinal Cord Syndromes:

- **anterior cord syndrome:** damage to anterior section of spinal cord
- **posterior cord syndrome:** damage to posterior section of spinal cord
- **central cord syndrome:** damage to central section of spinal cord,
- **Brown-Séquard syndrome:** unilateral damage to the spinal cord,
- **conus medullaris syndrome:** damage to the conical tapered end of the spinal cord (conus medullaris),
- **cauda equina syndrome:** damage to the spinal nerve roots at the end of the spinal cord (cauda equina).

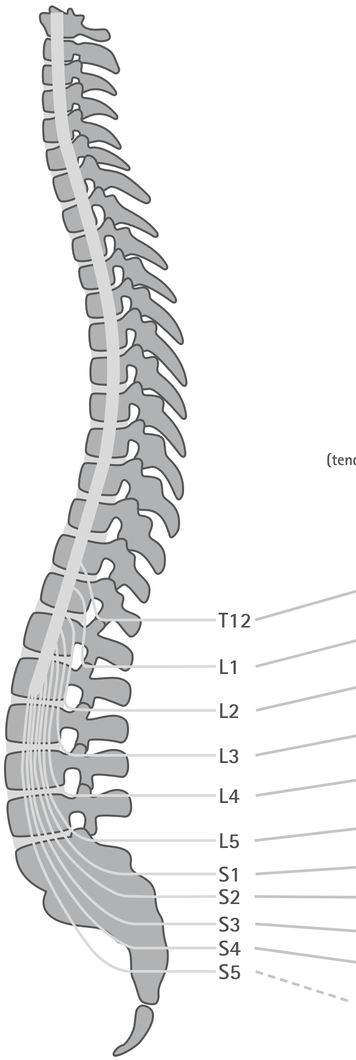
Correlation between Level of Injury and Muscle Strength

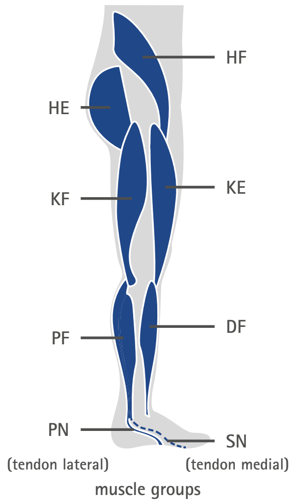
All muscle groups are composed of different muscles. These muscles are innervated by nerves originating from different segments of the spine [Put]. Accordingly, there is a spectrum of spine segments for each muscle group, within which residual function is still present depending on the level of injury.

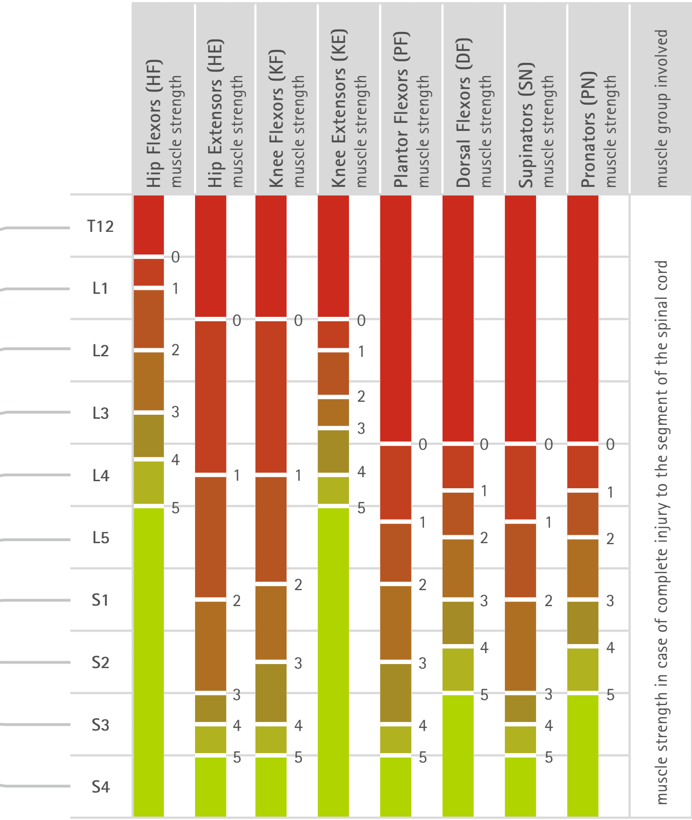
The muscle groups which are particularly important for walking and the evaluation of the potential for orthotic treatment are:

- **at hip level:** hip flexors and extensors
- **at knee level:** knee flexors and extensors
- **in the upper ankle joint:** plantar flexors and dorsal flexors
- **in the lower ankle joint:** supinators and pronators

Using the table below, estimates can be made as to whether and to what extent a muscle group is affected by the paraplegia based on the level of injury. This, in turn, makes it possible to estimate the muscle strength of the individual muscle groups and thus the potential for orthotic treatment. The grades defined for each muscle group can be utilised to assign possible orthosis types and joints to each level of injury in the same way (see pp. 22-23).







Evaluation of Potential for Orthotic Treatment

Patients with complete paraplegia (ASIA A)
The correlation between level of injury and muscle strength applies to the complete loss of the neural pathways below the level of injury. This makes it possible to estimate the muscle strength (see pp. 18-19) without difficulties, with the aim of evaluating the potential for orthotic treatment.

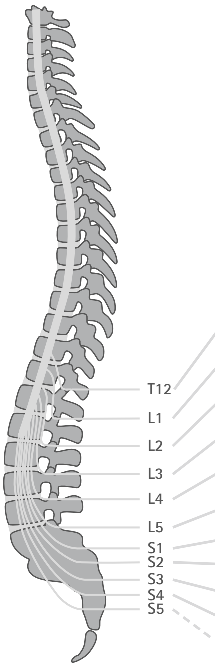
However, as coordinative and sensorimotor factors are also important for a precise control of the muscle groups, an extensive muscle function test must be performed for a precise determination of the muscle strength and planning of the orthotic treatment [Jan].

Patients with incomplete paraplegia (ASIA B–D)
With these patients, it is possible that some muscle groups will be affected less by the deficits or not at all. As such, the muscle strength identified in the table only represents the worst case scenario for the respective restriction. Consequently, orthoses may even be suitable for injuries above T12.

An extensive muscle function test is also essential here for a precise determination of the muscle strength and planning of the orthotic treatment [Jan].

Correlation between Level of Injury and Type of Orthosis

As the muscle strength can be estimated based on the level of injury in complete paraplegia (see pp. 18-19), possible orthosis types and joints can also be assigned to each level of injury in the same way. In the case of incomplete paraplegia, the orthosis types and joints shown in the table merely represent the maximum requirement for orthotic treatment. In many cases, orthotic treatment is also possible in cases of injuries above T12. However, in such cases it is essential to determine the precise muscle strength and perform an orthosis configuration (see pp. 24-25).



	AFO	KAFO		
		free moving	automatic	locked
T12	No recommendation	No recommendation	Alternative	Alternative
L1	No recommendation	No recommendation / Alternative	Recommendation	Recommendation / Alternative
L2	No recommendation	No recommendation / Alternative	Recommendation	Recommendation / Alternative
L3	No recommendation	No recommendation / Alternative	Recommendation	Recommendation / Alternative
L4	Alternative	Recommendation	Recommendation	Alternative
L5	Alternative / Recommendation	Recommendation	Recommendation	Alternative
S1	Recommendation	Recommendation / Alternative	Alternative	Alternative
S2	Recommendation	Alternative	Alternative	Alternative
S3	Recommendation	Alternative	Alternative	Alternative
S4	Alternative	No recommendation	No recommendation	No recommendation

Recommendation

Alternative

No recommendation

Determination of the Type of Orthosis via Configuration

In order to produce an orthosis for a patient with paraplegia which can withstand loads but is still light and meets all the functional requirements, a variety of patient data is required.

Examples of patient data:

- weight and height
- diseases and disabilities (type of injury/paralysis)
- knee and hip position (e.g. hyperextension)
- activity level and appliances for locomotion
- muscle strength

Examples of orthosis and joint functions:

- dorsiflexion stop
- foot lifter
- dynamic knee extension (in stance phase)
- maximum knee stability (in stance phase)
- knee flexion (in swing phase)

It is often very difficult for the orthotist to take each of these pieces of information into account individually when calculating and designing the orthosis. Only intelligent calculation systems such as the Orthosis Configurator by FIOR & GENTZ are capable of evaluating the wealth of data accurately.

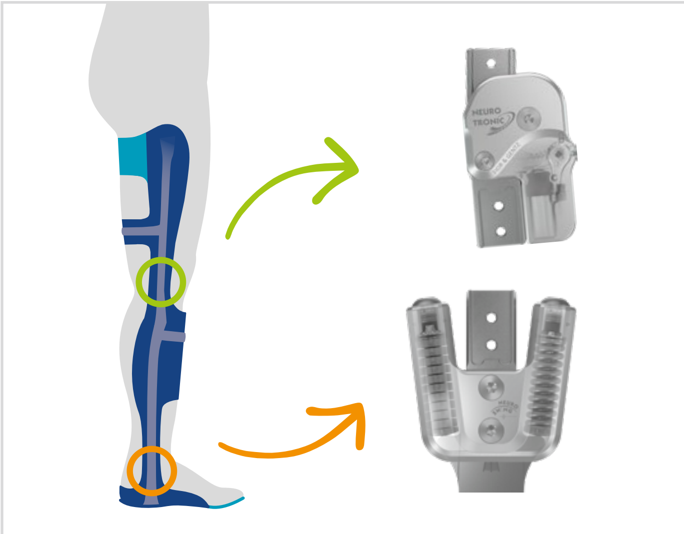
Orthosis Configurator

All of the patient data pertinent to the treatment is collected and entered into the input mask of the FIOR & GENTZ Orthosis Configurator over the course of the configuration process. The technician is then guided through the selection of the available types of orthoses and joint functions (see pp. 12-13) step by step until the final orthosis is designed.

The Orthosis Configurator in 4 Steps

1. **Patient Data**
The orthotist enters the patient data gathered into the corresponding fields in the input mask.
2. **System Components**
He selects between different alternatives and the Orthosis Configurator calculates the requisite system components on this basis.
3. **List of Articles**
Once the configuration is complete, the orthotist receives a list of the components required for the construction of the orthosis.
4. **Order/Shopping cart**
Now, the components calculated in this manner can be ordered. The configuration data can also be printed out.

Extract from a possible configuration result:



The Optimal Orthosis

A Patient's Perspective

Jarno Rintschwentner trained as a roofer and has suffered from incomplete paraplegia below the third lumbar vertebra since he fell from a height of 12 metres in 2006. He received his first orthosis on his own initiative. It was equipped with an automatic knee joint.

Here you can find out what Jarno Rintschwentner said about...

...his goal during rehabilitation:
In my first meeting with my representative from the Employers' Liability Insurance Association, I said, "I want to leave this facility on my own two feet."

...erroneous arguments for a wheelchair:
I have never had a wheelchair (...). In the rehabilitation centre, they kept on saying: "In a wheelchair, you will have your hands free and can at least carry something in your lap." That wasn't a convincing enough argument in my eyes.

...unjustified reservations about orthoses:
The same arguments surfaced time and time again (...); they were based on thinking from about 20 years ago when orthoses were made of steel and extremely heavy.

...the timing of his first orthotic treatment:
I got my first orthosis six months after my accident, which was quite late in my opinion. (...) I am firmly convinced that the earlier patients like me are fitted with an orthosis, the more successful the treatment will be.

...the improvement in his gait thanks to the orthosis:
When I walk without an orthosis, I extend my left leg too far. Thanks to the orthosis, my gait is pretty close to the physiological norm. If I wear the orthosis under my trousers and am having a good day, it is barely even noticeable..

Appendix 1 – The Physiological Gait

Detailed knowledge of the physiological gait is essential for a professional assessment of the extent of any gait disorders and the effect of the orthotic treatment. The physiological gait of humans can be described using a variety of different parameters.

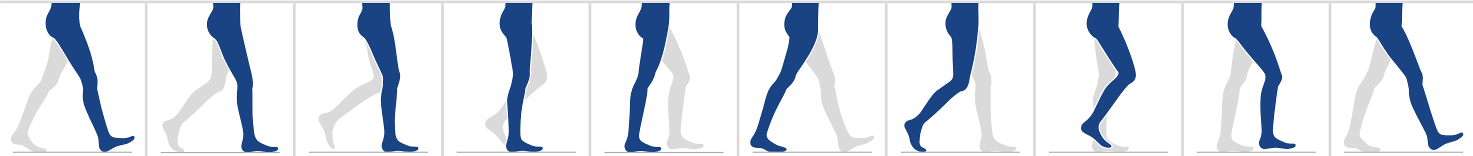
The following aspects can be evaluated and compared:

- the movements of the joints (kinematics)
- the forces and momentums acting on the joints (kinetics)
- the spatial and temporal parameters, e.g. speed, stride/step length and cadence (steps per minute)
- the energy required for walking

The most commonly employed method is Jacquelin Perry's description, in which the physiological gait of humans is divided into different phases (see table below). A stride is roughly divided into the stance phase (from IC to PSw) and the swing phase (ISw to TSw) for the leg in question.

Each individual phase constitutes a defined percentage share (%) of the stride and is characterised by a specific angle progression of the hip, knee and ankle. The English terms for these phases and their abbreviations have now also come to be commonly used around the world [Per].

Division of Physiological Gait into Different Phases According to Jacquelin Perry



Term (Abbreviation)									
initial contact (IC)	loading response (LR)	early mid stance (MSt)	mid stance (MSt)	late mid stance (MSt)	terminal stance (TSt)	pre swing (PSw)	initial swing (ISw)	mid swing (MSw)	terminal swing (TSw)
Percentage of Stride									
0 %	0–12 %	12–31 %			31–50 %	50–62 %	62–75 %	75–87 %	87–100 %
Hip Angle									
20° flexion	20° flexion	10° flexion	neutral position	5° extension	20° extension	10° extension	15° flexion	25° flexion	20° flexion
Knee Angle									
0-3° flexion	15° flexion	12° flexion	8° flexion	5° flexion	0-5° flexion	40° flexion	60° flexion	25° flexion	0-2° extension
Ankle Angle									
neutral position	5° plantar flexion	neutral position	5° dorsiflexion	8° dorsiflexion	10° dorsiflexion	15° plantar flexion	5° plantar flexion	neutral position	neutral position

Appendix 2 – Typical Gait Disorders

The gait disorders listed refer to a complete failure of the respective muscle group [Per]. The actual extent of the gait disorders described depends on the muscle strength. The graphics shown below refer to the complete paralysis of the respective muscle group in the typical gait phase. Depending on the level of injury, the gait is composed of multiple components:

Hip flexors The swinging through of the leg is disrupted. Patients compensate for the lack of hip flexion by means of circumduction, vaulting or hip hiking (see compensatory mechanisms, pp. 32-33).

Hip extensors The ground reaction force vector (GRF vector) falls in front of the hip joint at the beginning of stance phase. Patients compensate for the lack of hip stability by inclining their torso backwards starting at IC.

Knee flexors The lack of knee flexion at the beginning of PSw disrupts the introduction of swing phase. The GRF vector remains in front of the knee joint. Compensatory mechanisms develop (see pp. 32-33).

Knee extensors In order to compensate the missing knee stability, patients incline their upper body forwards at the beginning of LR. The GRF vector falls in front of the knee and prevents its flexion in PSw.

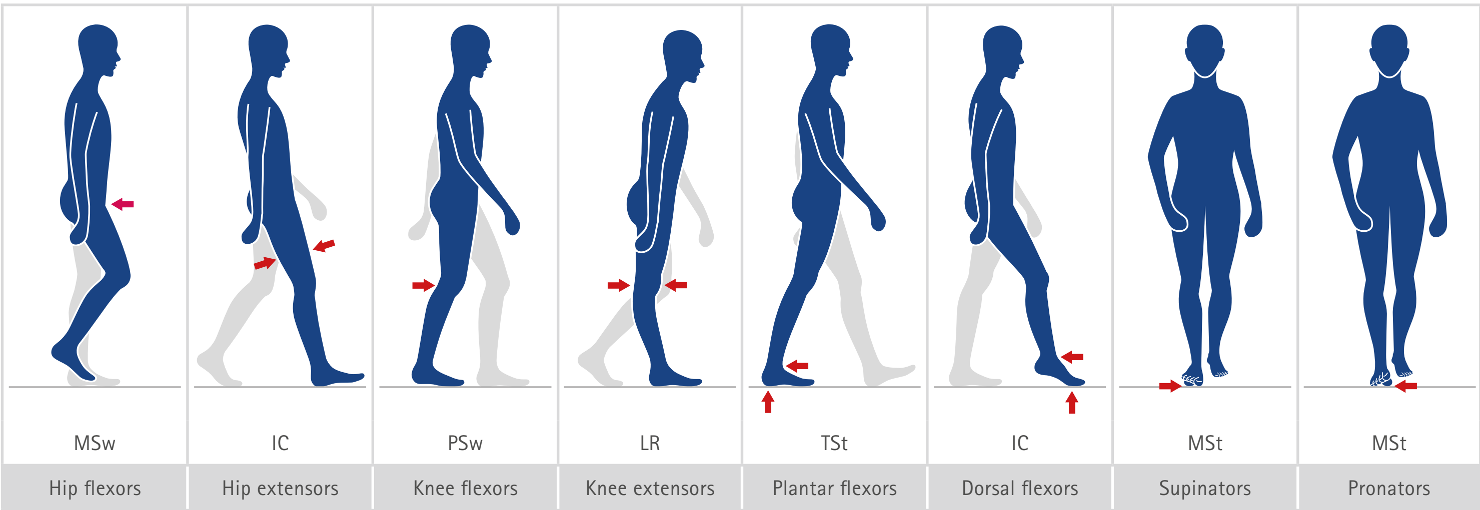
Plantar flexors The inactive forefoot lever results in a delayed heel lift, an excessive contralateral knee flexion and a shortened step length. The quadriceps is subjected to higher loading.

Dorsal flexors The foot lifting in swing phase is disrupted. The IC occurs with the flat foot or the forefoot. In order to allow a movement without stumbling, compensatory mechanisms develop (see pp. 32-33).

Supinators The foot is in an excessively pronate position. The more plantar flexor muscles are affected, the more obvious this deviation in stance phase is.

Pronators The foot is in an excessively supine position. The more plantar flexor muscles are affected, the more obvious this deviation in stance phase is.

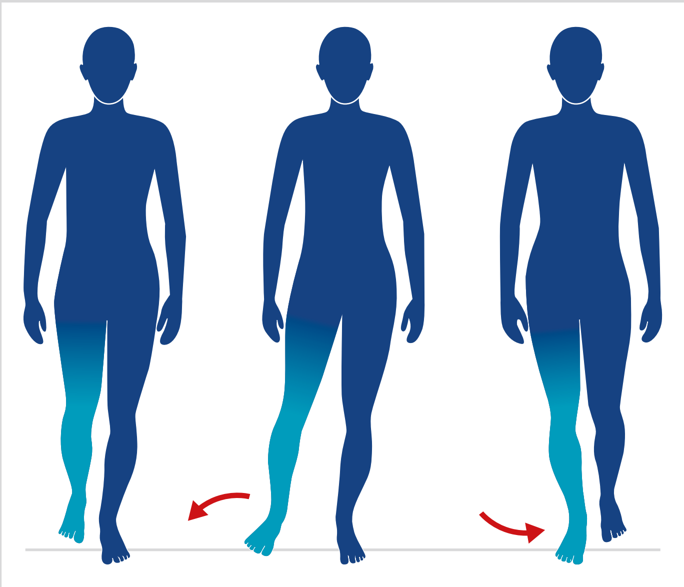
Deviations from the Physiological Gait in Case of Isolated Failure of the Muscle Groups



The swing leg must be effectively shortened for it to be possible to move forwards without stumbling when walking normally. This requirement is established by a physiological hip and knee flexion as well as dorsiflexion during swing phase.

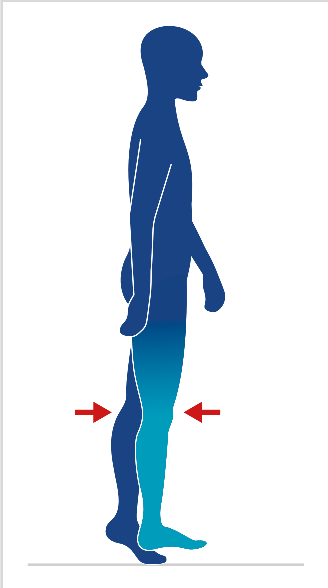
Certain gait disorders involve the disruption to this shortening of the leg, for example if the hip and knee flexors are malfunctioning. If the dorsal flexors are malfunctioning, the swing leg is effectively extended due to the increased plantar flexion in swing phase. When a locked KAFO is worn, the permanent locking of the knee joint also prevents knee flexion.

The body can compensate for this lack of functional shortening in three different ways:



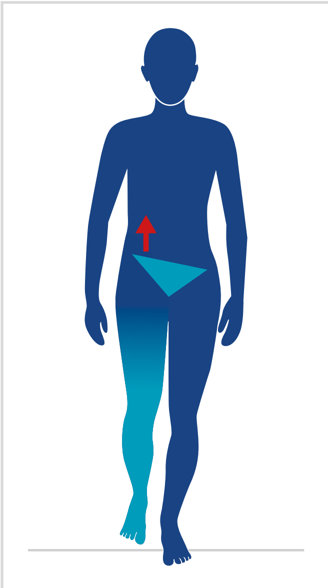
Circumduction

During swing phase, the swing leg is brought forward in a semicircular motion around the supporting leg. During this motion, external rotation occurs in the hip joint. In the long term, this motion can manifest and cause hip problems.



Vaulting

This compensatory mechanism describes contralateral plantar flexion. As the affected leg is effectively extended or cannot be flexed, the contralateral supporting leg is extended instead so as to allow the swinging through.



Hip hiking

Hip hiking refers to excessive lifting of the pelvis on the swing leg side. This provides the extended swing leg with the extra space to swing through without stumbling.

Abduction
(from Latin abducere = to withdraw, lead away): a distal movement of the leg away from the centre of the body. The countermovement of ↑adduction. Muscles which perform this movement are called abductors.

Adduction
(from Latin adducere = to bring up/to, contract): proximal movement of the leg towards the centre of the body. The countermovement of ↑abduction. Muscles which perform this movement are called adductors.

ADL Score
(activities of daily living): the ADL score is a procedure to measure the ability of patients suffering from degenerative diseases such as ↑multiple sclerosis to perform daily tasks.

Cadence
(from Latin cadere = to fall): in this context: rate of steps. Given in steps per unit of time (minutes or seconds).

Cerebral Connection
(from Latin cerebrum = [in broadest sense] brain): the brain saves control programmes for complex movement patterns. Repetitions of ↑physiological movement patterns lead to corrections of these control programmes in the brain [Hor]. In turn, each environmental disturbance can result in a repeated control programme error and thus in a ↑pathological movement pattern.

Circumduction
(from Latin circumducere = to lead in a circle): compensation for insufficient shortening of the leg in swing phase when walking. The affected swing leg is led around the supporting leg in a semicircular motion.

Contracture
(from Latin contrahere = to tighten): tissue shortening or shrinking, e.g. of certain muscles or tendons. It leads to a reversible or irreversible restriction of mobility or fixed deformity of the adjoining joints. There are elastic and rigid contractures.

Contralateral
(from Latin contra = against; latus = side, flank): found on the opposite side of the body.

Dermatome
(from Greek dérma = skin; tom = section): area of the skin ↑innervated by a nerve from the spinal cord providing it with sensory function.

Dorsiflexion
Lifting of the foot. The countermovement of ↑plantar flexion. Referred to as a “flexion” motion because it reduces the angle between the lower leg and foot, although technically a stretching movement in the sense of an ↑extension. Muscles which perform this movement are called dorsal flexors.

Dorsiflexion Stop
Constructional element of an orthosis which limits the degree of ↑dorsiflexion. The dorsiflexion stop activates the forefoot lever, creating an area of support. Furthermore, a dorsiflexion stop causes together with the foot piece of an orthosis a knee extension moment and a heel lift starting at terminal stance.

Exoskeleton
(from Greek exo = outer; skeletós = dried-up body): outer skeleton. Technical exoskeletons are employed to support or reinforce human movements, for example in medicine as part of the treatment of paralysis. By definition, an orthosis already counts as an exoskeleton.

Extension
(from Latin extendere = to stretch out): active or passive straightening of a joint. Straightening is the countermovement of bending (↑flexion) and characteristically increases the joint angle.

Flexion
(from Latin flectere = to bend): active or passive bending of a joint. Bending is the countermovement of straightening (↑extension) and characteristically reduces the joint angle.

Ground Reaction Force
(GRF): a force exerted by the ground in response to the forces a body exerts on it. The ground reaction force vector is a theoretical line representing the size, origin and direction of action of the ground reaction force.

Hip Hiking
Raising of the hip. Compensation for an insufficient shortening of the leg in swing phase when walking. The pelvis is raised on the swing leg side so as to allow swinging through without stumbling.

Innervate
(from Latin nervus = nerve): to supply an organ e.g. a muscle with neural stimuli.

Interdisciplinary
(from Latin inter = between): concerning the cooperation between various disciplines.

Ischaemia
(from Greek íschein = to hold back, to restrain): localised loss of blood, an inadequate blood supply or a complete restriction of the arterial blood flow. During an ischaemic insult, in the form of a stroke, the blood circulation in a distinct area of the brain can be reduced or interrupted.

Kinematics
(from Ancient Greek kinema = movement; kinein = to move): a branch of mechanics concerning the motion of points and bodies in space without their being acted upon by forces. In gait analysis, this movement is described for example by the changes in position of different segments of the body in relation to each other and expressed in angles.

Kinetics
(from Greek kínesis = movement): a branch of dynamics concerning the link between the forces and the resulting movements of a body in a space. In gait analysis, the main task is determining the ↑ground reaction force of the human body when walking, which is then used to calculate the forces and momentums acting on the joints.

Multiple Sclerosis
(MS): inflammatory disease of the central nervous system which results in progressive neuromuscular restrictions (e.g. problems concerning the ability to walk).

Muscle Strength
Muscle strength is an indicator used to evaluate the force exerted by a group of muscles (e.g. knee flexors). This force is determined by the muscle function test [Jan], which is used to test to what extent it is possible to perform the respective movement with each muscle group. The strength is classified on a six-level scale depending on whether or not the subject is able to overcome manually applied resistance or gravity.

0 (zero)	total paralysis, no evidence of contraction
1 (trace)	slight contraction, but no joint motion
2 (poor)	complete range of motion with gravity eliminated
3 (fair)	complete range of motion against gravity
4 (good)	complete range of motion against gravity with some resistance
5 (normal)	complete range of motion against gravity with full resistance

Neuroplasticity
Also referred to as neuronal plasticity. Structural changes to the central nervous system caused by altered ↑physiological requirements. For example, neighbouring areas of the brain take over the duties of the damaged areas in stroke victims. This can also occur for synapses, nerve endings and axons. This process can also be described as neuronal learning.

Neutral Position
A neutral position is characterised by an upright posture with feet nearly hip width apart. The joint's range of motion can be determined from the neutral position.

Paraplegia
(from Greek para = beside, near; plege = blow, paralysis): complete paralysis of two symmetrical extremities (usually legs).

Pathological
(from Greek pathos = pain; disease): (altered by) disease.

Physiological
(from Greek physis = nature; logos = science): concerning natural life processes.

Pin Prick Test
Clinical test whereby the skin's sensitivity to pain is examined using a sharp object (e.g. a needle).

Plantar Flexion
Dropping of the foot. Countermovement of ↑dorsiflexion. Muscles which perform this movement are called plantar flexors.

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Pronation
(from Latin pronare = to bow, to bend over): inward rotation of the foot around its longitudinal axis and/or lifting of the outer foot edge. Countermovement of ↑supination. Muscles which perform this movement are called pronators.

Quadratus Lumborum Muscle
Muscle located in the posterior abdominal wall. Among other functions, it lifts the pelvic brim laterally when the ribcage is fixed in place.

Quadriceps Femoris Muscle
Four-headed thigh muscle. Mainly permits ↑extension of the lower leg in the knee joint.

Sensorimotor
Refers to the combination of sensory and motor parts of the nervous system. For example, the sensory impressions of the sole of the foot influence the function of certain muscles. Sensorimotor elements can be integrated, for instance, in inserts, inner shoes or the foot piece of an orthosis.

Spasticity
(from Greek spasmos = cramp): an intermittent or sustained, involuntary muscle activity caused by a lesion of the upper motor neuron responsible for the sensorimotor system [Bas, p. 61; Pan, p. 2ff.].

Spina Bifida
(from Latin spina = thorn, spike; bifidus = split into two parts): spine defect resulting from incomplete closing of the vertebrae in the lumbar or sacral section of the spine during the embryonic stage. There is a differentiation between open and closed forms of the defect. Depending on the severity of the malformation, the patient may suffer physical impairments similar to those associated with paraplegia. The condition occurs in about 1 in 1,000 births.

Spinal
(from Latin spinalis = concerning the backbone): relating to the spinal cord or vertebrae.Spinal Muscular Atrophy (SMA): with this hereditary disease, the progressive deterioration of motor neuron cells in the spinal cord results in paralyses, which are primarily associated with muscle loss and reduced muscle tone. The condition occurs in about 1 in 10,000 births.

Supination
(from Latin supinare = to move backwards, to lean backwards): outward rotation of the foot around its longitudinal axis and/or lifting of the inner edge of the foot. The countermovement of pronation. Muscles which perform this movement are called supinators.

Tetraplegia
(from Greek tetra = four; plege = blow, paralysis): also known as quadriplegia. Complete paralysis of all four extremities (both arms and legs).

Vaulting
Compensation for insufficient shortening of the leg in swing phase when walking. During this movement, the ankle of the ↑contralateral supporting leg is brought into ↑plantar flexion. This balances out the lacking ↑dorsiflexion, hip flexion or knee flexion of the affected leg in swing phase and allows swinging through without stumbling.

Verticalisation
(from Latin vertex = peak): bringing the body into a vertical (upright) position.

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Abbr.	Source	Page
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