Distal Rectus Femoris Tendon Transfer for the Correction of Stiff-Knee Gait in Cerebral Palsy

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Introduction

Distal rectus femoris tendon transfer is the standard surgical procedure for the treatment of stiff-knee gait in patients with cerebral palsy and is commonly performed during single-event multilevel surgery. Stiff-knee gait is characterized by decreased knee flexion during swing phase leading to foot clearance problems as well as reduced gait velocity and step length and is often accompanied by tripping and falling^{1,2}. This gait disorder is commonly exhibited by patients with cerebral palsy³. The primary cause of stiff-knee gait is presumed to be spasticity of the rectus femoris muscle⁴⁻⁷, which acts differently compared with the vasti⁸. Under physiologic conditions, there is a constant interaction between the knee flexors and the rectus femoris at the end of stance phase and at the beginning of swing phase, where the rectus femoris controls knee flexion with eccentric contraction to avoid excessive knee flexion (Fig. 1). Patients with cerebral palsy often have difficulty controlling biarticular muscles⁹. As a result of a pathological activation of the rectus femoris muscle as a reflex of stretch, its overactivity during swing phase counteracts the knee flexion that is necessary for foot clearance⁴⁻⁷. During clinical examination, overactivity or shortness of the rectus femoris can be identified by using the prone Duncan-Ely test (Fig. 2)¹⁰.

Different definitions of stiff-knee gait based on clinical and gait analysis findings have been reported. Sutherland et al. described stiff-knee gait as delayed and decreased peak knee flexion in swing phase with diminished total knee motion². Rodda et al. classified it as decreased knee excursion throughout the whole gait cycle of $<30^{\circ}$ ¹¹, whereas Ounpuu et al. defined stiff-knee gait as a limitation in knee motion of $>20^{\circ}$ ^{12,13}.

In 1975, Sutherland et al. reported an improvement in knee flexion following distal rectus

femoris release surgery⁴. However, in 1987, Perry⁶ and Gage et al.⁷ recommended, for the first time, a transfer of the distal rectus femoris tendon instead of a simple release and reported good results. Three years later, these results were corroborated by the findings of Sutherland et al., who compared the outcomes of release with those of distal rectus femoris transfer and found that the transfer yielded superior outcomes². Since then, distal rectus femoris transfer has been accepted as the standard surgical procedure for the treatment of stiff-knee gait in children with cerebral palsy. The transferred tendon can be anchored either to the tendons of the medial or lateral hamstrings or to the sartorius muscle or the iliotibial tract, with the goal of improving knee motion and peak knee flexion in swing phase for foot clearance.

The operation is performed in five steps:

Step 1: Positioning and approach

Step 2: Preparation of the rectus femoris tendon

Step 3: Preparation of the gracilis or semitendinosus tendon for transfer

Step 4: Transferring the gracilis tendon to the rectus femoris tendon

Step 5: Tendon tensioning and suturing

Step 1: Positioning and Approach

With the patient supine, make a 3 to 4-cm longitudinal incision 2 to 3 cm above the patellar proximal pole.

- Position the patient supine. After preparing the patient, drape the pelvis and the legs free. Concomitant procedures on the hip or pelvis should be considered when draping.
- Position the knee in slight flexion (20° to 30°) with a roll placed under the popliteal region.

- Do not use a tourniquet as it compresses the quadriceps femoris and complicates the rectus femoris preparation and the balancing of the transfer.
- After palpation of the patella, make a 3 to 4-cm longitudinal incision directly anterior at the distal part of the thigh 2 to 3 cm above the proximal pole of the patella (Fig. 3).

Step 2: Preparation of the Rectus Femoris Tendon

Separate the rectus femoris tendon from the vasti; avoid releasing the entire quadriceps at all cost.

- Dissect the subcutaneous fat, and tag the fascia lata with two number-2-0 Vicryl (polyglactin 910) sutures (Figs. 4-A and 4-B).
- Incise the fascia between the two sutures; this can be used to reconstruct the fascia properly after transfer. This is important to avoid scar tissue between the rectus, the skin, and the vasti at the resection site.
- Beneath the fascia, expose the rectus femoris from proximal to distal and meticulously separate this tendon from the underlying quadriceps with scissors and a curved clamp (Fig. 5-A). This step is very important because of the danger of including the entire quadriceps femoris tendon. This should be avoided at all costs to preserve the quadriceps for knee extension.
- Place one or two anchoring sutures (number-1 Vicryl) in the rectus femoris tendon (Fig. 5-B) and then carefully release the tendon distally with a new scalpel (Fig. 6), without injuring the underlying quadriceps tendon.
- After the release, the palpating finger should slip smoothly between the rectus femoris and the underlying vastus intermedius, indicating the correct layer (Figs. 7-A and 7-B).
- Free the tendon manually and, with the use of scissors, from the encompassing tissue as high above as possible to create a straight course of the transferred tendon and muscle (Fig. 8-A). During this step, it is very important to dissect the medial fascia lata high enough to avoid a later angular deviation of the transferred rectus femoris tendon at the incision site (Fig. 8-B). Pay attention to crossing vessels that might be injured when the scissors slide proximally between the rectus femoris tendon and its adhesions to the vastus medialis and lateralis.
- Prepare the rectus femoris tendon for transfer. To check if just the rectus femoris tendon was

released, inspect the undersurface of the released tendon (Fig. 8-C).

Step 3: Preparation of the Gracilis or Semitendinosus Tendon for Transfer

Isolate the gracilis tendon proximally, release it from its muscle belly, and pull it out distally through a small incision at the pes anserinus insertion.

- The leg is now held by the assistant, with the hip abducted and flexed and the knee in slight-to-moderate extension. Extension of the knee while the hip is abducted tightens the gracilis and semitendinosus tendons, which can be easily palpated.
- Make another longitudinal incision at the middle third of the thigh dorsomedially over the palpable gracilis tendon. Be careful to avoid the saphenous vein and nerve (Fig. 9).
- Dissect the subcutaneous tissue and open the fascia longitudinally with a knife and scissors.
- The gracilis muscle belly can now be easily bluntly dissected by the palpating finger and exposed and undermined with a clamp (Fig. 10).
- With this clamp, pull a moist gauze pad through, under the muscle belly. In the next step, explore the intramuscular tendon of the gracilis and separate the tendon from the underlying muscle (Figs. 11-A and 11-B). Technical note: careful pulling of the moist sponge rotates the muscle belly and the intramuscular tendon pathway can be identified more easily.
- Follow the tendon as proximally as possible to obtain an adequate tendon length for the transfer (Fig. 12).
- Carefully check the tendon with regard to its size. In rare cases, the tendon may be very thin and the semitendinosus should be used for the transfer instead of the gracilis. Use the same approach and technique regardless of which tendon is used for transfer.
- Place anchoring sutures (number-1 Vicryl) in the gracilis tendon as proximally as possible (Fig. 13). Technical note: the level of the sutures determines the length of the distal gracilis tendon that will be used for the transfer. An adequate length should be gained by extending the knee.
- Release the gracilis tendon proximal to the sutures. Then flex the knee fully and sharply dissect the gracilis tendon from the remaining muscle belly as distally as possible (Figs. 14-A and 14-B). With the knee still in a flexed posi-

tion and with the assistant holding the tagging sutures of the gracilis tendon under tension, palpate the distal part of the tendon in the pes anserinus insertion.

- Make a mini-incision over the palpable tendon (Fig. 15) and dissect the tendon sheath.
- Use a clamp to expose the distal part of the gracilis or semitendinosus tendon (Fig. 16-A). Again, place a wet sponge underneath the tendon (Fig. 16-B).
- Deliver the gracilis tendon into the distal wound by pulling the sponge (Figs. 16-B and 16-C). Technical note: if this cannot be performed easily, the tendon should be further released from the muscle belly and any remaining adhesions proximally must be divided. Maximum knee flexion allows the preparation to be done as distally as possible.
- Check the tendon carefully for its length (the released rectus femoris tendon should be reachable) and for its size. If the tendon is too thin or too short, the semitendinosus tendon can be harvested instead by using the same technique.
- Note that an increased anterior pelvic tilt may result after semitendinosus resection for distal rectus femoris transfer. This should be considered during preoperative planning.

Alternative Technique for Gracilis or Semitendinosus Harvesting

- Alternatively, the gracilis or semitendinosus tendon may be harvested through a minimally invasive approach from the pes anserinus with use of a tendon harvest instrument.
- Through a small incision over the pes anserinus, identify the gracilis tendon by extending the flexed knee with the hip in maximum abduction and slight flexion.
- Incise the tendon sheath, and use the tendon harvest instrument according to the usual technique (Figs. 17-A through 17-D).
- Tag the harvested tendon with a number-1 Vicryl suture.
- With use of this technique, the tendon can be harvested very easily and quickly. However, we prefer the open technique for several reasons. First, the length of the harvested tendon is difficult to control. Furthermore, the size of the proximal part of the tendon cannot be estimated through the distal mini-incision. Especially in younger children, the distal tendon may be thick but rapidly spread into weak intramuscular bundles proximally. Another important argument for preferring the open technique is that intramuscular medial ham-

string lengthening, if needed, can be done through the same incision.

Step 4: Transferring the Gracilis Tendon to the Rectus Femoris Tendon

Insert a long tendon passer above the fascia and beneath the sartorius muscle belly from anterior to posterior to the mini-incision in the pes anserinus region to grasp and transfer the gracilis tendon to the anterior approach.

- Through the initial anterior approach, prepare the rectus femoris tendon transfer pathway by medial epifascial tunneling and preparation toward the approach in the popliteal fossa.
- For the tendon transfer, insert a long tendon passer above the fascia and beneath the sartorius muscle belly to avoid anterior subluxation of the transfer to the mini-incision in the pes anserinus region and spread it (Figs. 18-A and 18-B).
- Grasp the tagging sutures of the released gracilis tendon and pull the gracilis tendon behind the knee axis of rotation to the anterior approach (Fig. 18-C).

Step 5: Tendon Tensioning and Suturing

Weave the gracilis tendon into the released rectus femoris tendon with the interlacing technique described by Pulvertaft.

- To complete the transfer, position the leg in 20° to 30° of knee flexion over a roll.
- With a special sharp-tipped Pulvertaft¹⁴ clamp, interweave the gracilis tendon into the released rectus femoris tendon with the interlacing technique described by Pulvertaft¹⁴ under moderate tension (Figs. 19-A and 19-B) using number-1 Vicryl suture.

Facultative Medial Hamstring Intramuscular Lengthening

- If indicated, medial hamstring intramuscular lengthening of the semimembranosus and/or the semitendinosus muscle may be performed through the same posteromedial approach at the middle of the thigh.
- Incise the corresponding tendon sheath longitudinally. Intramuscular tendon transection (semitendinosus) or aponeurotic (semimem-

branosus) lengthening may be carried out at one or two levels.

Alternative Transfer

- Alternatively, the rectus femoris tendon may be transferred laterally to the iliotibial band or the biceps femoris tendon (Fig. 20). This technique is considered for patients in whom medial hamstring lengthening and especially tenotomy were carried out previously.
- Dissect the iliotibial tract through a separate lateral incision over the biceps femoris tendon.
- Create a tunnel by incising the lateral intermuscular septum with scissors.
- Pull the rectus femoris tendon laterally and fix it with interweaving sutures.

Results

Various studies have demonstrated good initial functional results, with an improvement in peak knee flexion in swing phase and overall knee motion in swing phase, following distal rectus femoris tendon transfer¹⁵⁻¹⁷. Nevertheless, some authors have suggested that distal rectus femoris tendon transfer does not generate a knee flexion moment, although the capacity of knee extension is diminished by the intervention¹⁸⁻²⁰. Some authors did not find a significant increase in peak knee flexion in swing phase but reported an increase in the total range of knee motion^{12,21-23}. Hence, the results after distal rectus femoris tendon transfer have been relatively inconsistent, which might be attributed to different surgical techniques. It is debatable if patients with severe flexed-knee gait who show highly increased knee flexion throughout stance and a normal or even increased peak knee flexion in swing phase should receive a “prophylactic” distal rectus femoris tendon transfer to preserve peak knee flexion in swing phase after correction of a knee flexion contracture with concomitant procedures such as hamstring lengthening or distal femoral extension osteotomy.

Only a few studies have addressed the longer-term outcomes of distal rectus femoris tendon transfer. Saw et al. showed maintenance of the improvement in peak knee flexion in swing phase but a decrease in the initial improvement in the range of knee flexion in swing phase associated with a loss of knee extension during stance phase 4.6 years after distal rectus femoris tendon transfer¹⁵. Moreau et al. found continuing benefit after a period of three years¹⁶.

We reported the long-term outcomes (at a mean of nine years) in a series of fifty-three diplegic patients in whom 106 distal rectus femoris transfers had been done as a part of multilevel surgery²⁴. Distal rectus femoris tendon transfer led to long-lasting improvements in peak knee flexion in swing phase and time of peak knee flexion in swing phase in patients who had had decreased peak knee flexion in swing phase preoperatively. The patients with more extensive involvement showed a greater potential to benefit from distal rectus femoris transfer in our study; a benefit with respect to peak knee flexion in swing phase cannot be expected when the preoperative peak knee flexion in swing was already $>53^\circ$ before surgery²⁴. This finding is in agreement with those in the long-term study by Thawrani et al., who concluded that patients with low peak knee flexion in swing had the greatest improvement²⁵. According to the results of these two long-term studies, distal rectus femoris tendon transfer as a part of multilevel surgery has the potential to counteract the natural deterioration of knee function in patients with spastic diplegia and selectively improves stiff-knee gait. However, because 18% of the patients in our study showed a permanently poor response, it appears that distal rectus femoris tendon transfer has no influence in some patients. Thus, different influencing mechanisms responsible for recurrence, which was found in 15% of our patients²⁴, should be discussed. Patients with severe knee flexion who were treated with prophylactic distal rectus femoris tendon transfer had a significant loss of peak knee flexion in swing phase.

In a randomized clinical trial, in which one group of patients with cerebral palsy was treated with rectus femoris transfer as part of multilevel surgery and another group did not receive the transfer, the increase in knee motion during swing and in knee flexion velocity was significantly higher in the transfer group²⁶. Peak knee flexion in swing phase was preserved in the transfer group and decreased significantly in the group without the transfer. These results underline the potential of distal rectus femoris transfer to correct stiff-knee gait. Furthermore, subgroup analysis showed that patients with decreased peak knee flexion in swing preoperatively (Figs. 21-A and 21-B) benefited most from the transfer, whereas patients with severe flexed-knee gait who had normal or increased peak knee flexion in swing phase (Figs. 22-A and 22-B) did not benefit. Since distal rectus femoris transfer weakens knee extensor power, it is not recommended as a “prophylactic” procedure for these patients, for whom improvement of knee extension is the primary concern. If stiff-knee gait occurs after the improvement of stance-phase extension, distal rectus femoris tendon transfer may still be done as a secondary procedure during implant removal.

What to Watch For

Indications

The criteria for the performance of a distal rectus femoris tendon transfer are inconsistent in the literature^{1,2,6,12,15-18}. Most authors consider distal rectus femoris tendon transfer for patients with (1) a positive Duncan-Ely-sign¹⁰, (2) a decrease in knee motion of $>15^\circ$ during swing phase, and (3) continuous activation of the rectus femoris muscle during swing shown by dynamic electromyography¹. On the basis of the findings of the recent studies, the indications for distal rectus femoris tendon transfer can be redefined as follows:

- Clinical indications
 - Children with cerebral palsy and symptomatic stiff-knee gait (impaired swing phase, tripping, falling, and increased anterior shoe wear) are potential candidates for this procedure.
- Kinematic indications (Figs. 21-A and 21-B)
 - Decreased peak knee flexion in swing phase ($<52^\circ$)²⁴.
 - A decrease in the range of knee flexion of $>15^\circ$ in swing phase.
 - Decreased knee flexion velocity with a plateau-like increase in knee flexion.
 - Delayed peak knee flexion in swing phase.
- Relative indications
 - Positive Duncan-Ely sign.
 - Pathological rectus femoris electromyographic activity at stance-swing transition and during swing phase.

Contraindications

- Severe flexed-knee gait ($>35^\circ$ in stance phase) with normal or increased peak knee flexion in swing²⁶ (Figs. 22-A and 22-B).
- Jump-knee gait (Fig. 23) with normal or increased peak knee flexion in swing.
- Quadriceps weakness (<4 according to the Medical Research Council [MRC] scale²⁷) and a negative Duncan-Ely sign²⁸.

Pitfalls & Challenges

- Identification of the rectus femoris tendon and separation from the underlying quadriceps tendon is essential. Releasing the whole quadriceps tendon during the first step is a cardinal mistake with possible knee extensor weakness as a consequence.

- It is important to release the rectus femoris tendon from the underlying quadriceps tendon as proximally as possible and to split the fascia medially as proximally as possible to avoid kinking of the transfer at the transfer site.
- Avoid a subcutaneous route anterior to the sartorius muscle for the transfer to prevent anterior subluxation of the transferred tendon.
- Do not underestimate the length of the gracilis or semitendinosus tendon used for the transfer. Adequate planning of the approach location at the medial aspect of the thigh is essential.
- Avoid the femoral vessels underlying the medial hamstrings at the medial thigh approach.
- Avoid excessive tightening of the transfer during suturing as this might lead to a knee flexion contracture.
- In patients with flexed-knee gait in stance phase and decreased peak knee flexion in swing phase with patella alta and knee flexion contracture, distal rectus femoris tendon transfer may be carried out in combination with patellar advancement and distal femoral extension osteotomy.

Clinical Comments

- In patients with decreased and delayed peak knee flexion in swing and a reduced knee flexion range in swing and decreased knee flexion velocity, distal rectus femoris tendon transfer leads to significant improvements in stiff-knee gait that generally are long-lasting.
- Patients with severe flexed-knee gait who have normal or increased peak knee flexion in swing obtain little benefit from distal rectus femoris tendon transfer. Since distal rectus femoris transfer further weakens knee extensor power, it is not recommended as a "prophylactic" procedure for these patients, for whom improvement of knee extension is the primary concern. If stiff-knee gait occurs after the improvement of stance-phase extension, distal rectus femoris tendon transfer may still be done as a secondary procedure during implant removal.

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Figures

Fig. 1

The normal functional interaction between the rectus femoris muscle and the hamstrings during gait. There is an eccentric contraction (stretching) of the rectus femoris muscle at the stance-swing phase transition to avoid excessive knee flexion. At the end of swing phase, the rectus femoris muscle is contracted concentrically while the hamstrings are contracted eccentrically. In patients with cerebral palsy, this rapid change in muscular function is impaired. (Reproduced, with permission of Springer Science+Business Media, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol*. 1999;11[3]:213-22.)

Fig. 2

The Duncan-Ely test¹⁰. The patient is placed prone on the examination table. Passive knee flexion will activate an increased stretch reflex in the rectus femoris muscle, leading to anterior pelvic tilt and therefore pelvic rise. (Reproduced, with permission of Springer Science+Business Media, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol*. 1999;11[3]:213-22.)

Fig. 3

The surgical approach (2 cm in length) for preparation of the rectus femoris tendon, which should be done 2 to 3 cm above the proximal patellar pole. The vertical pink line indicates the later incision of the fascia lata. The black horizontal lines represent the threads for tagging of the fascia lata. (Reproduced, with permission of Springer Science+Business Media, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol*. 1999;11[3]:213-22.)

Fig. 4-A

Illustration showing exposure of the fascia lata and tagging with two number-2-0 Vicryl sutures. This enables later reconstruction. The pink line indicates the resection line of the rectus femoris tendon. (Reproduced, with permission of Springer Science+Business Media, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol*. 1999;11[3]:213-22.)

Fig. 4-B

Photograph showing exposure and tagging of the fascia lata as illustrated in Fig. 4-A.

Fig. 5-A

The rectus femoris tendon is separated from the underlying quadriceps tendon with a clamp. It is important to ensure that only the rectus femoris tendon is released and that the rest of the quadriceps tendon is preserved.

Fig. 5-B

Two anchoring sutures (number-1 Vicryl) are placed in the rectus femoris tendon. The pink line indicates the later resection line for rectus femoris release. (Reproduced, with modification, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol.* 1999;11[3]:213-22. Reproduced with permission of Springer Science+Business Media.)

Fig. 6

The tagged rectus femoris tendon is released as distally as possible without injuring the underlying quadriceps tendon.

Fig. 7-A

Illustration showing the rectus femoris muscle carefully mobilized from the underlying quadriceps by digital preparation. The palpating finger slips smoothly between the rectus femoris muscle and the underlying quadriceps. The pink line indicates the later resection line for the rectus femoris release. (Reproduced, with permission of Springer Science+Business Media, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol.* 1999;11[3]:213-22.)

Fig. 7-B

Photograph showing the rectus femoris muscle mobilized from the underlying quadriceps, as illustrated in Fig. 7-A.

Fig. 8-A

The rectus femoris tendon is freed from the encompassing tissue with use of the scissors.

Fig. 8-B

It is very important to dissect the medial fascia lata enough to avoid a later angular deviation of the transferred rectus femoris tendon at the incision site.

Fig. 8-C

The released rectus femoris tendon undersurface is shown. It is important to check if just the rectus femoris tendon was released. At the undersurface, the rectus femoris tendon is normally covered by a thin sheath, indicating that this is the correct layer.

Fig. 9

The anatomy of the medial aspect of the thigh. Anatomical structures should be considered when performing the medial approach for the preparation of the gracilis or semitendinosus tendon. (Reproduced, with modification, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol.* 1999;11[3]:213-22. Reproduced with permission of Springer Science+Business Media.)

Fig. 10

After incision of the fascia, the gracilis muscle belly can be exposed by the use of one finger or with a clamp.

Fig. 11-A

Illustration showing how the intramuscular tendon of the gracilis is explored and separated from the underlying muscle belly with use of scissors. (Reproduced, with permission of Springer Science+Business Media, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. Oper Orthop Traumatol. 1999;11[3]:213-22.)

Fig. 11-B

Photograph showing exploration and separation of the intramuscular tendon of the gracilis, as illustrated in Fig. 11-A.

Fig. 12

The tendon is then followed as proximally as possible to obtain an adequate tendon length for the transfer.

Fig. 13

After separation of the tendon from its muscle belly, anchoring sutures (number-1 Vicryl) are placed in the tendon as proximally as possible. (Reproduced, with modification, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. Oper Orthop Traumatol. 1999;11[3]:213-22. Reproduced with permission of Springer Science+Business Media.)

Fig. 14-A

After the gracilis tendon is released proximally to the tagging suture, the knee is fully flexed and the gracilis tendon is separated from the muscle belly as distally as possible.

Fig. 14-B

The tendon is freed from all remaining muscle tissue in order to guarantee a smooth transfer.

Fig. 15

The mini-incision for pulling out the gracilis tendon is made 1 to 2 cm above the pes anserinus (pink line). The gracilis tendon can be identified during palpation of the distal part of the tendon at the pes anserinus while the assistant tensions the gracilis by pulling at the tagging sutures proximally. (Reproduced, with modification, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. Oper Orthop Traumatol. 1999;11[3]:213-22. Reproduced with permission of Springer Science+Business Media.)

Fig. 16-A

After the incision, the tendon sheath of the gracilis tendon is opened and the gracilis tendon is exposed with a clamp.

Fig. 16-B

Illustration showing how the gracilis tendon is pulled out with use of a moist sponge. (Reproduced, with permission of Springer Science+Business Media, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. Oper Orthop Traumatol. 1999;11[3]:213-22.)

Fig. 16-C

Photograph showing the gracilis tendon pulled out with a moist sponge, as illustrated in Fig. 16-B. Again, the surgeon should check if the tendon is long enough for the transfer.

Fig. 17-A

Through a distal medial incision above the palpable gracilis tendon, a small incision (standard approach for distal z-lengthening or sliding of medial hamstrings) is made and the tendon sheath of the gracilis tendon is opened to expose the tendon.

Fig. 17-B

A tendon harvest instrument is used, and the tendon is merged.

Fig. 17-C

The tendon harvester is then driven proximally by palpating with the other hand.

Fig. 17-D

A cutting mechanism is used, and the tendon is pulled out distally afterward. (Figs. 17-A through 17-D show the standard technique for gracilis harvesting used by Dr. Walter Strobl, pediatric neuro-orthopaedic surgeon from the Paediatric Orthopaedic Hospital Speising in Vienna, Austria.)

Fig. 18-A

Through the initial anterior approach, the transfer path is prepared by medial epifascial tunneling toward the approach in the popliteal fossa. For the tendon transfer, a long clamp is then inserted above the fascia and below the sartorius muscle belly to the mini-incision in the popliteal fossa. (For the reason of simplification in visualization, the rest of the quadriceps is not shown.) (Reproduced, with modification, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol.* 1999;11[3]:213-22. Reproduced with permission of Springer Science+Business Media.)

Fig. 18-B

Photograph showing the technique illustrated in Fig. 18-A.

Fig. 18-C

The tagging sutures of the released gracilis tendon are grasped, and the gracilis tendon is then transferred behind the knee axis of rotation to the anterior wound.

Fig. 19-A

With the transfer clamp, the gracilis tendon is weaved in the released rectus femoris tendon with the interlacing technique described by Pulvertaft¹⁴ under moderate tension with use of number-1 Vicryl suture, while the leg is positioned in 20° to 30° of knee flexion on the roll.

Fig. 19-B

Illustration showing the technique described in Fig. 19-A. (For the reason of simplification in visualization, the rest of the quadriceps is not shown.) (Reproduced, with modification, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris bei Patienten mit spastischer Diparese. *Oper Orthop Traumatol.* 1999;11[3]:213-22. Reproduced with permission of Springer Science+Business Media.)

Fig. 20

Alternative technique for transfer of the rectus femoris tendon to the iliotibial band, which is indicated when a hamstring lengthening was previously done. The same technique is used to prepare the rectus femoris tendon (Steps 1 and 2). It is important to release the rectus femoris tendon especially laterally when a lateral transfer is done. A lateral approach is performed at the lateral aspect of the distal part of the thigh. After the dissection of subcutaneous tissue, the iliotibial band is exposed. A small (1-cm) incision is made, and the transfer clamp is inserted through this incision to the anterior approach, where the tagging threads of the rectus femoris tendon are grabbed. Then the rectus femoris tendon is pulled laterally and weaved and stitched in the iliotibial band with use of the Pulvertaft technique¹⁴. (Reproduced, with modification, from: Wenz W, Döderlein L. Die Verpflanzung der Sehne des Musculus rectus femoris

bei Patienten mit spastischer Diparese. Oper Orthop Traumatol. 1999;11[3]:213-22. Reproduced with permission of Springer Science+Business Media.)

Fig. 21-A

Preoperative sagittal plane knee kinematics of a patient with stiff-knee gait, characterized by decreased peak knee flexion in swing, decreased knee flexion velocity, decreased knee flexion in swing, and a delay in peak knee flexion in swing. The dashed line represents the right limb and the solid line represents the left limb. The gray area represents reference data for physiologic knee kinematics obtained from a group of twenty-five normal subjects. Positive values indicate knee flexion.

Fig. 21-B

Preoperative sagittal plane knee kinematics of another patient with stiff-knee gait, characterized by decreased peak knee flexion in swing, decreased knee flexion velocity, decreased knee flexion in swing, and a delay in peak knee flexion in swing. The dashed line represents the right limb and the solid line represents the left limb. The gray area represents reference data for physiologic knee kinematics obtained from a group of twenty-five normal subjects. Positive values indicate knee flexion.

Fig. 22-A

Preoperative sagittal plane knee kinematics of a patient with severe flexed-knee gait throughout the stance and swing phases, reaching normal and even increased peak knee flexion in swing. The dashed line represents the right limb and the solid line represents the left limb. The gray area represents reference data for physiologic knee kinematics obtained from a group of twenty-five normal subjects. Positive values indicate knee flexion.

Fig. 22-B

Preoperative sagittal plane knee kinematics of another patient with severe flexed-knee gait throughout the stance and swing phases, reaching normal and even increased peak knee flexion in swing. The dashed line represents the right limb and the solid line represents the left limb. The gray area represents reference data for physiologic knee kinematics obtained from a group of twenty-five normal subjects. Positive values indicate knee flexion.

Fig. 23

Preoperative sagittal plane knee kinematics of a patient with jump-knee gait¹¹. Both limbs show increased knee flexion at initial contact and normal or slightly increased knee extension during stance phase, which is characteristic of jump-knee gait. While the left limb reaches almost normal peak knee flexion in swing, the right limb shows relevantly decreased peak knee flexion in swing. The dashed line represents the right limb and the solid line represents the left limb. The gray area represents reference data for physiologic knee kinematics obtained from a group of twenty-five normal subjects. Positive values indicate knee flexion.

Fig. 1

Fig. 2

Fig. 3

Fig. 4-A

Fig. 4-B

Fig. 5-A

Fig. 5-B

Fig. 6

Fig. 7-A

Fig. 7-B

Fig. 8-A

Fig. 8-B

Fig. 8-C

Fig. 9

Fig. 10

Fig. 11-A

Fig. 11-B

Fig. 12

Fig. 13

Fig. 14-A

Fig. 14-B

Fig. 15

Fig. 16-A

Fig. 16-B

Fig. 16-C

Fig. 17-A

Fig. 17-B

Fig. 17-C

Fig. 17-D

Fig. 18-A

Fig. 18-B

Fig. 18-C

Fig. 19-A

Fig. 19-B

Fig. 20

Fig. 21-A

Fig. 21-B

Fig. 22-A

Fig. 22-B

Fig. 23