Different body and limb segments grow at different rates, inducing varying muscle tensions during growth.\textsuperscript{1} In addition, boys and girls grow at different rates.\textsuperscript{1} The rate of growth for girls spikes at ages 5, 7, 10, and 13 years.\textsuperscript{1} The estrogen-induced pubertal growth spurt in girls is one of the earliest manifestations of puberty. Growth of the legs and feet accelerates first, so that many girls have longer legs in proportion to their torso during the first year of puberty. The overall rate of growth tends to reach a peak velocity (as much as 7.5 to 10 cm) midway between thelarche and menarche and declines by the time menarche occurs.\textsuperscript{1} In the 2 years after menarche, most girls grow approximately 5 cm before growth ceases at maximal adult height.\textsuperscript{1} The rate of growth for boys spikes at ages 6, 11, and 14 years.\textsuperscript{1} Compared with girls’ early growth spurt, growth accelerates more slowly in boys and lasts longer, resulting in taller adult stature among men than women (on average, approximately 10 cm).\textsuperscript{1} The difference is attributed to the much greater potency of estradiol compared with testosterone in
promoting bone growth, maturation, and epiphyseal closure. In boys, growth begins to accelerate approximately 9 months after the first signs of testicular enlargement. The peak year of the growth spurt occurs approximately 2 years after the onset of puberty, reaching a peak velocity of approximately 8.5 to 12 cm of height per year. The feet and hands experience the growth spurt first, followed by the limbs and then the trunk. Epiphyseal closure in the upper and lower extremities occurs at approximately age 14 years for girls and 16 years for boys. For 2 additional years, the remaining growth occurs in the axial skeleton (spine).

During these periods of rapid growth, muscle contractures can occur, especially equinus deformity. Equinus is defined as the inability to dorsiflex the ankle enough to allow the heel to contact the supporting surface without some form of compensation in the mechanics of the lower limb and foot. During examination or assessment of children with equinus, it is important to understand the rates and intervals of rapid growth that may contribute to the equinus deformity.

The cause of pediatric ankle equinus may be primary or secondary. Primary equinus is caused by a pre-existing condition whereas secondary equinus develops from another cause. Equinus can be isolated, combined with other lower extremity deformities, or compensatory. In the pediatric population, congenital deformities, such as toe walking, Charcot-Marie-Tooth disease, cerebral palsy (CP), spina bifida, myelomeningocele, flatfoot, muscular dystrophy, arthrogryposis, fibular hemimelia, clubfoot, and limb length discrepancy, can produce equinus deformity. Acquired deformities from poliomyelitis, trauma, burns, and limb lengthening can also cause equinus. In adults, equinus can occur because of immobilization after trauma, lack of function of involved limb, or compensation for other conditions (Box 1).

It is important to distinguish between an equinus deformity and an equinus contracture. Equinus deformity is caused by an osseous condition that may or may not have soft tissue involvement whereas an equinus contracture is caused by only soft tissues (eg, tendons, ligaments, capsule, muscle, or fascia). Multiple factors may contribute to ankle equinus, including soft tissue (eg, posterior muscle group, ankle capsule, and subtalar joint) or bony deformities (eg, procurvatum and ankle osteophytes). Many types of equinus have been described in the literature, including osseous equinus, pseudoequinus (plantarflexed forefoot without ankle equinus), gastrocnemius equinus, gastrocnemius-soleus equinus, and a combination of types.

PHYSICAL EXAMINATION AND RADIOGRAPHIC EVALUATION

Thorough evaluation of the pediatric foot is an essential portion of the examination. The purpose of the examination is to localize symptoms, identify dynamic and static mechanical abnormalities, and detect underlying disease states. Evaluation of major motor milestones determines whether a nervous system insult has occurred. During the stance phase of gait, the greatest degree of dorsiflexion required is just before heel lift when the knee is maximally extended and the ankle must dorsiflex past perpendicular for smooth ambulation. There is controversy in the literature as to the amount of dorsiflexion truly necessary for this to occur. It is better, therefore, to consider a normative range of values necessary for normal gait rather than a definitive number. The accepted range of normal ankle joint dorsiflexion is 3° to 15° past perpendicular with the knee extended. When evaluating the negative influence of equinus on the limb, the method of compensation that a patient may exhibit is as important as the measurements of equinus and ankle joint dorsiflexion that are obtained during physical examination.

Patients may compensate for equinus deformity in many different ways and to varying degrees. The methods that patients use to compensate often determine which
symptoms and pathologic conditions may coexist. Pronation of the subtalar joint with consequent unlocking of the oblique midtarsal joint axis, allowing for dorsiflexion and abduction to occur at the midfoot, constitutes fully compensated equinus. Common methods of compensation for equinus include forward torso lean, pelvic rotation, hip flexion, knee hyperextension, and external rotation of the leg. Therefore, patients can present with a variety of conditions, such as lower back pain, chondromalacia of the knee, Achilles tendinopathy, posterior tibial tendinopathy, painful flatfoot, plantar fasciitis, calcaneal apophysitis, Lisfranc’s joint arthrosis, juvenile Charcot arthropathy, hallux valgus or rigidus, plantar ulceration, forefoot calluses, metatarsalgia, and hammertoe contractures.

The foot of an infant is malleable, which makes it difficult to distinguish between a temporary positional deformity and true structural deformity. Diagnosing equinus in this population requires knowledge of anatomy. Measuring a young child’s ankle dorsiflexion, however, can help a physician diagnose primary equinus as the cause of flexible flatfoot, correction of which is essential for normal foot function. Normal range of ankle dorsiflexion at age 3 years is 20° to 25°, diminishing to 10° by age 15. The Silfverskiöld test helps a physician differentiate among gastrocnemius-soleus equinus, osseous equinus, soft tissue contracture, and soft tissue or osseous deformity (Fig. 1). Decreased ankle dorsiflexion during knee extension and flexion indicates gastrocnemius-soleus equinus whereas limited dorsiflexion with knee extended indicates only gastrocnemius equinus. After the pathology of the equinus is determined and primary or secondary equinus is ruled out, treatment options may be determined.

<table>
<thead>
<tr>
<th>Box 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examples of acquired and congenital equinus deformity</strong></td>
</tr>
<tr>
<td><strong>Acquired equinus</strong></td>
</tr>
<tr>
<td>Poliomyelitis</td>
</tr>
<tr>
<td>Trauma</td>
</tr>
<tr>
<td>Burns</td>
</tr>
<tr>
<td>Limb lengthening</td>
</tr>
<tr>
<td>Lack of function of the involved limb</td>
</tr>
<tr>
<td>Compensation for other conditions</td>
</tr>
<tr>
<td><strong>Congenital equinus</strong></td>
</tr>
<tr>
<td>Cerebral Palsy</td>
</tr>
<tr>
<td>Charcot-Marie-Tooth disease</td>
</tr>
<tr>
<td>Spina bifida</td>
</tr>
<tr>
<td>Myelomeningocele</td>
</tr>
<tr>
<td>Flatfoot</td>
</tr>
<tr>
<td>Arthrogryposis</td>
</tr>
<tr>
<td>Clubfoot</td>
</tr>
<tr>
<td>Fibular hemimelia</td>
</tr>
<tr>
<td>Idiopathic toe walker</td>
</tr>
<tr>
<td>Muscular dystrophy</td>
</tr>
</tbody>
</table>
Radiography can be a critical tool in evaluation of pediatric foot abnormalities. The calcaneus usually starts to ossify by week 23 of gestation; the talus typically starts to ossify at approximately week 28. At birth, only rounded ossific nuclei of some bones of the foot are visible radiographically. Substantial portions of the calcaneus and talus usually are ossified by the first month of infancy. The cuboid ossifies by 6 to 7 months of age, whereas the navicular ossifies between 9 months and 5 years of age. The cuneiforms begin ossification between 3 months and 2.5 years of age, with the lateral cuneiform ossifying first. The metatarsals and phalanges are usually ossified at birth. On average, many of the ossification centers appear on radiographs earlier in girls than in boys.

Radiographic evaluation of the pediatric foot differs from radiographic assessment of the adult foot because radiographs of pediatric patients can contain less radiographic information secondary to variation in ossification. In addition, normative radiographic values for adults cannot necessarily be applied to the pediatric population because values tend to change with age. Ultimately, radiographic studies can be used as an adjunct to clinical diagnosis of equinus and can be used to exclude other deformities.

Accurate diagnosis and assessment of equinus pose a challenge. Radiographs, with proper positioning and focus of the radiographic beam on the appropriate area of interest, are a valuable adjunct for accurate diagnosis of equinus deformities. Normal ranges and mean values of radiographic measurements of the pediatric foot change with age. Inadequate dorsiflexion of the foot or significant equinus creates a falsely decreased talocalcaneal angle on the radiograph and should be clinically correlated when attempting to visualize the tibial and fibular shafts on the anteroposterior view. Lack of ankle dorsiflexion on lateral view radiographs may be secondary to improper positioning or an equinus deformity and also creates a falsely decreased talocalcaneal angle. During normal dorsiflexion, the range of the lateral talocalcaneal angle declines with age and is decreased with equinus or varus. In maximum dorsiflexion, however, increases in the talocalcaneal and tibiocalcaneal angles occur with equinus or varus deformities. A radiograph showing maximum dorsiflexion also evaluates for anterior ankle bony block, which may produce equinus.

**EQUINUS: ASSOCIATED CONDITIONS**

**Idiopathic Toe Walking**

Toe walking is also known as habitual toe walking or congenital short Achilles tendon. The diagnosis is made by excluding all neuromuscular pathologies, especially when
toddlers begin to walk. Toe walking may be considered normal when children begin to walk (until age 18 months). Normally, by 5 years of age, children have developed a stable heel-and-toe gait pattern, and by age 7 years, they usually have an adult gait pattern.\(^1,6\) When children who are capable of heel-and-toe gait prefer to walk on their toes, it is considered habitual. Children with autism and attention-deficit hyperactivity spectrum disorders may have toe walking tendencies.\(^4,7\) If untreated, idiopathic toe walking may lead to fixed contracture of the Achilles tendon and to valgus deformity of the hindfoot.\(^4,7\)

Unilateral toe walking can be caused by limb length discrepancy, spastic equinus from stroke or hemiplegia, or Achilles tendon contracture. Common causes of bilateral toe walking include idiopathic toe walking and spastic diplegia. Bilateral toe walking is also associated with psychologic problems, such as autism and learning disorders. Late-onset bilateral toe walking can be attributed to multiple sclerosis, Charcot-Marie-Tooth disease, Duchenne’s dystrophy, and spinal cord anomalies.

**Muscular Dystrophy**

Duchenne’s dystrophy is a hereditary disease occurring only in boys and characterized by progressive skeletal muscle weakness. Children with Duchenne’s dystrophy seem normal at birth and have normal developmental milestones.\(^1\) At approximately 3 years of age, they develop a tendency to fall.\(^1\) Toe walking is compensatory early on and is necessary to maintain an upright posture. Usually, by age 5, the parents bring a child in for examination and there is a finding of pseudohypertrophy of the calf muscles, a positive Gowers sign, and toe walking because of an equinus contracture of the calf muscles.\(^1\)

**Charcot-Marie-Tooth Disease**

Charcot-Marie-Tooth disease is inherited as an autosomal recessive trait and is a common peripheral neuropathy involving the peroneal nerve in the lower extremity and the ulnar nerve in the upper extremity. The involvement is bilateral with one extremity affected more than the other; both extremities become progressively worse as a child grows. Weakness of the peroneal muscles with diminished deep tendon reflexes is noted.\(^1\) The weak dorsiflexors force the recruitment of the long extensors to dorsiflex the foot during the swing phase.\(^1\) Asymmetric muscle weakness leads to a cavus foot type with clawing of the toes that causes painful metatarsal heads and callus.\(^1\) Shoe modification may benefit those with a mild deformity. Surgical correction of the cavus and claw toe deformities preserves function. The equinus in Charcot-Marie-Tooth disease is primarily forefoot rather than hindfoot equinus.\(^1\)

**Cerebral Palsy (Spastic Equinus)**

CP is a result of a brain lesion (nonprogressive) with subsequent motor impairment. The four major classifications of CP describe different impaired movements: spastic, ataxic, flaccid, and athetoid. Spastic CP can be divided into three types. Children with hemiplegic spastic CP have dynamic equinus on the affected side and can be prescribed ankle-foot orthoses (AFOs) for prevention of equinus. Diplegic spastic CP is the most common type. These children are ambulatory with a scissor gait and flexed knees and hips of varying degrees (Fig. 2). Children with quadriplegic spastic CP usually do not walk because of the profound effects on all four limbs.

Children with CP walk at a later age than normal and do not adequately extend the knee during the swing phase of gait.\(^8,9\) The deep tendon reflexes are hyperactive. Muscle contractures can worsen with time even though the underlying neurologic lesion is static and nonprogressive.\(^5,9\) In children of preschool age, hemiplegic CP is
suspected for asymmetric equinus, upper motor neuron syndrome, or sensory integration dysfunction for symmetric equinus.8,9 The examination of equinus in athetoid CP is challenging, as it changes from moment to moment.

Spina Bifida (Spastic Equinus)

Spina bifida is the most common neural birth defect in the United States.1 There are four types: occulta, closed neural tube defects, meningocele, and myelomeningocele. Occulta and closed neural tube defects rarely cause symptoms. Myelomeningocele can result in severe paralysis that prevents a child from walking. Multiple foot deformities occur including equinus, equinovarus, calcaneovalgus, cavovarus, varus, and calcaneus. Conservative measures, such as serial casting, often fail.2,3 Soft tissue correction, including tendon releases or radical posteromedial release with Achilles tenotomy and plaster casting, is typically required.2,3

Equinus in Flatfoot

The phasic activity and function of the gastrocnemius muscle reach their peak at 50% to 60% of midstance of gait when the gastrocnemius muscle simultaneously flexes the knee and plantarflexes the ankle.4,10 This is the moment when the maximum effect of an equinus deformity is noted. When a tight posterior muscle group is present, however, the foot or leg must compensate to maintain the foot securely on the ground. If a foot is able to compensate, the hindfoot severely pronates through the subtalar joint, allowing the midtarsal joint to unlock and dorsiflexion to increase through the oblique axis of the midtarsal joint. The degree of deformity depends on the foot type; some foot types are stable when affected by equinus whereas others are highly unstable (see Fig. 2). The lower limb compensates with hip flexion, lumbar lordosis, genu recurvatum, or persistent knee flexion to maintain the foot on the ground or to
lift the heel off the ground early in the gait cycle. Function of the foot is compromised, and patients develop symptoms depending on their own method of compensation. Flexible flatfoot is the result of an equinus contracture whereas rigid flatfoot has a secondary equinus contracture because of the fixed foot position. At younger ages, the foot is more flexible and children weigh less, allowing the foot to withstand abnormal forces. As children age, however, their weight increases and the foot becomes less flexible. This causes compensation to be less tolerated and pain to ensue.

**Osseous Equinus**

Many types of osseous equinus exist and have contributing factors, including recurvatum of the tibia, forefoot equinus, flattrop talus, anterior ankle osteophytes, forefoot cavus, trauma, and other congenital deformities. Radiographs should be used to evaluate the anterior and posterior ankle joint, the ankle joint morphology, the juxta-articular angles, and the overall foot and limb deformities to determine osseous involvement. Bony blocks from previous surgery or trauma of the anterior or posterior ankle can result in osseous equinus and painful impingement. When joint morphology is altered, as in a flattrop talus, normal range of motion is not possible and equinus results. Pseudoequinus of forefoot cavus is an osseous foot deformity that results in a subsequent osseous equinus. Procurvatum deformity of the distal tibia may follow a partial growth arrest after trauma.

**Clubfoot**

In the United States, clubfoot occurs in 1 of 500 births. Idiopathic clubfoot is characterized by equinocavovarus and is the most common congenital deformity of the foot. During the initial examination, the idiopathic clubfoot has nonreducible equinus of the ankle, which is the characteristic presentation (Fig. 3). The initial treatment of clubfoot is the Ponseti method of serial casting. The Ponseti method has proved successful in the correction of idiopathic clubfoot. The equinus component is the last component of this deformity to be corrected and typically requires an Achilles tenotomy in 90% of cases. When recurrence of clubfoot occurs, the first treatment is repeat casting using the Ponseti method. On occasion, a repeat tenotomy is required for recurrence in younger infants. For older infants or children, an open tendo-Achillis lengthening (TAL) with or without a posterior muscle group recession and or ankle/subtalar joint capsule release is required to correct recurrent equinus (Fig. 4).

**Arthrogryposis**

Arthrogryposis is a syndrome that is characterized by contractures at birth. It can involve all four extremities and is often isolated to the distal extremities (ie, hands and feet). In the lower extremity, it is not uncommon for the hips to be flexed, abducted, and externally rotated with unilateral or bilateral hip dislocation. The knees are in extension although flexion is possible. Children with arthrogryposis have a characteristic clubfoot deformity that rarely responds to serial casting or physical therapy. Clubfoot associated with arthrogryposis is resistant to manipulation and casting and usually requires surgical correction. In this patient population, the Ponseti method of clubfoot casting may provide initial correction of the deformity. Many cases relapse, however, and require open (eg, intra-articular and/or extra-articular release) or closed (eg, gradual correction with external fixation) surgical intervention.
Fibular Hemimelia

Fibular hemimelia is the most common congenital limb deficiency in the lower extremity. It is characterized by a hypoplastic fibula, anterolateral bowing of the tibia, equinovalgus of the foot, tarsal coalition, short affected limb, absent tarsal bones or rays, ball-and-socket ankle, and syndactylization of digits (Figs. 5–7). Equinus is a powerful deforming force of the hypoplastic foot and ankle and thus causes severe foot and ankle deformities. Typically, fibular hemimelia is treated at multiple levels and

Fig. 3. Idiopathic right clubfoot with equinus, varus, forefoot cavus, and adduction. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)

Fig. 4. Recurrent left clubfoot with cavoequinovarus. Note the incisions from previous surgical procedures. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)
through various soft tissue procedures, including equinus correction and osseous procedures. Lengthening of the short bones exacerbates the tendency for equinus, necessitating concomitant releases.

CONSERVATIVE TREATMENT OF EQUINUS

Physical therapy, taping/strapping, orthoses, intramuscular injections, and serial casting are the conservative treatments that typically are used to combat equinus.

Fig. 5. Clinical photograph of a child with left fibular hemimelia. Note the short limb with equinus and the four toes. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)

Fig. 6. Erect limb radiograph of an infant with right fibular hemimelia. Note the absent fibula, tibial bowing, and three metatarsals. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)
These conservative modalities can be used alone or in combination as the first stage of treatment.\textsuperscript{10}

In general, physical therapy involves passive stretching exercises to prevent or delay hip flexion, hamstring, and equinus contractures because they can lead to the cessation of walking. Children can perform these exercises under the supervision of a therapist or parent. The goal is to enhance motor skills and maintain muscle length and flexibility.

Another option is kinesiotaping, which allows free joint movement without over-stretching adjacent muscles and is applied as a single layer of tape to improve circulation. The latex free elastic tape can be left in place for 3 to 5 days. The tape is applied along the length of the muscle as it is stretched. When applied at the insertion along the length of muscle to origin, the muscle relaxes or is inhibited. When applied at the origin along the length of muscle to insertion, the muscle is promoted to contract (\textbf{Fig. 8}).

Orthoses are beneficial to correct a flexible equinus deformity. An orthotic can be used for flexible flatfoot deformity to prevent excessive pronation caused by equinus. A contraindication for using an orthosis to control equinus is ankle range of motion that is restricted below neutral because a child is not able to achieve a plantigrade foot while wearing the orthosis. An isolated heel lift or an orthotic with a built-in heel lift can accommodate the equinus deformity, however. Skin ulceration and breakdown can occur when an orthosis is applied to a foot that excessively compensates for equinus. Skin ulceration or breakdown can also occur when a foot is insensate or patients are cognitively impaired and unable to report pain. Contractures must be reduced before fitting the AFO; any child who cannot achieve neutral ankle position cannot

\textbf{Fig. 7.} Child with right fibular hemimelia and limb length discrepancy. Note the right equinus compensation for the limb length discrepancy. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)

Gourdine-Shaw et al
be braced.\textsuperscript{4,10} An AFO can enclose the calf and should capture the leg just below the knee and include the foot to ensure control of the equinus deformity. Construction of the AFO may include restriction of ankle plantarflexion or ankle dorsiflexion assist. A prearticulated AFO can be made static and can be used by children until they have adequate tone reduction and can use the articulations. If children have severe hypertonia and no ankle range of motion, a solid AFO is prescribed. If there is no hypertonia and a physician suspects simple habitual toe walking, an articulated AFO can be used.

Botulinum toxin type A is a bacterial toxin produced by \textit{Clostridium botulinum} that paralyzes the neuromuscular junction, which temporarily weakens the muscle. Botulinum toxin type A is the active ingredient in Botox (Allergan, Irvine, California). Although Botox is best known for its therapeutic use in CP, it can be used to treat equinus. Botox is best used to treat equinus deformities that result from dynamic contracture, a form of contracture that occurs when the muscle tension is so great that attempts at dorsiflexion fail.\textsuperscript{17} Botox is injected into the overactive muscle rendering the muscle weaker for approximately 3 months; thus, injections may need to be repeated. High cost and the potential to develop antibodies against the toxin after repeat injections are disadvantages. Botox is reconstituted with 0.9% normal saline at a concentration of 100 U in 10 mL. Botox is administered to the gastrocnemius (medial and lateral heads) and soleus muscles at a dose of 10 U/kg of body weight.\textsuperscript{17} The dosage should not exceed 12 U/kg (or 400 U) per visit or 50 U per injection site.\textsuperscript{17}

Injection sites are identified using surface anatomy. General anesthesia or local anesthetic can be administered depending on the needs of the patient. Depending

---

**Fig. 8.** Clinical photographs of kinesiotaping. (A) The latex free tape is applied in one layer, and the ends of the tape are rounded off before application. The tape is applied along the length of the muscle from insertion to origin as the muscle is stretched. When taping from insertion to origin, the muscle is encouraged to relax. Note that the tape may also be applied from the origin to the insertion, which will encourage the muscle to contract. (B) Leg is shown after kinesiotaping is applied. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)
on the involvement of the soleus and gastrocnemius muscles, four sites on the calf muscle are injected with Botox (Fig. 9). Botox is injected into the superficial gastrocnemius muscle or deeper into the soleus muscle by pumping the syringe to distribute the medicine equally in different directions. Botox should not be injected into the vascular compartment. If necessary, Botox can be injected into the hip adductors and hamstrings. After the intramuscular injections, the leg is placed in a walking cast for 4 weeks. Alternatively, cast application can be delayed and the leg evaluated 1 to 2 weeks after the injections and, if necessary, the cast can be applied. If the contracture is myostatic in nature and causes the muscle to be permanently shortened, the only way to achieve joint motion is by lengthening the tendon.

As an alternative, phenol (carbolic acid) may be injected around the nerve carrying the exaggerated nerve signals to produce a similar kind of controlled time-bound muscle paralysis of a spastic muscle. Only one or two injections can be administered for fear of scar formation on the nerve, whereas Botox may be used numerous times.

Equinus can also be corrected by applying a series of casts that are changed weekly or biweekly. Placing a patient in a cast helps maintain improvement after manipulation. Application of casts should begin early in childhood to take advantage of the elasticity of contracted ligaments, joint capsules, and tendons. A long leg cast with the foot dorsiflexed to 90° and the knee extended provides the most stretch to the posterior muscle group. Short leg casts are not as effective in stretching the gastrocnemius muscle. Care should be taken not to cause cast sores or a rockerbottom foot deformity. At times, Botox is injected in combination with serial casting.

SURGICAL MANAGEMENT

Patients with isolated equinus or equinus as a component of a more complex deformity can undergo surgical treatment. Preoperative evaluation should include an assessment of whether multiple muscles in the lower extremities are involved.

---

Fig. 9. Location of the four injection sites for Botox injection of the calf muscle. Botox can be injected superficially or deep into the gastrocnemius or soleus muscles as required based on the Silfverskiöld test. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)
Evaluation of dorsiflexion with the knee straight and the knee flexed as described by the Silfverskiöld test is important to differentiate gastrocnemius equinus from gastrocnemius-soleus equinus. The Silfverskiöld test guides a surgeon’s approach to correcting the equinus condition.

TAL, gastrocnemius recession, and gastrocnemius-soleus recession have been described to resolve equinus deformity. Each procedure has different advantages. As with any lengthening or tendon transfer, there is some residual deficit in the function of the muscle. Muscle recession has been shown to cause less muscle weakness than tendon lengthening.\textsuperscript{2,3} The authors’ have found, in their experience with children, less gastrocnemius-soleus weakness after gastrocnemius recession as compared with TAL.

**Tendo-Achillis Lengthening**

The most common operative procedure for the treatment of equinus is lengthening of the Achilles tendon. Multiple TAL procedures have been described for the correction of equinus deformity, including the Hoke, White, and Z lengthening procedures.\textsuperscript{2,3} A percutaneous approach is used to reduce time in the operating room and the risk of delayed healing. Hoke\textsuperscript{18} described a triple hemisection open TAL for triceps surae equinus. This procedure provides a reduced risk of rupture compared with the percutaneous approach but an increased risk of complication with delayed healing and hypertrophic scar formation. A surgeon usually performs the open TAL in the frontal plane, transecting the inferior fibers anteriorly and transecting the superior fibers posteriorly. Surgeons should be cautious not to overlengthen the tendon as this could result in profound weakness and dysfunction. Overlengthening is common when treating spastic equinus and, therefore, the authors prefer the Baumann (i.e., gastrocnemius recession) procedure in which the soleus muscle is not as involved.

**Gastrocnemius Recession**

Many gastrocnemius recession procedures have been described in the literature, and each has its own risks and benefits. The Baumann procedure is performed proximally in the triceps surae muscle belly to treat equinus contracture (Fig. 10).\textsuperscript{2,3} The incision is made two fingerbreadths from the medial border of the tibia. The crural fascia is then divided to expose the gastrocnemius muscle. Blunt dissection of the interval between the soleus muscle and gastrocnemius muscle is performed before dividing the plantaris tendon. The tendinous layer on the posterior surface of the gastrocnemius muscle is divided. It is important to identify the lateral-most edge of the gastrocnemius tendon. Next, tension is placed on the gastrocnemius muscle by dorsiflexing the ankle joint with the knee extended. A blade is used to make one transverse incision across the entire gastrocnemius muscle (gastrocnemius recession). The intermuscular septum between the medial and lateral heads of the gastrocnemius muscle also is carefully incised. After each recession, maximum ankle dorsiflexion is assessed clinically with the Silfverskiöld test. When two gastrocnemius recessions are indicated, the incisions are made 1 to 2 cm apart and are placed parallel to each other. Again, the ankle joint is manually dorsiflexed with the knee flexed and extended and, if desired, similar recessions can be made along the soleus muscle. The soleal cuts are placed distally to avoid overlapping the proximal gastrocnemius recession(s).\textsuperscript{2}

One of the most common gastrocnemius recession techniques is the Baker\textsuperscript{19} or reverse Baker,\textsuperscript{4} in which the gastrocnemius tendon is lengthened in a tongue and groove fashion. Advantages of this technique include very controlled lengthening with sliding of the tendon to the appropriate length. The disadvantage, however, is that patients usually must be placed prone on the operating room table. This increases
surgical risk and necessitates turning patients to a supine position if a surgeon must perform other procedures. Another potential disadvantage is that surgeons usually perform this procedure slightly more inferior than the aponeurosis of the gastrocnemius muscle.

The Strayer procedure, described in 1950,\textsuperscript{20} is a popular approach. The Strayer procedure involves lengthening of the gastrocnemius aponeurosis. The advantage of the Strayer procedure is that surgeons may perform it from a medial or posteromedial approach with patients in a supine position. This procedure isolates the gastrocnemius fibers with no soleal component. Since the procedure’s rise in popularity, however, there has been an increase in the reported number of surgical or iatrogenic injuries to the sural nerve. The sural nerve pierces through the fascia in this area with some variability and is difficult to visualize on the lateral side of the gastrocnemius through the medial incision. The use of endoscopy for this procedure may aid in the visualization of the nerve, but the sural nerve remains at risk of injury with the Strayer or Baker technique.\textsuperscript{21} The endoscopic gastrocnemius recession technique is limited in that the obturator and cannula instrumentation are straight whereas the structure that is to be lengthened (ie, the gastrocnemius) is round.

**Gastrocnemius-Soleus Recession**

The authors have found that the majority of children and adults present with combined gastrocnemius-soleus equinus. As an alternative to TAL, which weakens the entire triceps surae muscle, gastrocnemius-soleus recession is preferred. The authors do not perform gastrocnemius-soleus recession, to treat severe cases of contracture for which maximal lengthening is needed. Their technique is a modified form of the Vulpius technique\textsuperscript{22} of gastrocnemius-soleus recession (Fig. 11). Under general anesthesia, patients are positioned supine with a thigh tourniquet. A 3-cm longitudinal midline incision is made at the most distal end of the soleus muscle. Careful dissection is then performed at that interval to identify the sural nerve and lesser saphenous vein. The tendon sheath is identified, and a longitudinal incision is made through it. The plantaris is identified and released. With the ankle dorsiflexed, the combined gastrocnemius and soleus tendons are cut transversely, stopping when the soleus muscle

![Fig. 10. Baumann procedure is performed through a mid-calf medial incision. Note the single incision across the gastrocnemius fascia (gastrocnemius recession). If increased dorsiflexion is needed, a second or third incision can be made with each incision placed 1 cm apart. m., muscle. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)](image-url)
fibers are seen. Then the ankle should be maximally dorsiflexed with the knee in full extension to separate the cut tendons (ie, recession). The Silfverskiöld test is again performed and if the equinus deformity is not completely corrected, the soleus tendon median raphe is identified and cut. The sheath covering the outer border of the tendon and skin is closed.

**Other Procedures**

Open ankle joint or subtalar joint releases may also be performed to release an equinus contracture. Early range of motion is critical otherwise stiffness may ensue. The authors prefer to avoid intra-articular releases if possible, holding true to the philosophy of Ponseti.11

**Rehabilitation**

Rehabilitation typically is dependent on which concomitant procedures were performed. In general, after undergoing a recession or TAL the leg is protected by placing it in a weight-bearing short leg cast or boot for 4 weeks. For 4 weeks at night, patients maintain the maximum stretch on the gastrocnemius muscle by using a knee immobilizer or keeping the foot on a pillow to extend the knee. Physical therapy is started 4 weeks after surgery.

**Complications**

The most common complications are recurrence of equinus deformity or overlengthening. The functional limitation created by overlengthening of the Achilles tendon is crouch or calcaneal gait. This occurs because of the inability of the weakened triceps surae muscle to restrain the forward movement of the tibia when the center of gravity moves in front of the ankle center of rotation during gait.2,3 Because patients lose the normal plantarflexion or knee extension, the weight-bearing line becomes anterior to the ankle and hip center of rotation and posterior to the knee joint, resulting in flexion at the knee and hip with dorsiflexion of the ankle.2,3 This causes secondary hip and knee
flexion contractures and severe patellofemoral pain, which may lead to the cessation of walking. Weakening of the soleus muscle could also create knee instability.

EXTERNAL FIXATION

Gradual correction of the equinus deformity is an alternative to open procedures and is well tolerated in pediatric patients. When large or open surgery has failed, gradual correction of equinus with external fixation (constrained or unconstrained) is preferred (Fig. 12). External fixation allows patients to ambulate when treating a complex and sometimes multiplanar deformity. The risk of adversely affecting the Blix contractile force curve as in tendon lengthening is largely avoided with distraction. Ilizarov distraction is the preferred method to correct stiff ankles, as performing repeat open surgery through extensive scar tissue formation is an overwhelming task. By using external fixation, the authors avoid procedures, such as takedown and triple arthrodesis, that are disabling. In such cases, the joints typically are normal and the equinus that developed compensates for other deformities.

At the authors’ institution, the Ilizarov method is often used to correct clubfoot, equinus, supinated foot, pronated foot, hemimelia, arthrogryposis, and myelodysplastic deformity. The constrained frame allows patients to perform physical therapy whereas the Taylor Spatial Frame (Smith & Nephew, Memphis, Tennessee) and unconstrained constructs do not. Children younger than 8 years can undergo soft tissue and joint distraction, whereas children 8 years and older typically undergo distraction osteogenesis. Younger children undergo soft tissue and joint distraction because they still possess some degree of biologic plasticity (ie, remodeling potential) of their bones and cartilage. The Ilizarov method of joint and soft tissue distraction is analogous to treating infants with serial casting. With casting, pressure is applied to the skin and the joints primarily experience compressive forces. In distinction, the Ilizarov method applies distraction forces across the joints. The stiff soft tissues are stretched rather than surgically released, avoiding extensive pericapsular and intra-articular fibrosis scarring.

Fig. 12. (A) Clinical photograph obtained before correction. A 3-year-old girl with recurrent clubfoot had undergone prior open surgery. External fixation was applied for gradual soft tissue correction of the equinus and adductovarus. Note the talar neck wire is connected to the tibial ring for the adductovarus correction (first stage) about the subtalar joint. The ankle is in equinus. (B) Clinical photograph obtained after correction. Note the talar neck wire is connected to the foot ring for the equinus correction (second stage) about the ankle joint. The ankle is excessively dorsiflexed to allow for slight rebound of equinus. When full correction was obtained, the external fixator was maintained for 6 additional weeks. (Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD.)
The foot should be overcorrected by 5° to 10° in the plane of correction because rebound of the soft tissues is predictable. The foot should be held in the overcorrected position for 4 to 6 weeks. Major corrections require control of the toes with slings, transverse wires, or longitudinal wires. After removal, a long leg cast is applied to maintain the overcorrected position. A custom molded AFO should be worn for the first 6 months. If dynamic recurrence is experienced, the appropriate tendon transfer should be considered. Rigid recurrences might require appropriate corrective osteotomies or arthrodesis.

The Ilizarov External Fixator (Smith & Nephew, Memphis, Tennessee) and Taylor Spatial Frame can also be used, in conjunction with the principles described by Ponseti,11 for correction of equinovarus (ie, clubfoot) deformity (see Fig. 12). In the Ponseti sequence, the foot is first externally rotated through the subtalar joint. The initial correction with the Taylor Spatial Frame is programmed for external rotation, valgus correction, and minimal dorsiflexion. A lateral olive wire through the talar neck mimics the thumb that Ponseti uses for counterpressure. This wire is attached to the proximal tibial ring. Once the foot is externally rotated approximately 40°, the talus neck olive wire is connected to the foot ring to allow for dorsiflexion of the ankle. Next, an additional program is created to allow for ankle dorsiflexion and then the overcorrected position is maintained for 6 weeks. The combined correction of the subtalar and ankle joint (described previously) is called kinematic coupling.

SUMMARY

A thorough physical examination and radiographic analysis should be used to determine whether conservative or surgical treatment is the best option. The age of a patient, the cause of the deformity, and potential complications should also be considered. Typically, conservative treatment options are initially used to manage equinus. When conservative treatments are no longer effective, patients can undergo open or percutaneous surgical correction. For more complex deformities, gradual correction with external fixation may be the best option.

ACKNOWLEDGMENTS

The authors would like to thank Amanda Chase, MA, for her expeditious editing of this manuscript; Roland Starr, MS, for his assistance; Joy Marlowe, MA, for her illustrative expertise; and Joe Michalski, MA, for his expert photography.

REFERENCES