Musculotendinous equinus deformity correction: gastrocnemius or gastrosoleus release

Vincenzo De Luna
 Francesco Oliva
 Gaetano Lo Bue
 Cosimo Tudisco
 Pasquale Farsetti

Department of Orthopaedic Surgery, University of Rome "Tor Vergata", Rome, Italy

Corresponding author:

Vincenzo De Luna
 Department of Orthopaedic Surgery,
 University of Rome "Tor Vergata"
 Viale Oxford 81
 00133 Rome, Italy
 Tel.: +39 3923553828
 E-mail: videluna@tin.it

Summary

Introduction: Equinus is a condition in which the upward bending motion of the ankle joint is limited. Someone with equinus lacks the flexibility to bring the top of the foot toward the front of the leg. Equinus can occur in one or both feet. There are several possible causes for the limited range of ankle motion, this deformity of the foot may result from either musculotendinous forms, osseous forms, or combined forms. Congenital deformities and neuromuscular diseases are the main causes of musculotendinous equinus, and they will be the subject of our review.

Material and methods: Gastrocnemius release: An isolated gastrocnemius contracture (IGC) is often encountered in patients with foot and ankle pathology. Gastrocnemius contracture has been reported as an isolated entity as well as a problem associated with several forefoot, midfoot, or hindfoot pathologies. The gastrocnemius recession is one the oldest orthopaedic procedures described in the literature. This procedure has been performed for many years for contracture associated with pediatric neuromuscular disorders, and now it is an effective and predictable method for the treatment of spastic and non-spastic gastrocnemius equinus deformities. Over the past decade, there has been an increase in use of this procedure in the adult population. In general, surgical procedures for the

correction of any form of ankle equinus are more effective, with better long-term results, in patients who are more physically active. Physical activity and state of health help to determine the surgical procedure and may indeed contraindicate surgical intervention. Once surgical correction has been elected, a surgical procedure aimed at correcting the specific condition may be chosen.

Gastrosoleus release: Many surgical procedures have been described for the correction of a gastrosoleus equinus deformity. Most of these techniques have been oriented to elongation of the Achilles tendon, but there are other kinds of operations, like selective neurectomy and anterior advancement of the Achilles tendon, for the spastic forms of gastrosoleus equinus only. A tenotomy of the Achilles tendon may be considered for correction of either spastic or non-spastic gastrocnemius-soleus contractures, but it should generally not be used for the correction of a gastrocnemius equinus deformity.

Discussion: Surgical procedures for the correction of equinus deformity by lengthening of the gastrocnemius or the gastrocnemius-soleus complex vary in terms of selectivity, stability, and range of correction. Procedures for the correction of musculotendinous equinus deformity have different anatomical, biomechanical and clinical characteristics.

Level of evidence: Ia.

KEY WORDS: equinus deformity, gastrocnemius release, gastrosoleus release.

Introduction

Equinus is a condition in which the upward bending motion of the ankle joint is limited. Someone with equinus lacks the flexibility to bring the top of the foot toward the front of the leg. Equinus can occur in one or both feet. There are several possible causes for the limited range of ankle motion, this deformity of the foot may result from either musculotendinous forms, osseous forms, or combined forms (Tab. I). Congenital deformities and neuromuscular diseases are the main causes of musculotendinous equinus, and they will be the subject of our review.

The musculotendinous foot equinus includes spastic and non-spastic forms. Spastic equinus is usually found in patients with neuromuscular diseases such as cerebral palsy, where the posterior muscles overpower the

Table I. Causes of foot equinus deformity.

Musculo-tendinous forms		Osseus forms	Combined forms
Spastic forms	Non spastic forms		
<ul style="list-style-type: none"> • Neuromuscular diseases 	<ul style="list-style-type: none"> • Congenital shortness of triceps surae • Low insertion of the soleus muscle • Accessory soleus muscle • Clubfoot • Vertical talus • Syndromic clubfoot • Hereditary gastrocnemius soleus contractures • Prolonged plantar-flexed positions • Healing in a shortened position after Achilles tendon rupture • During leg lengthening • Iatrogenic causes 	<ul style="list-style-type: none"> • Talo-tibial exostoses • Congenital or acquired osseus deformity • Tibiofibular syndesmosis ossification 	<ul style="list-style-type: none"> • Recurrent forms or residual deformities of clubfoot in older children

anterior muscles of the leg; however non-spastic equinus is increasing in frequency and is now considered to be more common than spastic muscular foot equinus. To the best of our knowledge, several non-spastic forms of foot equinus have been described. Sometimes non-spastic equinus can be hereditarily acquired. Congenital non-spastic shortness of the triceps surae that causes a foot equinus deformity was first reported by Hall et al. in 1967¹. In these cases, an abnormally low insertion of the soleus muscle or an accessory soleus muscle may be identified². Abnormal shortening of the Achilles tendon in clubfoot or vertical talus is associated with other congenital anomalies and therefore surgical release of posterior capsule-ligaments of subtalar joint and lengthening of the Achilles tendon are often necessary to correct the equinus deformity. Several Authors have described hereditary non-spastic gastrocnemius-soleus contractures as an autosomal dominant condition with variable severity of expression³. Sometimes the acquired deformity may be due to the foot structure and over time the Achilles tendon becomes shortened. If the total length of the tendon is not used and not needed, it will contract over time, which happens with a flatfoot deformity. There are also acquired forms of shortness of the posterior crural musculature creating a foot equinus. Soft tissue contracts to

its altered position, and this is the underlying etiologic factor in most cases of acquired muscular foot equinus. Acquired causes of non-spastic foot equinus forms are prolonged or repeated plantar-flexed positions of the ankle. Common examples are prolonged casting or repetitive use of high-heeled shoes. Acquired shortness may also result from an Achilles tendon rupture with healing in a shortened position, and in children during leg lengthening; iatrogenic causes are rare.

Talotibial exostoses represent one of the osseous forms of foot equinus and include any osseous projections from the margins of the trochlear surface of the talus to the distal articular surface of the tibia that could limit ankle joint dorsiflexion. This is very uncommon in paediatric practice. The osseous causes of foot equinus deformity also include congenital or acquired osseous deformity and tibiofibular syndesmosis ossification. An equinus deformity can exist when there is a bone block at the ankle not allowing the foot to dorsiflex at the ankle. This type appears more commonly following trauma or arthritis.

Combined forms of foot equinus deformity can also be observed, such as recurrent forms or residual clubfoot deformities in older children. Non-operative treatments for an equinus deformity of the ankle include stretching exercises, bracing⁴, serial casting, and temporary or

permanent denervation with botox^{5,6}, alcohol, or phenol⁷.

Many surgical procedures have been proposed to correct equinus deformity. If the equinus is caused only by the gastrocnemius muscle it is possible to perform an isolated gastrocnemius release but if the deformity is caused by the whole triceps surae muscle, it is necessary to perform a gastrosoleus release. Gastrocnemius releases include gastrocnemius neurectomy, proximal recession and distal recession. Gastrosoleus releases include: gastrosoleus neurectomy, advancement of the Achilles tendon, lengthening of the Achilles tendon and intramuscular lengthening of the gastrocnemius and soleus.

Materials and methods

Gastrocnemius release

An isolated gastrocnemius contracture (IGC) is often encountered in patients with foot and ankle pathology. Barske et al. reported the presence of an IGC in 65% to 88% of non-neuropathic patients with midfoot or hindfoot symptoms, compared with 25% of asymptomatic controls. Gastrocnemius contracture has been reported as an isolated entity as well as a problem associated with several forefoot, midfoot, or hindfoot pathologies⁸. The gastrocnemius recession is one the oldest orthopaedic procedures described in the literature. This procedure has been performed for many years for contracture associated with pediatric neuromuscular disorders, and now it is an effective and predictable method for the treatment of spastic and non-spastic gastrocnemius equinus deformities. Over the past decade, there has been an increase in use of this procedure in the adult population. In general, surgical procedures for the correction of any form of ankle equinus are more effective, with better long-term results, in patients who are more physically active. Physical activity and state of health help to determine the surgical procedure and may indeed contraindicate surgical intervention. Once surgical correction has been elected, a surgical procedure aimed at correcting the specific condition may be chosen.

Silfverskiöld distinguished between isolated gastrocnemius equinus and gastrocnemius soleus equinus by comparing ankle dorsiflexion with the knee flexed to dorsiflexion with the knee extended⁹. Whereas the soleus only crosses the ankle and subtalar joint, the gastrocnemius also crosses the knee joint. As such, the excursion of the gastrocnemius and soleus muscles can be differentiated on physical exam with the Silfverskiöld test. When performing this test, the examiner passively dorsiflexes the ankle with the patient's knee extended and the subtalar joint held in neutral position. The patient's knee is then flexed while the examiner continues to dorsiflex the ankle. An improvement in dorsiflexion with knee flexed is considered a positive test and indicative of IGC. A criterion to indicate an isolated gastrocnemius contracture is less than 10° of dorsiflexion with the knee extended, which improves with

knee flexion. The Silfverskiöld test has a sensitivity of 89% and a specificity of 90%¹⁰.

Three types of operation have been described for the correction of foot equinus caused primarily by the gastrocnemius: selective neurectomy of branches of the tibial nerve supplying the gastrocnemius muscle, described by Stoffel in 1913¹¹; proximal release of the muscular heads of the gastrocnemius, described by Silfverskiöld⁹; and distal recession of the gastrocnemius aponeurosis. All three types were described for correction of the spastic gastrocnemius muscle, but only distal recession of the gastrocnemius aponeurosis should be considered for correcting non-spastic congenital or acquired gastrocnemius foot equinus.

The gastrocnemius recession may be used in isolation or as an adjunct to other foot and ankle procedures. The associated pathologies for which the gastrocnemius recession procedure has been used include acquired adult planovalgus flatfoot¹², plantar fasciitis¹³, metatarsalgia¹⁴, Achilles tendinopathy¹⁵, posterior tibialis dysfunction¹⁶, arthritis, forefoot ulcers¹⁷⁻²⁰ and hallux valgus.

A recent systematic review of the literature performed by Cychosz et al. shows how the scientific literature continues to grow in support of using isolated gastrocnemius recession as an effective treatment strategy for a variety of lower limb pathologies, although it remains clear that higher evidence levels and more carefully controlled investigations will be necessary to more convincingly define the true efficacy and ideal applications of gastrocnemius recession in the adult population¹⁴.

Stoffel was the first in 1913 to describe the gastrocnemius neurectomy, a selective denervation of branches of the tibial nerve to the gastrocnemius muscle, for correction of the spastic muscular forms of equinus deformity (Fig. 1)¹¹.

With the patient prone, a transverse incision is made in the popliteal fossa parallel with the skin creases, beginning at 1 cm lateral to the biceps femoris tendon and ending at 1 cm medial to the semitendinosus tendon. The incision is made deeper transversely through the deep fascia in order to expose the two heads of origin of the gastrocnemius muscle, identify the tibial nerve and isolate its motor branches to the heads of origin of the gastrocnemius; one or two branches emerge from each side of the nerve and course obliquely distal ward to the medial or lateral head. These branches can be pinched gently to identify them, and a small segment is then resected from enough of these branches to interrupt half or more of this innervation; care must be taken for the popliteal vein which lies immediately deep to the tibial nerve. It was thought that selective denervation would weaken the gastrocnemius muscle and reduce the equinus deformity. However, with this technique, surgical experience has been less than satisfactory and has been associated with a relatively high rate of recurrence and a consistent loss of function of the gastrocnemius muscle²¹.

All the studies concluded that neurectomy was useful only in cases of spastic gastrocnemius contracture with associated clonus. The problem with neurectomy is that

Figure 1. Selective denervation of branches of the tibial nerve to the gastrocnemius muscle as described by Stof-fel.

it will not be permanent because either the muscle fibers that have been denervated will atrophy and there will be further weakening of an already weak muscle, or the muscle fibers will be reinnervated by another motor neuron, thereby increasing the size of the motor unit and further decreasing variable motor control ability²². Neither the theoretical advantages nor historical experience suggests that gastrocnemius neurectomy is a viable modern treatment option. Today, neurectomies are rarely performed alone, because of the difficulty in achieving a quantitative control in spasticity of the triceps surae, but occasionally are done in conjunction with other forms of spastic muscular equinus correction. Regarding to the proximal recession Silfverskiöld, in 1924, through a transverse incision in the popliteal crease, advocated a release of the gastrocnemius muscular origins from the femoral condyles above the knee joint and reinsertion posteriorly to the proximal tibial area below the knee joint⁹. Once the two heads of origin of the gastrocnemius muscle have been exposed, a curved clamp is used to elevate each head of the gastrocnemius muscle and it is freed from the posterior aspect of the femoral condyle by dividing it transversely near its attachment to the bone. Care must be taken to avoid injuring the peroneal nerve, which courses near the lateral head. Then, by dissecting bluntly with a gauze sponge, the two heads of the muscle are elevated until they are free to a level distal to the knee joint. The three-joint gastrocnemius is converted to a two-joint muscle and is effectively lengthened by shortening the distance from origin to insertion (Fig. 2).

In 1954, Baker reported a surgical procedure similar to Silfverskiöld operation; it entails releasing the gastroc-

nemius heads proximally but without reattaching them distally to the tibia²³. In 1959, Silver and Simon described their experience with a modification of the Silfverskiöld procedure involving a proximal release without reinsertion of the heads of the gastrocnemius muscle but with the neurectomy of the tibial branches of the medial heads of the gastrocnemius muscle²⁴. Their study included a total of 110 cases, with 5 recurrences. In addition to the moderate recurrence rate^{21,24}, the Silfverskiöld procedure and its modifications have several other disadvantages: the possibility of postoperative knee effusion, a lack of protection to the posterior knee, and the possibility of creating a postoperative genu recurvatum deformity and posterior knee instability²⁵. The procedure remains in use today, however, and is especially useful in cases of fixed knee flexion and muscular foot equinus occurring in combination with a spastic gastrocnemius muscle.

Unlike the other forms of treatment for gastrocnemius equinus, distal aponeurotic recession may be used for lengthening the muscle-tendon complex in either a spastic or non-spastic attitude. Gastrocnemius recession is a surgical procedure that involves transecting or lengthening the gastrocnemius aponeurosis at its insertion into the soleus aponeurosis²⁶. Gastrocnemius recession essentially creates a surgically induced gastrocnemius tear²⁷.

Distal gastrocnemius recession procedures were initially proposed for the surgical correction of spastic muscular foot equinus. However, because of their distal orientation and distance from vital neurovascular structures around the knee joint, distal recessions have been performed more frequently. In addition, the distal

Figure 2. Proximal release of the gastrocnemius origins as described by Silfverskiöld.

recession may be performed within the gastrocnemius aponeurosis, to allow more precise correction and fewer complications. For these reasons, distal recessions are frequently adapted for the correction of non-spastic gastrocnemius foot equinus.

Vulpus and Stoffel, in 1913, were the first to describe a distal recession or lengthening of the gastrocnemius aponeurosis (Fig. 3) for the correction of spastic contractures²⁸. Their original description included a transverse lengthening that they later modified to an inverted V-shaped lengthening of the distal aponeurosis of the gastrocnemius²⁹. A posterior longitudinal incision 7,5 cm long is made over the middle of the calf. The sural nerve is identified and retracted. Then the aponeurotic tendon of the gastrocnemius is exposed and an inverted V-shaped incision is made through it. The ankle is forced into slight dorsiflexion and the segments of the tendon are separated. They did not suture the retracted portion of the gastrocnemius aponeurosis to the underlying muscle. Sharrard and Bernstein reported recurrence of the foot equinus deformity in the 15% of the cases necessitating a second corrective procedure with the Vulpus technique³⁰. It is useful in patients with plantar flexion contractures in which both gastrocnemius and soleus muscles are restricted and who have a negative Silfverskiöld test on physical examination.

Recently Park et al. affirmed that the Vulpus procedure is an effective surgical procedure for correcting equinus deformity in residual and relapsed clubfeet after Ponseti protocol. All feet, treated with the Vulpus procedure, showed satisfactory results at last follow-up (range 24 to 78 months), with significant improvements in mean ankle dorsiflexion angle, mean tibiocalcaneal angle, and mean lateral talocalcaneal angle³¹.

Strayer, in 1950, modified the Vulpus-Stoffel procedure^{32,33}, using the original transverse lengthening and including additional dissection and retraction of the proximal portion of the gastrocnemius aponeurosis by suturing the retracted proximal aponeurosis to the underlying soleus (Fig. 4). With the patient prone, a posterior longitudinal incision 10 cm to 15 cm long is made

over the middle of the calf. The sural nerve is identified and protected, and through the fascia the medial and lateral margins of the gastrocnemius aponeurosis are identified. By blunt dissection, this muscle is separated from the underlying soleus distally to where its aponeurotic tendon joins that of the soleus to form the tendon calcaneus. A clamp is inserted deep to the gastrocnemius, and its tendon is severed. The aponeurotic tendon of the gastrocnemius is divided transversely near its junction with that of the soleus, and the foot is dorsi-

Figure 3. Distal recession of the gastrocnemius aponeurosis as described by Vulpus and Stoffel.

Figure 4. Distal recession of the gastrocnemius aponeurosis as described by Strayer.

flexed to the neutral position. The two muscle bellies are dissected from their medial and lateral attachments to the deep fascia proximally into the popliteal fossa, and a finger is passed side to side beneath the muscle to completely separate the gastrocnemius from the soleus. This allows the gastrocnemius to retract farther proximally. Then the retracted proximal part of the tendon is sutured to the underlying soleus at a level at least 2,5 cm more proximal than its original attachment. Recent modifications do not include suturing of the fascia. Strayer concluded that the operation is helpful because it alters the proprioceptive impulses received from the extremity, and these impulses in turn modify the stretch reflexes. He reported a 5-years follow-up series of 23 patients, of whom 16 had excellent results, 2 had fair results, and 5 had poor results³⁴. One poor result was caused by failure to extend the knees at the time of the gastrocnemius recession. The other 4 poor results were attributed to non-compliance with post-operative instructions and inadequate follow-up.

The relevant anatomy for the open technique of Strayer from a medial approach was recently studied by Pinney et al., who used a 7 cm medial incision³³. They state that cosmesis of the incision can be compromised by tethering of the skin to the underlying tissue, and report that this is a relatively frequent complication. They also mention that sural nerve injury can occur by direct trauma or excessive stretching, but do not report the actual rate of this complication. They affirmed that a postero-medial incision, that begins 2 cm distal to the gastrocnemius indentation and extends proximally, will minimize the length of the incision required and should al-

low to minimize the rate of sural nerve injuries and improve cosmesis³³.

Webb et al. noted that the sural nerve courses over the proximal aspect of the Achilles tendon from lateral to medial, and surgical incisions should take this into account³⁵. When the Silfverskiöld test revealed residual soleus contracture after the Strayer procedure, a single transverse stripe/division of the soleus fascia was performed. The combination of distal gastrocnemius recession and soleal fascial lengthening is called a modified Strayer procedure³⁶.

In 1956, Baker described a tongue-in-groove modification of the Vulpius-Stoffel and Strayer operations³⁷. He used an inverted U incision on the aponeurosis, keeping the lateral and medial portions intact with the underlying soleus muscle. The middle portion of the tongue is completely dissected from the soleus (Fig. 5). Baker believed that this additional soleus aponeurotic dissection eliminated the muscle's stretch reflex and thus decreased the chance of clonus or subsequent recurrence. The procedure was then completed by suturing the gastrocnemius aponeurotic bands to one another in a retracted position. Basset and Baker reported a recurrence of only 4% in 447 patients treated with Baker's technique²¹, but other Authors reported considerably less satisfactory results with a high recurrence rate, particularly if the initial operation was performed before the age of 5 years^{38,39}. Therefore the potential danger of this approach is undercorrection, recurrent deformity, and the need for repeat surgery; however in patients with cerebral palsy, "a little equinus is better than calcaneus" because overcorrection may set in

Figure 5. Distal tongue-in-groove recession as described by Baker.

motion a cascade of events that result in a severe crouch gait and loss of walking ability⁴⁰.

Fulp and McGlamry, in 1974, were the first to advocate distal recession of the gastrocnemius aponeurosis for the correction of a non-spastic gastrocnemius equinus (Fig. 6)⁴¹. They proposed that in a non-spastic patient, the deformity was not nearly as severe as in the spastic patient, and felt the deformity was mainly due to the gastrocnemius muscle without concomitant spasticity or clonus from the soleus muscle. Because it was not necessary to excise the central soleus aponeurosis in non-spastic cases, since elimination of clonus is not needed, Fulp and McGlamry found that the tongue-in-groove procedure described by Baker could be effectively performed with the cut inverted⁴¹.

The inverted Baker technique, with the medial and lateral cuts made proximally and the central cut made distally, offers the additional advantage of being technically easier in the younger patient with a more narrow gastrocnemius aponeurosis.

Ziv et al. showed that in the gastrocnemius of normal and spastic mice, 45% of growth occurs at the musculotendinous junction⁴². They also showed that spastic muscle grows at only 55% of the rate of bone, and this may explain the development of equinus contracture. They termed the musculotendinous junction the "growth plate" of the muscle. It is therefore possible that operating at this site, as in the Vulpius, Baker, Strayer and Fulp procedures, could further compromise the retarded growth of spastic muscle. Gastrocnemius recession,

Figure 6. Distal inverted tongue-in-groove recession as advocated by Fulp and McGlamry for nonspastic gastrocnemius contractures.

as compared with Achilles tendon lengthening, may result in fewer complications such as calcaneal deformity, but the larger incision and nerve injury may be a drawback. Recurrence rate is not the only factor to be evaluated, but postoperative antigravity stability after selective gastrocnemius recession should also be evaluated at the same time. If antigravity stability is preserved after gastrocnemius recession, recurrence is not always an unacceptable pitfall as it can be treated with additional use of minimal Achilles tendon lengthening.

In recent years, endoscopic gastrocnemius release has been used to lengthen the gastrocnemius aponeurosis, thereby avoiding larger incisions and visualizing the sural nerve^{43,44}. With the patient supine, a 5 to 10 mm long longitudinal incision is made on the medial aspect of the leg, distal to the medial head of gastrocnemius muscle, typically 16 to 17 cm proximal to the medial malleolus⁴⁵. After a blunt dissection to the fascia, the fascia is elevated and a cannula is introduced through the medial incision; a 4-mm endoscope is then inserted to visualize the gastrocnemius aponeurosis and sural nerve. A lateral portal is then made, with trans-illumination of the lateral surface of the skin via a medial approach. A 5-mm incision is made laterally over the cannula. Next, a hook blade is inserted laterally into the cannula, and the aponeurosis is transected entirely from the medial aspect to the lateral aspect under direct endoscopic view, while a dorsiflexion is applied to the foot with knee extended. This technique is a mini-

mally invasive procedure with a low rate of complications, which can significantly increase ankle dorsiflexion, but it has potential complications including sural nerve injury and lateral dysesthesia (0-11%), and unacceptable cosmesis (11%) as the most common^{43,44,46-48}.

Tashjian et al. first described the technique in cadaveric limbs⁴³ in 2003, Saxena and Widtfeldt reported a series of 18 patients⁴⁴ and in 2005 Trevino et al. reported a series of 28 patients treated with the endoscopic technique⁴⁸.

Several Authors have reported the benefits of endoscopic gastrocnemius recession for the treatment of non-traumatic equinus contracture. However, little is known about its potential for correcting severe post-traumatic equinus contracture. Recently Anghong and Kanitnate affirmed that dual-portal endoscopic gastrocnemius recession, with or without modified percutaneous tendon-Achilles lengthening, is a promising treatment, with satisfactory effectiveness and lower risks of complications, for correcting the very severe post-traumatic equinus deformity⁴⁹.

Endoscopic gastrocnemius recession was performed by Phisitkul in 320 consecutive patients who were diagnosed with isolated gastrocnemius contracture and failed non operative treatments. This technique demonstrated promising results in the treatment of isolated gastrocnemius contracture, ankle dorsiflexion was significantly improved with minimal morbidity and the procedure was found effective in improving functional outcomes and relieving pain as a sole operative treatment and as a part of combined procedures in the patients. Postoperative morbidity included weakness of ankle plantarflexion in 11 patients and sural nerve dysesthesia in 10 patients⁵⁰.

Gastrosoleus release

Many surgical procedures have been described for the correction of a gastrosoleus equinus deformity. Most of these techniques have been oriented to elongation of the Achilles tendon, but there are other kinds of operations, like selective neurectomy and anterior advancement of the Achilles tendon, for the spastic forms of gastrosoleus equinus only. A tenotomy of the Achilles tendon may be considered for correction of either spastic or non-spastic gastrocnemius-soleus contractures, but it should generally not be used for the correction of a gastrocnemius equinus deformity.

In 1913, Stoffel described selective denervation for the correction of the spastic muscular forms of foot equinus¹¹, the gastrosoleus neurectomy. As mentioned earlier, neurectomies, which have provoked considerable debate, have primarily dealt with denervation of the muscles contributing to any clonus present. Most Authors have attributed the majority of ankle clonuses to the gastrocnemius muscle and have denervated it alone.

Eggers and Evans, in 1963, used neurectomy of the soleus muscle in instances of soleus clonus without gastrocnemius-soleus contracture or in combination with a tenotomy of the gastrocnemius-soleus complex in cases of severe contracture with clonus⁵¹.

In 1960, Martz reported favorable results in 23 cases of soleus denervation performed on patients in whom spasticity and clonus were predominant in the soleus muscle⁵². However, neurectomy should be used only in cases in which clonus is found to be present and then often in conjunction with an appropriate lengthening procedure.

In the field of neurosurgery, Sindou et al. reported selective neurectomy of motor branches of the posterior tibial nerve to the gastrocnemius and soleus for correction of equinus deformity by the microsurgical technique, partially sectioning the nerves selected (about two-third of their caliber) under the operative microscope⁵³. They reported in 1985 that surgery obtained complete suppression of the disabling spastic components, total pain relief and consequently improvement of the residual voluntary movements by achieving balance between agonist and antagonist muscles in 91% of the patients⁵³.

Decq et al. recently showed that soleus neurectomy is effective for the treatment of spastic equinus foot, leading to elimination of spasticity and improvement in the range of ankle motion during the stance phase of gait⁵⁴. Anterior advancement of the Achilles tendon was originally described by Esteve of Paris in 1936 (Fig. 7)⁵⁵. This procedure was reintroduced by Pierrot and Murphy in 1974 for correction of the spastic equinus deformity⁵⁶. The procedure is simple and involves the transfer of the insertion of the Achilles tendon onto the dorsum of the calcaneus. Advancing the insertion of the Achilles tendon in this manner effectively shortens the lever arm of the gastrocnemius-soleus muscle complex about both the ankle joint fulcrum and the metatarsophalangeal joint fulcrum. The plantar-flexor power of the gastrocnemius-soleus muscle complex at the ankle joint is markedly decreased in relation to the small decrease in toe-off power at the metatarso-phalangeal joints.

This technique is in contrast to Achilles tendon lengthening procedures. Pierrot and Murphy theorized that skeletal growth would not affect the end result and that correction could be maintained without the use of splints and orthotic devices⁵⁶. They found a recurrence of equinus or calcaneus deformity in 25% of the patients. Murphy subsequently claimed a better success rate (81%) when he altered the advancement by routing the Achilles tendon deep to the flexor hallucis longus tendon. He stated that the tendon will return to its original insertion in a high percentage of the cases if it is not routed anterior to the flexor hallucis longus. The procedure is for moderate to severe forms of spastic gastrocnemius or gastrosoleus equinus, and a success rate of 75% to 90% is excellent in these cases. Throop et al. used the Murphy procedure for correction of equinus and reported significant improvement in 89% of the patients⁵⁷.

Traditionally, the Achilles tendon has been reattached to the calcaneus, with the tendon sutured in Bunnel fashion and the suture then passed plantarly through the calcaneus and tied over a button on the plantar aspect of the foot.

Figure 7. Anterior advancement of the Achilles tendon described by Esteve of Paris.

Downey and McGlamry suggested one such alternative type of reinsertion by passing the suture medially and laterally to the sides of the calcaneus and tying the suture ends posteriorly (Fig. 8)⁵⁸.

This method avoids the problems associated with the traditional plantar button like plantar ulceration. Alternatively, the Achilles tendon may be reinserted with screws, staples or bone anchors, but this may necessitate later removal in the younger patient or if the fixation devices become prominent (Fig. 9). After the Achilles tendon advancement, with routing anterior to the flexor hallucis longus tendon, the rate of recurrence is minimized but the posterior heel is more prominent, and this can occasionally lead to posterior calcaneal irritation much like that associated with Haglund's deformity. In 1990, Strecker et al. reported outcomes of Murphy procedure in 161 involved lower extremities of 100 patients. They mentioned that most of the patients have done well with significant improvements in their gait, with no recurrence or calcaneal gait, although intramus-

cular lengthening of the gastrocnemius was needed in selected cases to achieve full correction of the deformity. So, this report can be considered a result of combined approach of heel cord advancement and Vulpius procedures⁵⁹.

To improve the outcome, also Yoshimoto et al. treated patients with severe contracture of the Achilles tendon, by heel cord advancement combined with an additional lengthening of the gastrocnemius muscle using the Vulpius technique⁶⁰. With this technique, they obtained a good correction of the equinus deformity with no recurrence, and with improvement of the physical activity level.

Achilles tendon lengthening can be performed in many ways, open *versus* percutaneous, sliding *versus* Z-lengthening. In 1931, Hoke described the use of a triple hemisection of the Achilles tendon⁶¹. Through an incision over the medial aspect of the tendon, Hoke cut the Achilles tendon in half in three places, posteriorly in the proximal and distal aspects of the incision and anterior-

Figure 8. Alternative reinsertion for the anterior advancement of the Achilles tendon as described by Downey and McGlamry.

Figure 9. Alternative reinsertion with screws for the anterior advancement of the Achilles tendon.

ly in the central portion of the incision. The foot was then dorsiflexed at the ankle, to allow sliding to a lengthened position.

Hatt and Lamphier, in 1947, described a similar approach through three separate puncture wounds, instead of one open incision⁶². Alternatively, a triple hemisection may be performed by making the cuts medially and laterally, as opposed to anteriorly and posteriorly (Fig. 10)⁶³. The percutaneous lengthening of the Achilles tendon has several advantages over open

Figure 10. Triple hemisection slide lengthening of the Achilles tendon as described by Hoke.

lengthening. It can be performed at any age and can be done for a repeat lengthening of the tendon. There is no incision, the postoperative pain is considerably less, we have low rate of complications and recurrence, and the absence of secondary deformation of the calcaneus⁶⁴.

The medial half of the tendon is divided at both the proximal and the distal extents of the tendon, and the lateral half is divided midway between the two medial cuts. The site of the entry portals is just above the insertion into the calcaneus, at the most proximal portion of the tendon, just below the muscular tendinous junction, and midway between the two medial cuts. The two incisions are on the medial side if the heel is in varus, as it usually is. If the heel is in valgus, two incisions are placed laterally and one medially in between. The proximal and distal cuts should be made first and the middle cut last. If the middle cut is made before the proximal and distal cuts, either the proximal or distal segment can lengthen because tension is kept on the tendon. When the middle cut is made, the foot should go into dorsiflexion, and the tension fibers start to slide.

Moreau and Lake found that the percutaneous tendon Achilles lengthening is a quick, complication-free, inexpensive approach to a common pediatric orthopedic problems, it is an excellent technique due to its reliability, easy execution, and the quality of the fiber healing⁶⁵. Overall results were excellent, there were no infections and with 97% improvement in gait⁶⁵.

It's often necessary, in the clubfoot treated with the Ponseti method, to perform a percutaneous Achilles tenotomy (Fig. 11). Likewise, the risk of overcorrection via heel-cord tenotomy with subsequent calcaneus positioning and heel cord weakness has been shown to be exceedingly low in a long-term follow-up study⁶⁶. Ippolito et al. have demonstrated greater weakness when posterior release was performed instead of the simpler heel-cord tenotomy⁶⁷. Although Ponseti recommended heel-cord sectioning in cases where the foot does not obtain 10 degrees of dorsiflexion at the end of casting,

Figure 11. Percutaneous Achilles tenotomy for clubfoot treated with the Ponseti method.

he also said that if there is any doubt about appropriateness of performing a heel-cord tenotomy, then it should be performed. The operating suite is preferred in children who are older than 6 months of age and complete heel-cord tenotomy can be performed without concern of overlengthening or weakness in children up to 18 months of age or older.

Heel-cord tenotomy is performed using a semisterile technique by prepping with sterile surgical soap. The knee is held by an assistant, and the foot is positioned to avoid excessive dorsiflexion, as this would obscure the tendon to palpation within the surrounding soft tissue. The surgeon should be aware of the location of the medial neurovascular bundle and remember the elevated calcaneal pitch. The tenotomy is performed about 1.5 cm above the palpable tuberosity of the calcaneus. Complete tenotomy is heralded by a palpable pop and an increase in dorsiflexion of approximately 20 degrees. A plaster cast with maximum dorsiflexion and abduction of the foot is then applied for 3-4 weeks. Whereas some Authors have encountered significant bleeding from this procedure⁶⁸, the bleeding can be well controlled by applying pressure with sterile gauze. To reduce the risk of neurovascular injury during Achilles tenotomy, some Authors introduced the mini-open technique for the Achilles tendon tenotomy. They have not seen any complication with this procedure^{69,70}.

Based on his observation that the calcaneus tendon rotates about 90° on its longitudinal axis between insertion and origin, and on the possibility, to perform a lengthening while living the fibers in continuity, White in 1943 described his method of lengthening the Achilles tendon⁷¹. Slide lengthening of the heel cord is performed by two partial transverse tenotomies of the calcaneus tendon (Fig. 12). Although initially described as a percutaneous technique, this is most often performed as an open technique. The incision should be placed on the medial side on the ankle, 2 cm anterior to the Achilles tendon where the skin has a good layer of subcutaneous tissue and will pose no problems for wound

closure. The first cut is made just above the insertion of the tendon into the calcaneus. Starting on the anterior surface of the tendon, the anterior two thirds of the fibers are divided almost completely across to the lateral side. Then applying a moderate force in dorsiflexion to the foot, the medial two thirds of the tendon are divided 5 to 8 cm proximal to the site of the distal division remaining in the purely tendinous portion of the tendon. Shortly after half of the tendon is divided, the foot should start to go into dorsiflexion as the two halves of the tendon start to slide past one another. Suturing the

Figure 12. Slide lengthening of Achilles tendon as described by White.

Figure 13. Slide lengthening of Achilles tendon as described by Frost and Conrad.

tendon usually is unnecessary because it remains in continuity and because further undesired lengthening is prevented by the cast, but it may be done when its continuity is doubtful.

Frost, in 1963, described sectioning the medial three-fourths of the tendon distally and the lateral three-fourths of the tendon approximately 2 or 3 cm proximally (Fig. 13)⁷². The entire lengthening was done within 3 cm of the tendon's insertion. Conrad and Frost reported a 23% of recurrences in 98 cases⁷³.

Borowski et al. analyzed the subcutaneous Achilles tendon lengthening in the treatment of spastic equinus deformity in 104 patients, with an average age at surgery of 6.19 years. In conclusion he suggested that, in view of the simplicity of operation, the cosmetic outcome, and earlier resumption of rehabilitation, the subcutaneous lengthening should be considered the method of choice⁷⁴.

In 1971, Slargato reported on a Z-plasty technique that involved severing the anterior two-thirds of the tendon distally and the posterior two-thirds of the tendon proximally⁷⁵.

He performed the procedure through two transverse incisions 8 to 10 cm apart. Further, he advocated a slight bias in the cuts, severing more medial fibers proximally and more lateral fibers distally. The lack of consistent, predictable results eventually led to more open tenotomies, so the exact length surgically achieved could be directly visualized.

Figure 14. Open sagittal plane Z-plasty lengthening as discussed by Grabe and Thompson.

In 1979, Grabe and Thompson discussed the use of an open sagittal plane Z-plasty lengthening (Fig. 14)⁷⁶. They reported good results in the 87% of the cases. With a sagittal plane sectioning, the distal cut may be placed medially and the proximal cut laterally or vice versa. Generally, in a patient with a cavovarus foot type, the distal cut is placed medially, so after reattachment, a slight pronatory pull is affected. In a patient with a planovalgus foot type, the distal cut is placed laterally, so a residual supinatory pull is created.

It is easiest to start the incision at the proximal extent of the tendon. A knife is inserted completely through the tendon and, with a sawing motion, is drawn distally, producing a division down the middle of the tendon. As the knife reaches the insertion to the calcaneus, it is turned 90 degrees, and the distal-medial half of the tendon is detached from the calcaneus. The knife is reinserted into the proximal extent of the longitudinal cut and turned laterally, dividing the proximal lateral half of the tendon. When cutting halfway across a tendon, it is best to start in the middle of the tendon and cut to the side of the tendon. This will prevent accidentally transecting the entire tendon, which can occur when cutting from the border of the tendon proceeding toward the tendon's center. The foot can be dorsiflexed and the tendon should be sutured holding the foot in the correct position. This may be done by overlapping the two ends of the tendon and suturing them side to side. It also possible to cut off the excess length from one or both sides and perform an end-to-end repair with a buried suture.

Figure 15. Open frontal plane Z-plasty lengthening.

Open frontal plane Z-plasty type of lengthening of the Achilles tendon has been described for cases of spastic and non-spastic contracture of the gastrocnemius-soleus complex (Fig. 15)^{58,76}.

Fewer complications and less recurrence after the open frontal plane Z-plasty lengthening were found than with other types of tenotomy⁵⁸.

Dietz et al. assessed the medium-term follow-up results of treatment of spastic ankle equinus deformity in cerebral palsy using Hoke or coronal Z-lengthening of the Achilles tendon⁷⁷. In this study, there was no significant difference in outcome between the Hoke and the Z-lengthening procedures. Patients who underwent more procedures and bilateral procedures were more likely to require anterior-floor-reaction bracing. The high rate of over-lengthening after either a Hoke or coronal Z-lengthening resulting in crouch gait requires further examination. The increasing incidence of crouch gait in these series as these children get older lends itself to the conclusion that these patients are overpowering their triceps surae as they become older and heavier⁷⁷. Recently Kim et al., to minimize the risk of complications after Achilles tendon Z-lengthening, proposed to perform this technique with a transverse skin incision⁷⁸. This procedure was performed by using a short transverse incision on a skin crease of the heel. In the severe cases, more than 20° of equinus deformity, two or three transverse incisions were required for greater lengthening of the tendon. They compared the results with those obtained with percutaneous sliding lengthening and Z-lengthening with a medial longitudinal incision. The functional and cosmetic satisfaction was achieved with this new technique, and the mean American Orthopaedic Foot & Ankle Society score improved from 56.1 to 81.8. Therefore, advantages of this procedure are the excellent cosmesis and a low rate of complications such as scarring, adhesion or neurovascular damage⁷⁸.

Paley and Lamm proposed a percutaneous technique

for Achilles tendon lengthening^{79,80}.

A longitudinal percutaneous incision is made centrally and just proximal to the Achilles tendon insertion into the calcaneus. The incision is deepened through the Achilles tendon and a Smillie knife is inserted into the tendon, under the tendon sheath, and pushed approximately 4 cm proximally. A second percutaneous longitudinal central tendon incision is made over the tip of the Smillie knife. Then each half of the tendon is cut transversely, in different directions proximally and distally, at the level of the incisions, being careful not to injure the tendon sheath. Dorsiflexing the foot the tendon lengthens within the sheath. Because this procedure preserves the Achilles tendon sheath, the Thompson's test produces a normal plantarflexion. After surgery, the ankle is then immobilized for 3 weeks.

Any Achilles tendon lengthening procedure may be combined with neurectomy in cases of severe spasticity or clonus. Open lengthening is often required in recurrent equinus because the normal rotation of the tendon fibers is no longer present and a sliding tenotomy cannot be done easily. Posterior capsulotomy of the ankle may be needed in a patient with severe equinus deformity, especially if it is of long-standing duration. The posterior ankle capsule will be contracted, and a posterior capsulotomy of the talotibial joint may be necessary to allow adequate ankle dorsiflexion. Rattey et al. report cases of recurrence after Achilles tendon lengthening by open Z-plasty in 57 children, both hemiplegic and diplegic⁸¹.

In line with the literature data, recurrence was found in 18% of the diplegics and 41% of the hemiplegics. In particular it emerged that children aged 6 years and over did not present post-operative recurrence, as opposed to a significant increase in cases of recurrence encountered among those operated on before the age of 4 years. The optimal technique for lengthening of the Achilles tendon in patients with cerebral palsy is controversial⁸².

Results are best in patients with hemiplegia and non-hemiplegic patients who require only single leg surgery, and who do not require concomitant or subsequent surgery. Alternative treatment, such as gastrocnemius fascial lengthening, or non-surgical treatment may be the optimal treatment of ambulatory patients with spastic diplegia and quadriplegia who have spastic foot equinus during gait⁷⁷.

Kocher and Sucato performed a randomized clinical trial of three different procedures, Z-lengthening of the Achilles tendon, Vulpius gastrocnemius recession, and percutaneous Hoke lengthening of the Achilles tendon, in nineteen patients with spastic diplegia. They found that all three procedures improved functional gait, but Z-lengthening of the Achilles tendon was the most effective in terms of maintenance of the initial correction⁸³.

The results of four procedures, aponeurectomy of gastrocnemius, Achilles tendon lengthening by Z-plasty, a combination of these two procedures and sliding elongation of musculus triceps surae, are analyzed by Cobeljic et al. The analysis was based on 417 operations in 291 patients of the average age of 9 years. The analysis shows that the best results were achieved by sliding elongation of musculus triceps surae after the age of 7 years⁸⁴.

In a recent study, the length of the gastrocnemius and soleus muscle was examined before and after surgery in two clinical populations, cerebral palsy and idiopathic toe walking, who received two different surgical procedures, tendon-Achilles lengthening or gastrocnemius recession with Vulpius procedure. The Authors found differences in outcomes between surgery types but not diagnoses; in other words, diagnosis did not appear to affect the outcome of muscle-tendon lengths following calf surgery⁸⁵.

Yngve and Chambers also presented a comparative study between the Vulpius method and Z-lengthening and concluded that there were no significant differences in any of the parameters between these two methods at follow-up⁸⁶.

However, critical views about Achilles tendon lengthening have also been presented.

Segal et al. expressed serious concerns about the post-operative calcaneal gait and reported that calcaneal deformity could be a significant iatrogenic complication, after single Achilles tendon lengthening⁸⁷.

In general, we can affirm that if Achilles tendon is over-lengthened, calcaneal deformity or calcaneal gait could be caused and if the heel cord is lengthened insufficiently recurrences occur easily.

In 2013 Firth et al. in their anatomical and biomechanical study in human cadavers, compared the gastrocnemius-soleus complex lengthening with six different surgical procedures⁸⁸.

The gastrocnemius-soleus musculotendinous unit was subdivided into three zones. The Baumann and Strayer procedures performed in the zone-1 were very stable but were limited with regard to the amount of lengthening achieved. Zone-2 lengthening of the conjoined gastrocnemius aponeurosis and soleus fascia, with Vulpius

and Baker procedures, were not selective but were stable and resulted in significantly greater lengthening than Zone-1 procedures. Zone-3 lengthening of the Achilles tendon, with Hoke and White procedures, were neither selective nor stable but resulted in significantly greater lengthening than Zone-1 or 2 procedures⁸⁸. Therefore, Firth et al. affirmed it may be appropriate for surgeons to select a procedure involving the zone best suited to the clinical needs of a specific patient. More recently Krupinski et al. presented a long-term follow-up, an average of 10 years, of subcutaneous Achilles tendon lengthening in the treatment of spastic equinus foot in patients with cerebral palsy, after Hooke's or White's isolated procedure. Although the recurrence of the deformity was reported in 43.42% of the patients, the Authors affirm that subcutaneous Achilles tendon lengthening is not associated with a risk of serious complications, while providing good long-term therapeutic outcomes as well as very good cosmetic and functional effects, minimizing the costs and time of patients' hospitalisation⁸⁹.

Farshad et al. proposed, with an *in vitro* study, a new method for tendon - lengthening preserving a degree of tendon continuity. The Achilles tendons were cut along a helical axis located at the tendon centerline, with helical angles of 60°, 45°, and 30°; these tendons either were left unsutured or were sutured with mattress stitches along the cut lines (Fig. 16). The maximal length increase was achieved with a cut angle of 30°. Farshad et al. affirm that the helical cutting reliably leaves the tendon in continuity, allows more lengthening than that which can be achieved with Z-plasty, and can offer improved resistance to tensile loads. Therefore this *in vitro* study lays a biomechanical foundation

Figure 16. Lengthening of Achilles tendon through helical axis cutting as described by Farshad et al.

Figure 17. Intramuscular lengthening of the gastrocnemius and soleus as described by Baumann and Koch.

for a subsequent clinical investigation in patients⁹⁰.

Intramuscular lengthening of the gastrocnemius and soleus was described by Baumann and Koch in 1989⁹¹ (Fig. 17). It involves multiple incisions in the anterior aponeurosis of the gastrocnemius and the adjacent fascia of soleus, over the muscle bellies. A medial incision, 8 to 12 cm long, is made at the junction of the upper and middle thirds of the lower leg. By blunt dissection, the plane between gastrocnemius and soleus is opened. The plantaris tendon is resected. The ankle is dorsiflexed to put tension on the strong anterior aponeurosis covering the two muscle bellies of the gastrocnemius. Starting proximally the aponeurosis over the muscle bellies is divided in two or three parallel transverse incisions 1,5 cm apart. The septum between the medial and lateral head of the gastrocnemius which blends into Achilles tendon is preserved. Similar incisions for aponeurotic lengthening of the soleus are made distally to avoid overlapping with those in the gastrocnemius aponeurosis. The ankle is then gradually dorsiflexed until a neutral position is achieved with the knee in full extension, and separation of the gastrocnemius and soleus fascia can be seen.

The Baumann procedure has several advantages, addresses the thicker and relatively inelastic anterior gastrocnemius aponeurosis. If indicated, the soleus

aponeurosis can also be lengthened. Multiple incisions spread the tension on the muscle fibers during subsequent stretching, and reduce the danger of stress concentration which could lead to rupture. This procedure respects the "growth plate" of the muscle and allows an individual correction of both muscles and the muscle power of the triceps surae was not reduced after operation⁹².

The Baumann procedure has been studied in cadaver specimens by Herzenberg et al. The gastrocnemius and soleus muscles of 15 cadaver specimens had four sequential releases: a single gastrocnemius recession, a second gastrocnemius recession, a single soleus recession, and an Achilles tenotomy. In the conclusions Herzenberg et al. affirm that the Baumann procedure is effective in treating the equinus contracture of the gastrocnemius muscle by improving ankle joint dorsiflexion when the results of the Silfverskiöld test are positive⁹³. Saraph et al. in their study did not find recurrences or over corrections with the Bauman procedure⁹². Dreher et al. affirmed that gastrocnemius-soleus intramuscular aponeurotic recession, as a part of multilevel surgery, leads to satisfactory correction of mild and moderate equinus deformity in children and adolescents with spastic diplegia, without relevant risk for overcorrection, and should be preferred over Achilles tendon lengthening to avoid over-lengthening. The long-term results in the study demonstrate that the improvements are long-lasting on average, but individual patients tend to develop recurrence and may need secondary gastrocnemius-soleus intramuscular aponeurotic recession⁹⁴.

Rong et al. reviewed 35 pediatric and adult patients (43 feet) with flatfoot who underwent the Baumann procedure for the concomitant equinus deformity⁹⁵. The mean follow-up was 39.4 months. They affirm that the Baumann procedure can effectively correct the tightness of the gastrocnemius or the gastrocnemius-soleus complex in patients with flatfoot deformity. Recurrence of equinus was observed in 4 feet and there were no cases of overcorrection, neurovascular injury, healing problems or other postoperative complications. Similarly, Blitz and Rush prefer to perform isolated transaction of the muscular bound portion of the gastrocnemius muscles, a procedure termed gastrocnemius intramuscular aponeurotic recession. In this situation, the insertion of the gastrocnemius aponeurosis is undisturbed⁹⁶.

A lengthy gastrocnemius aponeurosis is easily separated from the underlying soleus aponeurosis, and it may be selectively transacted. A case with a short aponeurosis is more challenging, it may not be possible to perform the transaction with a single transverse cut across the aponeurosis, and transaction of the distal part of the gastrocnemius musculature may occur⁷⁸. A short aponeurosis can often be converted into a long aponeurosis by forcible blunt dissection. In some cases, the gastrocnemius aponeurosis may be extended, thus allowing sufficient aponeurosis for transaction. When the deep surface of the distal part of the gastrocnemius muscle itself attaches directly to the soleus without an aponeurosis, the recession cannot be com-

pleted without either transecting the soleus aponeurosis or detaching the gastrocnemius muscle from its direct insertion⁹⁷.

This may result in iatrogenic transaction of sections of the soleus aponeurosis and shredding of the musculature, and a gastrocnemius soleus recession is unintentionally performed. A recent retrospective study by Rush et al. demonstrated a low morbidity in 126 cases with a high gastrocnemius recession⁹⁸.

Lammet et al., few years ago, published their technique of gastrocnemius soleus recession through a posterior midline approach⁸⁰.

More recently Lin et al. proposed a new method to treat equinus deformity in patients with spastic cerebral palsy. A posteromedial longitudinal skin incision, 3-4 cm long, is made at the junction of the middle and lower thirds of the lower leg. By blunt dissection, the musculotendinous junction of the gastrocnemius is exposed. Mesh tenotomy of the tendinous portion of the gastrocnemius and soleus fascia is performed.

The mesh tenotomy includes multiple transverse cuts for 5-8 mm, around 5 x 5 cuts (row x column), with at least 3-5 mm apart between cuts. After tenotomy, the ankle was gently dorsiflexed, yielding a 4-6 mm longitudinal gap for each cut, and 20-30 mm lengthening of the Achilles tendon was gained (Fig. 18)⁹⁹.

The results were compared with those obtained with two other methods: the Vulpus and the Z-lengthening techniques. The Lin procedure achieves a successful correction of the equinus deformity comparable with that of the Vulpus procedure, with the advantages of preserving the gastrocnemius without a complete section resulting in a quicker recovery; whereas the cor-

rected dorsiflexion angle of the ankle obtained with the Z-lengthening was higher⁹⁹.

Conclusion

Surgical procedures for the correction of equinus deformity by lengthening of the gastrocnemius or the gastrocnemius-soleus complex vary in terms of selectivity, stability, and range of correction. Procedures for the correction of musculotendinous equinus deformity have different anatomical, biomechanical and clinical characteristics. More extensive clinical trials are needed to determine whether these differences are of clinical importance. It may be appropriate for surgeons to select a procedure involving the zone best suited to the clinical needs of a specific patient.

Ethics

The Authors declare that this research was conducted following basic ethical aspects and international standards as required by the journal and recently update in Padulo et al.¹⁰⁰.

References

1. Hall JE, Salter RB, Bhalla SK. Congenital short tendo calcaneus. *J Bone Joint Surg Br.* 1967;49:695-697.
2. Tachdjian MO. Neuromuscular diseases. In: Tachdjian M, ed. *The child's foot.* Philadelphia, PA: WB Saunders. 1985:352-509.
3. Levine MS. Congenital short tendo calcaneus: report of a family. *Am J Dis Child.* 1973;125:858-859.
4. Carmick J. Managing equinus in a child with cerebral palsy: merits of hinged ankle-foot orthoses. *Dev Med Child Neurol.* 1995;37:1006.
5. Carr LJ, Cosgrove AP, Gringras P, et al. Position paper on the use of botulinum toxin in cerebral palsy. UK Botulinum Toxin and Cerebral Palsy Working Party. *Arch Dis Child.* 1998; 79:271.
6. Corry IS, Cosgrove AP, Duffy CM, et al. Botulinum toxin A compared with stretching casts in the treatment of spastic equinus: a randomized prospective trial. *J Pediatr Orthop.* 1998;18:304.
7. Doute DA, Sponseller PD, Tolo VT, et al. Soleus neurectomy for dynamic ankle equinus in children with cerebral palsy. *Am J Orthop.* 1997;26:613-616.
8. Barske HL, DiGiovanni BF, Douglass M, Nawoczensky DA. Current concepts review: isolated gastrocnemius contracture and gastrocnemius recession. *Foot Ankle Int.* 2012;33(10): 915-921.
9. Silfverskiöld N. Reduction of the uncrossed two-joints muscles of the leg to one-joint muscles in spastic conditions. *Acta Chir Scand.* 1924;56:315-330.
10. Patel A, DiGiovanni B. Association between plantar fasciitis and isolated contracture of the gastrocnemius. *Foot Ankle Int.* 2011;32(1):5-8.
11. Stoffel A. The treatment of spastic contractures. *AM J Orthop Surg.* 1913;10:611-644.
12. Di Giovanni CW, Langer P. The role of isolated gastrocnemius and combined Achilles contractures in the flatfoot. *Foot Ankle Clin.* 2007;12(2):363-379.

Figure 18. Mesh tenotomy of the tendinous portion of gastrocnemius and soleus fascia as described by Lin et al.

13. Monteagudo M, Maceira E, Garcia-Virto V, Canosa R. Chronic plantar fasciitis: plantar fasciotomy versus gastrocnemius recession. *Int Orthop*. 2013;37(9):1845-1850.
14. Cychosz CC, Phisitkul P, Belatti DA, Glazebrook MA, DiGiovanni CW. Gastrocnemius recession for foot and ankle conditions in adults: Evidence-based recommendations. *Foot Ankle Surg*. 2015 Jun;21(2):77-85.
15. Gurdezi S, Kohls-Gatzoulis J, Solan MC. Results of proximal medial gastrocnemius release for Achilles tendinopathy. *Foot Ankle Int*. 2013;34(10):1364-1369.
16. Di Domenico L, Stein D, Wargo-Dorsey M. Treatment of posterior tibialis tendon dysfunction without flexor digitorum tendon transfer: a retrospective study of 34 patients. *J Foot Ankle Surg*. 2011;50:1-6.
17. Greenhagen RM, Johnson AR, Peterson MC, Rogers LC, Bevilacqua NJ. Gastrocnemius recession as an alternative to tendoAchillis lengthening for relief of forefoot pressure in a patient with peripheral neuropathy: a case report and description of a technical modification. *J Foot Ankle Surg*. 2010;49(2):159-163.
18. Colen LB, Kim CJ, Grant WP, Yeh JT, Hind B. Achilles tendon lengthening: friend or foe in the diabetic foot? *Plast Reconstr Surg*. 2013;131(1):37-43.
19. Dallimore SM, Kaminski MR. Tendon lengthening and fascia release for healing and preventing diabetic foot ulcers: a systematic review and meta-analysis. *J Foot Ankle Res*. 2015 Jul 30;8:33.
20. Cychosz CC, Phisitkul P, Belatti DA, Wukich DK. Preventive and therapeutic strategies for diabetic foot ulcers. *Foot and Ankle International*. 2016 March;37(3):334-343.
21. Basset FH, Baker LD. Equinus deformity in cerebral palsy. In: Adams JP, ed. *Current practice in orthopedic surgery*, vol. 3. St. Louis, MO: CV Mosby. 1966:59-73.
22. Miller F, Browne E. Cerebral palsy. Springer. 2005;715-716.
23. Baker LD. Triceps surae syndrome in cerebral palsy: an operation to aid in its relief. *Arch Surg*. 1954;68:216-221.
24. Silver CM, Simon SD. Gastrocnemius-muscle recession (Silverskiold operation) for spastic equinus deformity in cerebral palsy. *J Bone Joint Surg Am*. 1959;41:1021-1028.
25. Evans EB. The status of surgery of the lower extremities in cerebral palsy. *Clin Orthop*. 1966;47:127-139.
26. Blitz NM, Eliot DJ. Anatomical aspects of the gastrocnemius aponeurosis and its insertion: A cadaveric study. *J Foot & Ankle Surg*. 2007;46(2):101-108.
27. Cotrell W, Pearsall A, Hollis M. Simultaneous tears of the Achilles tendon and the medial head of the gastrocnemius muscle. *Orthopedics*. 2002;25(6):685-687.
28. Vulpius O, Stoffel A. *Orthopädische Operationslehre*. Stuttgart: Ferdinand Enke. 1913:29-31.
29. Vulpius O, Stoffel A. *Orthopädische Operationslehre*, 3rd ed. Stuttgart: Ferdinand Enke, 1924:30-31.
30. Sharrard WJW, Bernstein S. Equinus deformity in cerebral palsy: a comparison between elongation of the tendo calcaneus and gastrocnemius recession. *J Bone Joint Surg Br*. 1972;54:272-276.
31. Park SS, Lee HS, Han SH, Park JW, de Peralta MJ. Gastrocnemius fascial release for correction of equinus deformity in residual or relapsed clubfoot. *Foot Ankle Int*. 2012 Dec;33(12):1075-1078.
32. Strayer LM Jr. Recession of the gastrocnemius: an operation to relieve spastic contracture of the calf muscles. *J Bone Joint Surg Am*. 1950;32:671-676.
33. Pinney S, Sangeorzan B, Hansen S. Surgical anatomy of the gastrocnemius recession (Strayer procedure). *Foot Ankle Int*. 2004;25(4):247-250.
34. Strayer LM Jr. Gastrocnemius recession: five-year report of cases. *J Bone Joint Surg Am*. 1958;40:1019-1030.
35. Webb J, Moonjani N, Radford M. Anatomy of the sural nerve and its relation to the Achilles tendon. *Foot Ankle Int*. 2000;21(6):47-477.
36. Graham HK. Cerebral palsy. In: Drennan's the child's foot and ankle. 2nd ed. McCarthy JJ, Drennan JC, editors. Philadelphia: Lippincott, Williams & Wilkins. 2010:188-218.
37. Baker LD. A rational approach to the surgical needs of the cerebral palsy patient. *J Bone Joint Surg Am*. 1956;38:313-323.
38. Lee CL, Bleck EE. Surgical correction of equinus deformity in cerebral palsy. *Dev Med Child Neurol*. 1980;22:287-292.
39. Olney BW, Williams PF, Menelaus MB. Treatment of spastic equinus by aponeurosis lengthening. *J Pediatr Orthop*. 1988;8(4):422-425.
40. Firth GB, Passmore E, Sangeux M, Thomason P, Rodda J, Donath S, Selber P, Graham HK. Multilevel surgery for equinus gait in children with spastic diplegic cerebral palsy. *J Bone Joint Surg Am*. 2013;95:931-938.
41. Fulp MJ, McGlamry ED. Gastrocnemius tendon recession: tongue in groove procedure to lengthen gastrocnemius tendon. *J Am Podiatry Assoc*. 1974;64:163-171.
42. Ziv I, Blackburn N, Rnag M, Koreska J. Muscle growth in normal and spastic mice. *Dev Med Child Neurol*. 1984;26:94-99.
43. Tashjian RZ, Appel AJ, Bancrjee R, Di Giovanni CW. Endoscopic gastrocnemius recession: evaluation in a cadaver model. *Foot Ankle Int*. 2003;24:607-613.
44. Saxena A, Widtfeldt A. Endoscopic gastrocnemius recession: preliminary report on 18 cases. *J Foot Ankle Surg*. 2004;43:302-306.
45. Salamon ML, Pinney SJ, Van Bergey A, Hazelwood S. Surgical anatomy and accuracy of percutaneous Achilles lengthening. *Foot Ankle Int*. 2006;27:411-413.
46. Saxena A, Gollwitzer H, Widtfeldt A, DiDomenico LA. Endoscopic gastrocnemius recession as therapy for gastrocnemius equinus. *Zeitschrift für Orthopädie und Unfallchirurgie*. 2007;145(4):499-504.
47. Di Domenico LA, Adams HB, Garchar D. Endoscopic Gastrocnemius Recession for the Treatment of Gastrocnemius Equinus. *J AM Podiatr Med Assoc*. 2005;95(4):410-413.
48. Trevino S, Gibbs M, Panchbhavi V. Evaluation of results of endoscopic gastrocnemius recession. *Foot Ankle Int*. 2005;26:359-364.
49. Anghong C, Kanitnate S. Dual-portal endoscopic gastrocnemius recession for the treatment of severe post-traumatic equinus deformity: a case series and a review of technical modifications. *J Nippon Med Sch*. 2012;79(3):198-203.
50. Phisitkul P, Rungprai C, Femino JE, Arunakul M, Amendola A. Endoscopic Gastrocnemius Recession for the Treatment of Isolated Gastrocnemius Contracture: A Prospective Study on 320 Consecutive Patients. *Foot Ankle Int*. 2014 May 21;35(8):747-775.
51. Eggers GWN, Evans EB. Surgery in cerebral palsy. *J Bone Joint Surg Am*. 1963;45:1275-1305.
52. Martz CD. Talipes equinus correction in cerebral palsy. *J Bone Joint Surg Am*. 1960;42:769-776.
53. Sindou M, Abdennebi B, Boisson D, Eyssette M, Goutelle A. Treatment of spastic foot by selective neurotomy of the tibial nerve. Results of a series of 31 cases. *Neurochirurgie*. 1985;31(3):189-197.
54. Decq P, Filipetti P, Cubillos A, Slavov V, Lefaucœur JP, Nguyen JP. Soleus neurotomy for treatment of the spastic equinus foot. *Commentary. Neurosurgery*. 2000;47(5):1154-1160.
55. Esteve P. Un procédé d'équilibration des pieds spastiques. *Vie Med*. 1970;1:51-53.
56. Pierrot AH, Murphy OB. Heel cord advancement: a new approach to the spastic equinus deformity. *Orthop Clin North Am*. 1974;5:117-126.
57. Throop FB, DeRosa GP, Reeck C, Waterman S. Correction of equinus in cerebral palsy by the Murphy procedure of tendo calcaneus advancement: a preliminary communication. *Dev Med Child Neurol*. 1975;17(2):182-185.

58. Downey MS. Ankle equinus. In McGlamry E, ed. Comprehensive textbook of foot surgery. Baltimore: Williams & Wilkins. 1987:368-402.
59. Strecker WB, Via MW, Oliver SK, Schoenecker PL. Heel cord advancement for treatment of equinus deformity in cerebral palsy. *J Pediatr Orthop.* 1990;10(1):105-108.
60. Yoshimoto M, Kura H, Matsuyama T, Ssaki T, Yamashita T, Ishii S. Heel cord advancement combined with Vulpus' lengthening of the gastrocnemius. *ClinRelat Res.* 2005;434:213-216.
61. Hoke M. An operation for the correction of extremely relaxed flat feet. *J Bone Joint Surg.* 13:773-783, 1931.
62. Hatt RN, Lamphier TA. Triple hemisection: a simplified procedure for lengthening the Achilles tendon. *N Engl J Med.* 1947; 236: 166-169.
63. Hsu JD, Hsu CL. Motor unit disease. In: Jahss MH, ed. Disorders of the foot and ankle: medical and surgical management, vol. 1, 2nd ed. Philadelphia: WB Saunders. 1991:739-753.
64. Cheng JCY, So WS. Percutaneous elongation of the Achilles tendon in children with cerebral palsy. *International Orthopaedics.* 2004;17(3):162-165.
65. Moreau MJ, Lake DM. Outpatient percutaneous heel cord lengthening in children. *J Pediatr Orthop.* 1987;7(3):253-255.
66. Cooper DM, Dietz FR. Treatment of idiopathic clubfoot: a thirty-years follow-up. *J Bone Joint Surg Am.* 1995;77:1477-1489.
67. Ippolito E, Farsetti P, Caterini R, Tudisco C. Long-term comparative results in patients with congenital clubfoot treated with two different protocols. *J Bone Joint Surg Am.* 2003;85(7):1 286-1294.
68. Dobbs MB, Gordon JE, Walton T, et al. Bleeding complications following percutaneous tendoachillestenotomy in the treatment of clubfoot deformity. *J Pediatr Orthop.* 2004;24(4):353-357.
69. Dogan A, Kalender AM, Seramet E, Uslu M and Sebik A. Mini-Open Technique for the Achilles Tenotomy in Correction of Idiopathic Clubfoot. *J Am Podiatr Med Assoc.* 2008;98(5):414-417.
70. MacNeille R, Hennrikus W, Stapinski B, Leonard G. A mini-open technique for Achilles tenotomy in infants with clubfoot. *Journal of Children's Orthopaedics.* 2016 Feb;10(1):19-23.
71. White WJ. Torsion of the Achilles tendon: its surgical significance. *Arch Surg Am.* 1943;46:784-787.
72. Frost HM. Subcutaneous tendo Achilles lengthening. *Am J Orthop.* 1963;5:256-7.
73. Conrad JA, Frost HM. Evaluation of subcutaneous heelcord lengthening. *Clin Orthop.* 1969;64:121-127.
74. Borowski A, Synder M, Sibinski M. Subcutaneous Achilles tendon lengthening in the treatment of spastic equinus contracture. *OrtopTraumatolRehabil.* 2004;6(6):784-788.
75. Slargato TE. A compendium of podiatric biomechanics. San Francisco: California College of Podiatric Medicine. 1971:287-296.
76. Grabe RP, Thompson P. Lengthening of the Achilles tendon in cerebral paresis: basis principles and follow-up study. *S Afr Med J.* 1979;56:993-996.
77. Dietz FD, Albright JC, Dolan L. Medium Term Follow-up of Achilles Tendon Lengthening in the Treatment of Ankle Equinus in Cerebral Palsy. *Iowa Orthop J.* 2006;26:27-32.
78. Kim HT, Oh JS, Lee LS, Lee TH. Z-lengthening of the Achilles tendon with transverse skin incision. *Clin Orthop Surg.* 2014;6 (2):208-215.
79. Paley D. Principles of deformity correction. 2° edition, Springer, Berlin. 2003
80. Lamm BM, Paley D, Herzenberg JE. Gastrocnemius soleus recession: a simpler, more limited approach. *J Am. Podiatr Med Assoc.* 2005;95:18-25.
81. Rattey TE, Leahey L, Hyndman J, Brown DC, Gross M. Recurrence after Achilles tendon lengthening in cerebral palsy. *J PediatrOrthop.* 1993;13(2):184-187.
82. Goldstein M, Harper DC. Management of cerebral palsy: equinus gait. *Developmental Medicine & Child Neurology.* 2001; 43:563-569.
83. Kocher MS, Sucato DJ. What's new in pediatric orthopaedics. *J Bone Joint Surg.* 2006;88:1412-1421.
84. Cobeljic G, Vukasinovic Z, Apostolovic M, Bajin Z. Choice of operative procedures to correct equinus deformity in patients with cerebral palsy. *Acta Chir Iugosl.* 2006;53(4):21-26.
85. Jahn J, Vasavada AN, McMulkin ML. Calf muscle-tendon lengths before and after Tendo-Achilles lengthenings and gastrocnemius lengthenings for equinus in cerebral palsy and idiopathic toe walking. *Gait Posture.* 2009;29(4):612-617.
86. Yngve DA, Chambers C. Vulpus and Z-lengthening. *J Pediatr Orthop.* 1996;16(6):759-764.
87. Segal LS, Thomas SE, Mazur JM, Mauterer M. Calcaneal gait in spastic diplegia after heel cord lengthening: a study with gait analysis. *J Pediatr Orthop.* 1989;9(6):697-701.
88. Firth GB, McMullan M, Chin T, Ma F, Selber P, Eizenberg N, Wolfe R, Graham HK. Lengthening of the gastrocnemius-soleus complex: an anatomical and biomechanical study in human cadavers. *J Bone Joint Surg Am.* 2013 21;95(16):1489-1496.
89. Krupinski M, Borowski A, Synder M. Long term follow-up of subcutaneous Achilles tendon lengthening in the treatment of spastic equinus foot in patients with cerebral palsy. *Ortop Traumatol Rehabil.* 2015 Mar-Apr;17(2):155-161.
90. Farshad M, Gerber C, Snedeker JG, Meyer DC. Helical Cutting as a New Method for Tendon-Lengthening in Continuity. *J Bone Joint Surg Am.* 2011 Apr 20;93(8):733-738.
91. Baumann JU, Koch HG. Ventrals aponeurotische Verlängerung des musculus gastrocnemius. *Operat OrthopTraumatol.* 1989;1:254-258.
92. Saraph V, Zwick EB, Uitz C, Linhart W, Steinwender G. The Baumann procedure for fixed contracture of the gastrosoleus in cerebral palsy. *J Bone Joint Surg Br.* 2000;82(4):535-540.
93. Herzenberg JE, Lamm BM, Corwin C, et al. Isolated recession of the gastrocnemius muscle: the Baumann procedure. *Foot Ankle Int.* 2007;28(11):1154-1159.
94. Dreher T, Buccoliero T, Wolf SI, Heitzmann D, Gantz S, Wenz W. Long-term results after gastrocnemius-soleus intramuscular aponeurotic recession as a part of multilevel surgery in spastic diplegic cerebral palsy. *J Bone Joint Surg Am.* 2012 Apr 4;94(7):627-637.
95. Rong K, Ge WT, Li XC, Xu XY. Mid-term results of intramuscular lengthening of gastrocnemius and/or soleus to correct equinus deformity in flatfoot. *Foot Ankle Int.* 2015;36(10):1223-1228.
96. Blitz NM, Rush SM. The gastrocnemius intramuscular aponeurotic recession. A simplified method of recession. *J Foot Ankle Surg.* 2007;46(2):133-138.
97. Blitz NM, Eliot DJ. Anatomical aspect of the gastrocnemius aponeurosis and its insertion: A cadaveric study. *J Foot Ankle Surg.* 2007;46(2):101-108.
98. Rush SM, Ford LA, Hamilton GA. Morbidity associated with high gastrocnemius recession: retrospective review of 126 cases. *J Foot Ankle Surg.* 2006;45(3):156-160.
99. Lin CL, Lin CJ, Huang MT, Su WR, Wu TT. Mesh Achilles tendon lengthening – a new method to treat equinus deformity in patients with spastic cerebral palsy: surgical technique and early result. *J Pediatr Orthop B.* 2013;22(1):14-19.
100. Padulo J, Oliva F, Frizziero A, Maffulli N. Muscles, Ligaments and Tendons Journal - Basic principles and recommendations in clinical and field science research: 2016 update. *MLTJ.* 2016;6(1):1-5.