

A Concept for the Orthotic Treatment of Gait Problems in Cerebral Palsy

5th edition



## Introduction

In recent years, physicians, physiotherapists, gait instructors and orthopaedic technicians kept asking us to develop a new mechanical ankle joint. Different demands have been passed on to us from several fields, regions and nations. The *International Society of Prosthetics and Orthotics* (ISPO) also demands adjustment possibilities for ankle foot orthoses (AFOs) [Mor, p.258f.]. Hence, we have developed the NEURO SWING system ankle joint. Next to other fields of application, the NEURO SWING can be mounted in AFOs for the treatment of patients with cerebral palsy (CP patients).

During our research on cerebral palsy (CP) we noticed that there is much unused potential in the management of CP patients and especially in the orthotic treatment. At this point in time, different strategies are pursued worldwide. This is based on the fact that until now, on the one hand, a uniform classification of the pathological gait patterns of CP patients and, on the other hand, an orthotic joint that meets all demands are missing. If CP patients cannot be standardised, it is very hard to give the interdisciplinary team a treatment concept and the appropriate orthotic fitting. At present, experts decide to use orthotic fittings that provide the most advantages but at the same time acceptable disadvantages.

Most of the orthotic concepts used until now for CP patients have to be reconsidered due to the NEURO SWING system ankle joint that leads to new opportunities in orthotic management. As a response to the different demands and in order to generate a concept for the whole interdisciplinary team, we felt it was very important to suggest a more adequate orthotic treatment based on an applicable and internationally accepted gait classification.

As a result, the present CP Guide – A Concept for the Orthotic Treatment of Gait Problems in Cerebral Palsy was created. It is addressed to physicians, physiotherapists, gait instructors, orthopaedic technicians, orthopaedic shoemakers, biomechanics and last but not least to the parents or attending persons of patients and, of course, to the patients themselves.

In order to understand our concept, a basic knowledge of the physiological gait pattern is absolutely required. Therefore, the most important terms and gait phases are also explained in this guide.

Since experts had a great interest it was possible to bring together various research results and experiences. We would like to thank all the persons involved for the help received.

We do not expect our CP Guide to be perfect. Rather, it should be the beginning of an innovative concept for the orthotic treatment of CP and we rely on your comments and critique to continually improve its quality.

Your FIOR & GENTZ Team

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### What is Cerebral Palsy?

In cerebral palsy, the impulses transmitted by the brain to the affected muscles are false and, as a result, the muscles are excessively, insufficiently or wrongly timed activated. This abnormal activation leads to dysfunctions of some muscle groups which normally result in a pathological gait [Gag1, p.65]. Additionally, these muscular dysfunctions can be associated with spasticity [Pea, p.89] which, in turn, change the muscle tone in such a way that it can result in a worsening or improvement of gait.

### Treating CP in the Interdisciplinary Team

It is important that the interdisciplinary team consisting of physician, physiotherapist, gait instructor, occupational therapist, orthopaedic technician and biomechanic pursue the same treatment concept and work closely together [Doe, p.113ff.]. The first step of the treatment concept should be an immediate start of physiotherapy [Kra, p.188] which is carried out by gait instructors or therapists certified for gait analysis. The goal of treatment is to make the right cerebral connections using motor impulses [Hor, p.5-26] as well as to strengthen single muscle groups by specific muscle training. Both procedures bring the patient closer to a physiological gait. In some CP patients, drug therapy, as with spasmolytics such as botulinum toxin [Mol, p.363], and orthopaedic surgery to correct deformities [Gag2] are required along with physiotherapy.

The illustration shows the different physiological gait phases of a healthy person. These phases refer to the right leg (reference leg). This physiological gait pattern serves as an orientation for the interdisciplinary team in the treatment of CP patients and helps them to achieve the goal of treatment.

1	2	3	4	5	6	7	8	9	10
Description									
Initial contact	Loading response	Early mid stance	Mid stance	Late mid stance	Terminal stance	Pre swing	Initial swing	Mid swing	Terminal swing
Hip angle									
20° flexion	20° flexion	10° flexion	Neutral position	5° extension	20° extension	10° hyper- extension	15° flexion	25° flexion	20° flexion
Knee angle									
5° flexion	15° flexion	10° flexion	5° flexion	5° flexion	5° flexion	40° flexion	60° flexion	25° flexion	0° flexion
Ankle angle									
Neutral position	5° plantar flexion	Neutral position	5° dorsiflexion	5° dorsiflexion	10° dorsiflexion	15° plantar flexion	5° plantar flexion	Neutral position	Neutral position

# The Orthotic Treatment of CP

## Orthotic Requirements

Effective orthoses are essential to support physiotherapy as well as surgical treatment. In some cases, the orthotic fitting needs to be complemented by orthopaedic shoes or shoe modifications or adjustments [Gru, p.30]. Depending on the patient's pathological gait, the physician's requirements and the goal of physiotherapy, the orthopaedic technician must align the orthosis in such a way that it provides a required lever effect [Nov, p.488ff.; Owe1, p.262].

Additionally, the result of surgery should be sustained with an orthosis that affords correct alignment and an adjustable range of motion without interfering with physiotherapy. This is when the orthopaedic technician comes into conflict because, until now, it has been difficult in practice to produce an effective orthosis due to the lack of adjustment possibilities.

## Difficulties of the Current Orthotic Treatments

Depending on the severity and the characteristics of the clinical picture, the treatment of the CP patients can be performed with a multitude of appliances. They range from simple orthotic appliances such as supramalleolar orthoses (SMOs) or special orthopaedic inserts up to ankle foot orthoses (AFOs) with or without ankle joint. Since all currently available orthotic fittings have advantages and disadvantages, treating CP can have both positive and negative effects [Rom, p.473].

## "One orthosis may not be optimal to address all of the goals." [Nov1, p.330]

An easy and common way of treating CP patients are orthopaedic inserts with a sensomotoric insole. Such a sensomotoric insole can also be integrated into SMOs which are supramalleolar orthoses. SMOs slightly correct the foot position and activate the muscles. If the Achilles tendon area is not covered, they also possess dynamic features. In comparison to AFOs, however, they do not have a foot lifting effect.

AFOs are mostly produced without ankle joint. They are divided into dynamic AFOs (DAFOs) and solid/ static AFOs (SAFOs) [Nov, p.330ff.]. For example, DAFOs allow movement in the anatomical ankle joint, however, without a defined pivot point and a defined range of motion.



SAFOs made of polypropylene do not allow any movement in the ankle.

SAFO

DAFO

AFOs with ankle joint (hinged AFOs) are used less commonly although they allow movement in the anatomical ankle joint with defined pivot point and range of motion. But in most cases, hinged AFOs only possess elastomer spring joints or ordinary joints with coil springs. The weak or non existing spring effect of these joints as well as the non existing dorsal stop can lead to the development of crouch gait [Nov1, p.345]. Therefore, hinged AFOs are hardly used in the orthotic treatment of CP patients.

Hinged AFO

At present, AFOs with spring effect such as a posterior leaf spring AFO are used. However, they do not have a defined pivot point nor a defined or adjustable range of motion.

AFOs with a ventral shell are usually named Floor Reaction AFOs (FRAFOs). These orthoses can, for example, lock the movement in the anatomical pivot point and its rigid sole with flexible toe section can facilitate to *push off* the ground with the toes. Posterior leaf FRAFO spring AFO

Almost all of the listed AFOs limit the physiological plantar flexion and make it difficult to achieve the best possible compromise of foot lifting effect, energy storage for the *push off* and heel rocker [Owe2, p. 49]. In a qualified gait training or physiotherapy, the very important heel lever is used. Thus, the right cerebral connections are made using motor impulses [Hor, p.5-26] as well as single muscle groups are strengthened with specific muscle training. This results in a more physiological gait [Nol, p.659]. Additionally, all mentioned orthotic fittings cannot be optimally adjusted to the pathological gait of the patient and, therefore, reduce the effect of the orthosis.

### *New Orthotic Treatment Possibilities thanks to the Adjustable NEURO SWING System Ankle Joint*

A modern orthotic concept is expected to be optimally adjusted to the patient's needs. This is the only way to ensure the realisation of all goals required for an AFO in Novacheck [Nov1, p.330]. And that is exactly why the adjustable NEURO SWING system ankle joint has been developed.

Both dynamic and static AFOs should be produced with an adjustable ankle joint so that the pathological gait as well as the needed range of motion can be altered. It is necessary to adjust the orthosis to the gait pattern since the position of the patient's foot during plastering differs from the position when putting weight on the leg wearing the orthosis. The adjustable range of motion makes it possible to react easily to changes in the pathological gait that can occur during treatment.

# The NEURO SWING in a Dynamic AFO



# The NEURO SWING in a Dynamic AFO



To achieve the required goal of treatment, the interdisciplinary team needs the same basis to assess the different characteristics of CP. The basis can be created by grouping CP patients according to determined criteria, a so-called classification.

### Gross Motor Skills and Mobility

The Gross Motor Function Classification System (GMFCS) helps to assess gross motor skills of CP patients in activities of daily living and to make a prognosis of their further development [Rus]. Mainly, it is about the locomotion with regard to the required help and it classifies patients according to their age into five or six levels [Õun, p.151ff.]. The *Functional Mobility Scale* (FMS) divides CP patients into six groups, depending on the mobility. The appliances used for the locomotion and the distance covered with them are included in the assessment [Gra, p.515].

### Spasticity

For an optimal treatment, it can be important to know the severity of spasticity. The *Modified Ashworth Scale* (MAS) is the clinically most used scale. During slow passive movements of the affected joint, muscle tone can be examined. With the velocity dependent resistance, the examining person categorises the spasticity on a scale from 0 to 4 [Boh, p.207].

### Pathological Gait

In 2001, Rodda and Graham analysed and divided patients with spastic hemiplegia and diplegia into four gait types using video recording and taking account of gait pattern and posture [Rod, p.98ff.]. Currently, this classification is the clinically most used.

Next to this classification the Amsterdam Gait Classification was developed especially for CP patients at the VU University Medical Center in Amsterdam. It classifies five types of gait according to their knee position and foot-floor contact in *mid stance* (see illustration below). A description of the physiological *mid stance* is given on page 4 and 5. The Amsterdam Gait Classification is equally suitable for patients that are affected either unilateral or bilateral [Gru, p.30]. Therefore, it can be used optimally as classification for a standardised orthotic treatment.

The Amsterdam Gait Classification enables to quickly classify CP patients according to their gait pattern. This facilitates the interdisciplinary communication as well as the selection of the right treatment. Furthermore, it contributes to standardise orthotic treatments and control their quality.

The books of Perry and Götz-Neumann present an easy to understand overview about the clinical gait analysis [Per; Goe].

	TYPES OF GAIT AC	CORDING TO THE	AMSTERDAM GAI	T CLASSIFICATION	
TYPES OF GAIT	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5
KNEE	normal	hyperextended	hyperextended	flexed	flexed
FOOT CONTACT	complete	complete	incomplete	incomplete	complete
TREATMENT	see p. 14-15	see p. 16–17	see p. 18–19	see p. 20-21	see p. 22-23
GAIT PATTERN	see p. 24-25	see p. 26-27	see p. 28-29	see p. 30-31	see p. 32–33

Illustration of gait types in mid stance

## Pathological Gait

An insufficient m. tibialis anterior and a mostly shortened m. gastrocnemius are typical for gait type 1. This muscular deficiency causes a weakness of foot dorsiflexion which, in turn, causes an dysfunctional foot lift in swing phase. In *mid stance*, the foot is plantigrade and the knee in a physiological position.

For a detailed description of the pathological gait for this gait type see pages 24 and 25.



## **Recommended Orthosis**

Dynamic AFO with ventral shell, long and partially flexible foot piece (rigid sole with flexible toe section) and the NEURO SPRING system ankle joint.





## Present Orthotic Treatment Possibilities

Because of the small difference in comparison to the physiological gait, CP patients of this gait type have been treated almost only with simple appliances until now. This includes ankle-high shoes, supramalleolar orthoses (SMOs) or sensomotoric inserts [Gru, p.33; Nov1, p.331]. Nevertheless, the foot lifting effect of these appliances, which is only minimal, must be considered critically. Moreover, maintained physiological movements can be restricted.

## Effect of the Orthosis (see Illustration below)

- Initial contact and loading response: The integrated spring unit of the NEURO SPRING system ankle joint is strong enough to maintain the foot in neutral position during swing phase in order to ensure that the heel contacts the floor at first in *initial contact*. At the same time, this foot lifting function enables the physiological plantar flexion since it replaces the eccentric muscle work of the pretibial muscles and thus allows the heel rocker. From *initial contact* to *loading response*, the foot drops controlled against the spring force.
- Mid stance: The dorsal stop of the NEURO SPRING system ankle joint can be removed up to the desired range of motion to enable the physiological dorsiflexion.
- *Terminal stance*: If necessary, a knee extension moment can be achieved through the adjusted dorsal stop which makes it easier to lift the heel off the ground.
- Pre swing and mid swing: The dorsal spring unit gets the foot from pre swing to mid swing in neutral position. The CP patient can walk without stumbling and, therefore, trunk and hip are relieved.

Treatment supports and above mentioned orthotic appliances such as sensomotoric insoles can also be integrated in the recommended orthosis.



## Pathological Gait

An insufficient m. tibialis anterior and, additionally, a wrong activation of the m. triceps surae are typical for gait type 2. In *mid stance*, the foot is plantigrade and the knee remains hyperextended.

For a detailed description of the pathological gait for this gait type see pages 26 and 27.



## **Recommended Orthosis**

Dynamic AFO with high ventral shell, long and partially flexible foot piece (rigid sole with flexible toe section) and the NEURO SWING system ankle joint.

A ventral shell because: Please read the last passage on the next page.

Spring units to be used:

- Dorsal: yellow marked (very strong spring force, max. 10° range of motion)
- Ventral: green marked (medium spring force, max. 15° range of motion)

## Adjustment Possibilities of the NEURO SWING System Ankle Joint

Individual adjustment to the pathological gait by:

- Exchangeable spring units
- Adjustable alignment
- Adjustable range of motion

All three adjustments can be changed separately and do not influence each other.



Spring force

## Present Orthotic Treatment Possibilities

Until now, hinged AFOs have been used in the treatment of almost all CP patients of this gait type. Its design allows free dorsiflexion and locks plantar flexion. Therefore, the foot is kept in neutral position or in slight dorsiflexion and the physiological plantar flexion is restricted [Gru, p.33]. Between *initial contact* and *loading response*, an excessive torque is applied to the lower leg and transmitted to the knee. This leads to an increased demand on the m. quadriceps (e.g. walking with a ski boot) [Goe, p.134ff.; Per, p.195].

## Effect of the Orthosis (see Illustration below)

- Initial contact and loading response: The dorsal spring unit of the NEURO SWING system ankle joint is strong enough to maintain the foot in neutral position in order to ensure that the heel contacts the floor at first in *initial contact*. It enables a physiological plantar flexion since it allows the eccentric work of the pretibial muscles. Therefore, the heel rocker is actively supported and no excessive torque is applied to the lower leg. From *initial contact* to *loading response*, the foot drops controlled against the spring force. This physiological plantar flexion should prevent the early activation of the m. gastrocnemius. If the recommended, very strong spring unit (yellow marked) severely restricts the heel rocker, it must be exchanged for the medium spring unit (green marked).
- Mid stance: The dorsal spring unit in the NEURO SWING system ankle joint prevents the hyperextension of the knee.
- Terminal stance: The very strong dorsal spring unit can lead to a physiological lifting of the heel.
- Pre swing: The ventral spring unit gets the foot from pre swing to mid swing in neutral position. The CP patient can walk without stumbling and, therefore, trunk and hip are relieved.

An orthosis with high ventral shell can be produced in this case due to the very high spring forces of the applied spring units. Due to the ventral shell, the CP patient's initial reflex to support on the dorsal shell to achieve stability is changed. The CP patient now feels save when pressing the body weight with the tibia against the ventral shell. This prevents an increasing knee hyperextension and contractures in the anatomical ankle joint.



## Pathological Gait

An insufficient m. tibialis anterior and, additionally, a too early or too early and excessive activation of the m. triceps surae are typical for gait type 3.

In *mid stance*, the load remains on the forefoot and the foot is not plantigrade. The knee remains hyperextended.

For a detailed description of the pathological gait for this gait type see pages 28 and 29.



## **Recommended Orthosis**

Dynamic AFO with high ventral shell, long and partially flexible foot piece (rigid sole with flexible toe section) and the NEURO SWING system ankle joint.

A ventral shell because: Please read the last passage on the next page.

Spring units to be used:

- Dorsal: green marked (medium spring force, max. 15° range of motion)
- Ventral: yellow marked (very strong spring force, max. 10° range of motion)

## Adjustment Possibilities of the NEURO SWING System Ankle Joint

Individual adjustment to the pathological gait by:

- Exchangeable spring units
- Adjustable alignment
- Adjustable range of motion

All three adjustments can be changed separately and do not influence each other.



Spring force

## Present Orthotic Treatment Possibilities

Until now, SAFOs with dorsal shell have been used in the treatment of almost all CP patients of this gait type. The foot is kept in neutral position or in slight dorsiflexion [Gru, p.33]. But this rigid construction restricts the physiological plantar flexion. Between *initial contact* and *loading response*, an excessive torque is applied to the lower leg and transmitted to the knee. This leads to an increased demand on the m. quadriceps (e.g. walking with a ski boot) [Goe, p.134ff.; Per, p.195]. Additionally, due to the unfavourable construction with a dorsal shell, the CP patient's reflex to support the calf on the shell is enhanced in order to get stability in stance. This provokes the hyperextension of the knee.

## Effect of the Orthosis (see Illustration below)

- Initial contact and loading response: The dorsal spring unit of the NEURO SWING system ankle joint is strong enough to maintain the foot in neutral position in order to ensure that the heel contacts the floor at first in *initial contact*. It enables a physiological plantar flexion since it allows the eccentric muscle work of the pretibial muscles. Therefore, the heel rocker is actively supported and no excessive torque is applied to the lower leg. From *initial contact* to *loading response*, the foot drops controlled against the spring force. This physiological plantar flexion is to prevent the early activation of the m. gastrocnemius.
- Mid stance: The tibial progression causes the dorsiflexion in the ankle which, in turn, preloads the ventral spring unit.
- Terminal stance: The spring unit is preloaded up to the adjusted range of motion. The energy brought in by the body weight is stored in the ventral spring unit.
- Pre swing: From terminal stance to pre swing, the ventral spring unit releases the stored energy that assists the push off.

An orthosis with high ventral shell can be produced in this case due to the very high spring forces of the applied spring units. Due to the ventral shell, the CP patient's initial reflex to support on the dorsal shell to achieve stability is changed. The CP patient now feels save when pressing the body weight with the tibia against the ventral shell. In contrast to the dorsal shell, this prevents an increasing knee hyper-extension and contractures in the anatomical ankle joint.



## Pathological Gait

An excessive activation of the ischiocrural muscles accompanied by a wrong activation of the m. gastrocnemius or m. psoas major are typical for gait type 4.

In *mid stance*, the load remains on the forefoot and the foot is not plantigrade. Besides, the knee and hip flexion remain.

For a detailed description of the pathological gait for this gait type see pages 30 and 31.



## **Recommended Orthosis**

Dynamic AFO with high ventral shell, long and rigid foot piece and the NEURO SWING system ankle joint. Spring units to be used:

- Dorsal: blue marked (normal spring force, max. 15° range of motion)
- Ventral: yellow marked (very strong spring force, max. 10° range of motion)



## Adjustment Possibilities of the NEURO SWING System Ankle Joint

Individual adjustment to the pathological gait by:

- Exchangeable spring units
- Adjustable alignment
- Adjustable range of motion

All three adjustments can be changed separately and do not influence each other.



Spring force

## Present Orthotic Treatment Possibilities

Until now, SAFOs with dorsal shell and rigid sole have been used in the treatment of almost all CP patients of this gait type. The foot is kept in neutral position or in slight dorsiflexion. But this rigid construction restricts the physiological plantar flexion. Between *initial contact* and *loading response*, an excessive torque is applied to the lower leg and transmitted to the knee. This leads to an increased demand on the m. quadriceps (e.g. walking with a ski boot) [Goe, p.134ff.; Per, p.195].

## Effect of the Orthosis (see Illustration below)

- Initial contact and loading response: If the CP patient has no plantar flexion contracture, the dorsal spring unit of the NEURO SWING system ankle joint is strong enough to maintain the foot in neutral position in order to ensure that the heel contacts the floor at first in *initial contact*. It enables a physiological plantar flexion since it allows the eccentric muscle work of the pretibial muscles. Therefore, the heel rocker is actively supported and no excessive torque is applied to the lower leg. From *initial contact* to *loading response*, the foot drops controlled against the spring force. If the recommended, normal spring unit (blue marked) is too weak to maintain the foot in neutral position in *terminal swing* because of an existing plantar flexion contracture, it must be exchanged for the very strong spring unit (yellow marked).
- Mid stance: The ventral spring unit and the long and rigid foot piece as well as the ventral shell cause a knee extension moment that brings the patient into an upright position and thus improves the pathological gait. Furthermore, he gets stability in stance. If the very strong spring unit (yellow marked) is not strong enough, it can be exchanged for the extra strong spring unit (red marked).
- Terminal stance: From mid stance to terminal stance, the ventral spring unit is
  preloaded up to the adjusted range of motion and stores the energy brought in
  by the body weight.
- Pre swing: From terminal stance to pre swing, the ventral spring unit releases the stored energy that assists the push off. Due to the construction of the orthosis as well as to the support of the ventral spring unit, the CP patient has a low energy consumption when walking.



## Pathological Gait

An excessive activation of the ischiocrural muscles accompanied by an insufficient activation of the m. gastrocnemius or a wrong activation of the m. psoas major are typical for gait type 5.

This leads to an increased knee and hip flexion in *mid stance*. Furthermore, the foot is plantigrade.

For a detailed description of the pathological gait for this gait type see pages 32 and 33.



## **Recommended Orthosis**

Dynamic AFO with high ventral shell, long and rigid foot piece and the NEURO SWING system ankle joint. Spring units to be used:

- Dorsal: blue marked (normal spring force, max. 15° range of motion)
- Ventral: red marked (extra strong spring force, max. 5° range of motion)



## Adjustment Possibilities of the NEURO SWING System Ankle Joint

Individual adjustment to the pathological gait by:

- Exchangeable spring units
- Adjustable alignment
- Adjustable range of motion

All three adjustments can be changed separately and do not influence each other.



Spring force

## Present Orthotic Treatment Possibilities

Until now, FRAFOs with ventral shell and rigid sole have been used in the treatment of almost all CP patients of this gait type. The foot is kept in neutral position or in slight dorsiflexion. The ventral shell and the rigid sole are supposed to extend the knee in *mid stance*. But the construction of the orthosis restricts the physiological plantar flexion. Between *initial contact* and *loading response*, an excessive torque is applied to the lower leg and transmitted to the knee. This leads to an increased demand on the m. quadriceps (e.g. walking with a ski boot) [Goe, p.134ff.; Per, p.195].

## Effect of the Orthosis (see Illustration below)

- Initial contact and loading response: The defined pivot point and the adjustable range of motion enable a physiological plantar flexion since they allow the eccentric muscle work of the pretibial muscles. Therefore, the heel rocker is actively supported and no excessive torque is applied to the lower leg. The foot drops controlled against the force of the dorsal spring unit.
- Mid stance: The ventral spring unit and the long and rigid foot piece as well as the ventral shell cause a knee extension moment that brings the patient into an upright position and thus improves the pathological gait. This effect is only possible if the knee flexion is such that the load line does not run behind the anatomical pivot point. Furthermore, he gets stability in stance.
- *Terminal stance:* From *mid stance* to *terminal stance*, the ventral spring unit is preloaded up to the adjusted range of motion and stores the energy brought in by the body weight. The lever effect of the foot piece and the adjusted dorsal stop cause the heel rise in the right moment.
- Pre swing: From terminal stance to pre swing, the ventral spring unit releases the stored energy that assists the push off. Due to the construction of the orthosis as well as to the support of the spring units, the CP patient has a low energy consumption when walking.



An insufficient m. tibialis anterior and a mostly shortened m. gastrocnemius are typical for gait type 1. This muscular deficiency causes a weakness of foot dorsiflexion which, in turn, causes an dysfunctional foot lift in swing phase. In *mid stance*, the foot is plantigrade and the knee in a physiological position.



## Description of a Possible Manifestation of the Gait Phases

- Initial contact and loading response: Not the heel contacts the floor at first, but the forefoot. The increased knee flexion allows placing the foot without stumbling.
- Mid stance: The foot is plantigrade and the knee in a physiological position [Gru, p.31; Bec, p.5].
- Terminal stance: There is no difference to the physiological gait.
- Pre swing: The dorsiflexion is impaired and the foot only lifts off the ground after a slightly increased knee flexion.
- Initial swing: The push off is slightly delayed.
- Mid swing and terminal swing: The knee flexion is increased to enable the leg to swing freely.



An insufficient m. tibialis anterior and, additionally, a wrong activation of the m. triceps surae are typical for gait type 2. In *mid stance*, the foot is plantigrade and the knee remains hyperextended.



## Description of a Possible Manifestation of the Gait Phases

- Initial contact and loading response: Not the heel contacts the floor at first, but the forefoot. The produced lever effect causes a knee extension moment. Furthermore, in *initial contact*, the m. soleus that is wrongly timed activated pulls the knee backward. Both lead to a hyperextension of the knee and, therefore, to stability in stance.
- Mid stance: The foot is plantigrade and the knee is hyperextended [Gru, p.31; Bec, p.5].
- Terminal stance: The foot remains plantigrade and the knee hyperextended [Gru, p.31].
- *Pre swing:* The prolonged hyperextension of the knee causes a late heel rise.
- Initial swing: The push off is impaired and late.
- Mid swing and terminal swing: The insufficient m. tibialis anterior causes a plantar flexion in the ankle. The knee and hip flexion are increased to enable the leg to swing freely.



An insufficient m. tibialis anterior and, additionally, a too early or too early and excessive activation of the m. triceps surae are typical for gait type 3.

In *mid stance*, the load remains on the forefoot and the foot is not plantigrade. The knee remains hyperextended.



## Description of a Possible Manifestation of the Gait Phases

- Initial contact and loading response: Not the heel contacts the floor at first, but the forefoot. The CP patient's knee is hyperextended to get stability in stance. This occurs due to two mechanisms which are independent of each other. The resulting lever effect as well as the m. soleus that is wrongly timed activated cause a knee extension moment.
- Mid stance: The load remains on the forefoot and the foot is not plantigrade. The knee is hyperextended [Bec, p.146].
- Terminal stance and pre swing: An insufficient m. gastrocnemius can lead to a
  prolonged activation of the m. vastus lateralis. This can result in a continued
  knee hyperextension in these phases [Gru, p.31; Bec, p.146].
- Initial swing: The knee is only slightly flexed when the toes lift off the ground. The ankle remains in plantar flexion.
- Mid swing and terminal swing: The ankle remains in plantar flexion due to the insufficient m. tibialis anterior. The knee and hip flexion are increased to enable the leg to swing freely.

Additionally to the knee hyperextension, a rigid plantar flexion contracture can develop in the ankle since the CP patient is never in dorsiflexion. Both can change the pathological gait in such a way that the hyperextension develops into a knee flexion. In this case, the CP patient must be classified to gait type 4.



An excessive activation of the ischiocrural muscles accompanied by a wrong activation of the m. gastrocnemius or m. psoas major are typical for gait type 4.

In *mid stance*, the load remains on the forefoot and the foot is not plantigrade. Besides, the knee and hip flexion remain.



## Description of a Possible Manifestation of the Gait Phases

- Initial contact and loading response: The hip and knee flexion cause that the forefoot and not the heel contacts the floor at first.
- Mid stance: The load remains on the forefoot and the foot is not plantigrade. Besides, the knee and hip flexion remain.
- Terminal stance and pre swing: The knee cannot be fully extended.
- Initial swing: The knee is flexed when the toes lift off the ground. The insufficient
  m. tibialis anterior causes a plantar flexion in the ankle.
- *Mid swing* and *terminal swing*: The knee and hip flexion are increased to enable the leg to swing freely. The ankle remains in plantar flexion.

Since the CP patient has a high energy consumption when walking [Bre, p.102], a worsening of the pathological gait can be expected. The affected muscles can shorten and knee and hip flexion contractures can develop [Gru, p.31; Bec, p.146]. In case of a shortening of the m. gastrocnemius, a plantar flexion contracture can also develop. In order to correct contractures, the shortened muscles can be surgically lengthened [Nov3, p.445ff.] or treated with spasmolytics such as botulinum toxin [Mol, p.367]. These excessive corrections can change the pathological gait so much that the heel drops to the floor. In this case, the CP patient must be classified to gait type 5.



An excessive activation of the ischiocrural muscles accompanied by an insufficient activation of the m. gastrocnemius or a wrong activation of the m. psoas major are typical for gait type 5.

This leads to an increased knee and hip flexion in *mid stance*. The foot is plantigrade.



## Description of a Possible Manifestation of the Gait Phases

- Initial contact and loading response: The increased hip and knee flexion cause that the forefoot or the complete sole of the foot contacts the floor at first.
- Mid stance and terminal stance: The knee and hip flexion are strongly increasing. Furthermore, the foot is plantigrade.
- Pre swing: The existing excessive dorsiflexion leads to late or no heel rise.
- Initial swing: The heel rise is late.
- Mid swing and terminal swing: The knee and hip flexion are increased to enable the leg to swing freely. The step length is extremely shortened due to the prolonged knee and hip flexion and the late toe-off.

Because of the increased knee and hip flexion the CP patient has a high energy consumption when walking [Bre, p.102]. Knee and hip flexion can aggravate and may result in crouch gait with contractures. The m. gastrocnemius can be insufficient because of not enough ankle movement, excessive surgical lengthening of the Achilles tendon as well as paralysis due to illness or artificial paralysis. The artificial paralysis can be caused by too much use of botulinum toxin [Goe, p.136]. In case of an excessive lengthening, the CP patient does not always have the neurological control to use the new gained ankle movement [Per, p.194ff.].

In contrast to other gait types, a CP patient of this type has only slight prospect of recovery without a continuous and persistent therapy. If the interdisciplinary treatment concept should not lead to a considerable improvement, the CP patient can completely lose his walking ability in puberty [Gru, p.31; Bec, p.146].



### AFO

(Ankle Foot Orthosis): Lower leg orthosis.

#### Amsterdam Gait Classification

Evaluating † pathological gait patterns of CP patients according to 5 gait types by defining knee position and foot-floor contact in *mid stance*. The *Amsterdam Gait Classification* was developed at the VU University Medical Center in Amsterdam assisted by Prof Dr Jules Becher.

#### botulinum toxin

Trade name i.a. Botox<sup>®</sup>. Botulinum toxin is one of the most powerful neurotoxins known. The toxic proteins inhibit the signal transmission of the nerve cells to the muscle.

#### cerebral connection

(lat cerebrum = in the broad sense brain): The brain saves control programmes for complex movement patterns. Repetitions of physiological movement patterns lead to corrections of these in the brain. In turn, each environmental disturbance can result in a repeated programme disturbance and thus in a pathological movement pattern.

#### cerebral palsy

(CP): Disorder of the muscle tone and muscle coordination caused by disorder of the central nervous system before, during or after birth. Depending on the type of disorder, paralyses can occur as ↑ hemiplegia, ↑ diplegia or ↑ paraplegia. For many patients these paralyses can be associated with ↑ spasticity.

#### concentric

(lat con = with; centrum = centre): Moving towards a centre; having a common centre. Mechanical: Force starts right at the centre. Physiological: Concentric muscle work is the work done by a muscle when shortening.

#### contracture

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

#### crouch gait

Gait pattern with permanently flexed hips and knees.

### DAFO

(Dynamic Ankle Foot Orthosis): Dynamic lower leg orthosis.

The term DAFO is internationally used for SMOs as well as for partially flexible  $\uparrow$  polypropylene  $\uparrow$  AFOs. The present use of this term is ambiguous since also  $\uparrow$  AFOs with joint should be named  $\uparrow$  dynamic  $\uparrow$  AFOs.

### diplegia

(gre dis = twice, double; plege = stroke, paralysis): Bilateral paralysis; In diplegia, two parts of the body (e.g. both arms or both legs) are affected.

### disc spring

A conical shell which can be loaded along its axis either statically or dynamically. Either a single spring or a stack of springs can be used. A spring stack can consist of either single disc springs or parallel spring sets. The geometric form of the disc spring leads to a † concentric force absorption and therefore to an almost linear spring characteristic curve.

#### dorsal

(lat dorsum = back): Pertaining to the back or to any dorsum; e.g. for an  $\uparrow$  AFO this means the shell is on the calf.

#### dorsal stop

Constructional element of an orthosis which limits the degree of the † dorsiflexion. The dorsal stop activates the forefoot lever resulting in an increase of the area of support. Furthermore, the dorsal stop causes a knee extension moment and in *mid stance* a heel lift.

#### dorsiflexion

Foot lifting. Countermovement: Foot dropping († plantar flexion).

#### dynamic

(gre dynamikos = active, strong): Showing a movement, characterised by momentum and energy; i.e. a dynamic † AFO allows a defined movement in the anatomical ankle joint.

#### eccentric muscle work

(lat ex centro = outside the centre): Work the muscle does by actively extending and controlling a slowing down joint movement such as a person who lifts weight over the head and slowly lowers it.

#### extension

(lat extendere = to extend): Active or passive straightening of a joint. Straightening is the countermovement of bending († flexion) and characteristically increases the joint angle.

#### flexion

(lat flectere = to bend): Active or passive bending of a joint. Bending is the countermovement of straightening (†extension) and characteristically reduces the joint angle.



### FRAFO

(Floor Reaction AFO): Solid orthosis with tventral shell which provides a knee or hip extension moment from *terminal stance*. FRAFOs can be made of toplypropylene as well as carbon fibre and they either have a rigid or a partially flexible foot piece. However, the name FRAFO is misleading since there are other AFOs which also interact with the topcound reaction force.

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#### ground reaction force

(GRF): A force exerted by the ground in response to the forces a body exerts on it.

#### heel lever

Is a lever whose pivot point is the point of heel strike and whose lever arm is the distance of this point to the pivot point of the anatomical ankle joint. In *initial contact*, the pround reaction force which moves proves form the ankle causes a rotation around the point of heel strike.

#### heel rocker

Means the whole rotation of the foot around the point of heel strike and in the anatomical ankle joint between *initial contact* and *loading response*:

From terminal swing to initial contact the swing leg drops to the ground from a height of about 1cm. The†ground reaction force starts at the†point of heel strike and its force vector (broken line) moves dorsal from the ankle. With the resulting†heel rocker a plantar flexion moment is created in the ankle which drops the foot. The†m. tibialis anterior works†eccentrically against this movement, thus allowing a controlled foot dropping.

#### hemiplegia

(gre hemi = half; plege = stroke, paralysis): Unilateral paralysis. A hemiplegia is the paralysis on one full side of the body.

#### hinged AFO

The classic hinged  $\uparrow$  AFO is an orthosis with dorsal shell made of  $\uparrow$  polypropylene with an elastomer spring joint or a simple coil spring joint. Hinged  $\uparrow$  AFOs allow a  $\uparrow$  dorsiflexion in the anatomical ankle joint. The elastomer spring joints are mostly not strong enough to allow  $\uparrow$  plantar flexion and, at the same time, keep the foot in  $\uparrow$  neutral position during swing phase. That is why the  $\uparrow$  plantar flexion in hinged  $\uparrow$  AFOs is locked in such cases.

#### insufficiency

The condition of being insufficient or inadequate to the performance of the allotted function.

#### interdisciplinary

(lat inter = between two or more): The cooperation between various disciplines.

#### ischiocrural muscles (1)

(hamstrings): Are on the back of the thigh; cause  $\uparrow$  extension in the hip and  $\uparrow$  flexion in the knee.

### m. gastrocnemius (2)

Musculus gastrocnemius: Two-headed calf muscle that causes  $\uparrow$  plantar flexion of the foot. Part of the  $\uparrow$ m. triceps surae.

#### m. psoas major (3)

Musculus psoas major: "Greater lumbar muscle" starting in lumbar vertebra, internal hip muscle that flexes thigh and rotates outwards.

Musculus quadriceps femoris: Four-headed muscle of the femur. Mainly causes † extension of the leg upon the thigh.

#### m. soleus (5)

Musculus soleus: Lower leg muscle, its tendon and the one of the † m. gastrocnemius form together the Achilles tendon. It causes † plantar flexion of the foot. Part of the † m. triceps surae.

#### m. tibialis anterior (6)

Musculus tibialis anterior: Anterior tibial muscle, from tibia to medial foot edge pulling muscle that causes torsiflexion of the foot.

#### m. triceps surae (2 and 5)

Musculus triceps surae: Three-headed calf muscle, the  $\uparrow$  m. gastrocnemius and the  $\uparrow$  m. soleus considered together.

#### m. vastus lateralis (4a)

Musculus vastus lateralis: Lateral aspect of femur,

from back of the thigh to the patella pulling part of the  $\uparrow$  m. quadriceps. Takes part of the  $\uparrow$  extension of the leg upon the thigh.

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#### muscular atrophy

(gre atrophia = emaciation): Visible volume loss of a skeletal muscle due to reduced demand.

#### neutral position

A person is in normal upright body position. In neutral position, the joint's range of motion can be determined.

#### paraplegia

(gre para = at, beside; plege = stroke, paralysis): Complete paralysis of two symmetrical extremities.

#### pathological

(gre path = pain; disease): Altered by disease.

#### physiological

(gre physis = nature; logos = science): Pertaining to natural life processes.

#### plantar

(lat planta = sole of the foot): Pertaining to the sole of the foot.

plantar flexion Foot dropping. Countermovement: Foot lifting (†dorsiflexion).

#### point of heel strike

Point where the heel contacts the floor at first in inital contact.

#### polypropylene

(PP): Group of thermoformable and weldable plastics. Is often used for the production of simple orthoses. Economical manufacturing technique. The considerably higher weight is a disadvantage against the materials of high quality at same rigidity.

#### posterior leaf spring AFO

(lat posterior = back): Lower leg orthosis with leaf spring attached behind the Achilles tendon, mostly made of carbon fibre.

#### pretibial

(lat prae = before; tibia = shin bone): Situated before the tibia.

#### push off

Rapid toe-off in pre swing assists the ankle's push off and advances the leg into swing.

#### rockers

Rotations around three different points of the foot in stance phase. 1st rocker (*heel rocker*) = rotation of the foot around the heel and of the lower leg around the anatomical ankle joint during *initial contact* and *loading response*, 2nd rocker (*ankle rocker*) = rotation of the lower leg around the ankle in *mid stance*, 3rd rocker (*toe rocker*) = rotation of the hindfoot around the heads of the metatarsal bones in *ter-minal stance*, 4th rocker = combined rotation around ankle and heads of the metatarsal bones in *pre swing*.



#### SAFO

(Solid Ankle Foot Orthosis): Rigid lower leg orthosis.

The term SAFO is internationally used for rigid  $\uparrow$  AFOs made of  $\uparrow$  polypropylene. The present use of this term is ambiguous since also static  $\uparrow$  AFOs are rigid.

#### sensomotoric

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. Sensomotoric elements can be produced, for instance, as inserts or also be integrated in † SMOs as insoles.

#### SM0

(supramalleolar orthosis): Supramalleolar orthoses made of reinforced leather or † polypropylene. If the Achilles tendon area is not covered, movement in the anatomical ankle joint is possible. That is why SMOs can possess † dynamic properties. If the Achilles tendon is covered, the † plantar flexion is limited.

#### spasmolytic

(gre spasmos = spasm): Relaxant drug. It decreases the tone of the smooth muscles or reduces muscle tension.

#### spasticity

(gre spasmos = spasm): Increase in tension of the skeletal muscle that leads to typical abnormal posture. It is always caused by a damage to the brain or spinal cord.

#### static

(gre statikos = standing, doing standing up): Pertaining to the balance of power and statics, being in balance and idle state, stagnant; i.e. a static<sup>†</sup>AFO allows no movement in the anatomical ankle joint.

#### tibial progression

(lat procedere = proceed, increase): Movement of the tibia (shin bone) in direction of motion around the anatomical ankle joint in *mid stance*. Also known as *ankle rocker*(†rockers).

#### ventral

(lat venter = belly, body): Denoting a position toward the belly surface, abdominal; e.g. for an † AFO this means the shell is on the front side of the lower leg.

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Notes



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