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Critical evaluation of the surgical techniques to correct the equinus deformity.

Avaliação crítica das técnicas cirúrgicas de correção do equino.

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ABSTRACT

The equinus deformity causes changes in the foot contact and may affect more proximal anatomical regions, such as the knee, hip and trunk, potentially leading to gait disorders. The equinus is usually secondary to retraction, shortening and/or spasticity of the triceps surae, and it may require surgical correction. Surgery for the correction of equinus is one of the oldest procedures in Orthopedics, and it was initially performed only at the calcaneus tendon. The technique has evolved, so that it could be customized for each patient, depending on the degree of deformity, the underlying disease, and patient´s profile. The aim is to correct the deformity, with minimal interference in muscle strength, thus reducing the incidence of disabling complications such as crouch gait and calcaneus foot. We conducted a literature search for the most common surgical techniques to correct the equinus deformity using classic books and original articles. Further, we performed a database search for articles published in the last ten years. From the anatomical perspective, the triceps surae presents five anatomical regions that can be approached surgically for the equinus correction. Due to the complexity of the equinus, orthopedic surgeons should be experienced with at least one procedure at each region. In this text, we critically approach and analyze the most important techniques for correction of the equinus, mainly to avoid complications.

Keywords: Foot. Ankle Joint. Achilles Tendon. Review. Equinus Deformity.

INTRODUCTION

The equinus gait pattern interferes with the foot rocking mechanism as it causes the first contact of the foot with the ground to occur in the forefoot. In addition, there are secondary pathological accommodations in the knee and hip. Changes in anatomically distant, but functionally associated actions, such as abnormal pelvic oscillations, lumbar lordosis increase, and compensatory scoliosis may occur, leading to changes in posture, gait, increased energy consumption and segmental mechanical overloading.

Surgical interventions on the Achilles tendon are one of the oldest reported operations in Orthopedics. It is attributed to Hessen (*apud* David[1]), in 1784, the first surgical section of the calcaneus tendon to treat a paralytic foot. Later, despite the favorable reports by renowned surgeons such as Petit, in 1799, Sartorius, in 1806, and Michaelis, in 1809 (*apud* David[1]), the procedure was widely criticized because it was believed to be very dangerous, with possibility of scarring, adhesions, and great risk of infection. To avoid such complications, Delpech, in 1816 (*apud* Strayer[2]), developed the percutaneous technique for the section of the Achilles tendon involved in the treatment of congenital clubfoot. William John Little, a pioneer of English Orthopaedics and well known for his contributions to the knowledge of cerebral palsy, had equinus secondary to poliomyelitis. During this author's training in Berlin, he was recommended for an evaluation of his sequela by Stromeyer, in Hanover. In 1836, Little (*apud* David[1]) underwent successful treatment to the percutaneous section of the calcaneus tendon. Little then became enthusiastic about the technique and spreading it in England and in the United States[1].

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The Achilles "Z" shaped section and lengthening were adequate for the cases of congenital club foot or flaccid paralysis caused by poliomyelitis. However, when these techniques were applied to the spastic equinus, some patients worsened and developed crouch gait. Equinus resulting from spasticity is frequently observed secondary to stroke and cerebral palsy and remains difficult to treat today. Any tendon lengthening always reduces muscle power, with possible interferences at the ankle, knee and, indirectly, at the hip. One of the first attempts to approach the equinus in a cerebral palsy patient was made by Stoffel[3]. This consisted of the selective denervation of both heads of the gastrocnemius, with the purpose of decreasing spasticity. However, other surgeons failed to reproduce the results reported by Stoffel, and the technique was forgotten.

In 1923, Silfverskiöld (*apud* Singh[4]) reported a clinical test to differentiate the equinus caused by the isolated retraction of the gastrocnemius from that caused by the retraction of the entire gastrocnemius-soleus complex. Silfverskiöld also developed a surgical technique to transfer the origin of both heads of the gastrocnemius, from the femur to the tibia[5]. This surgery was never popular, but, in 1950, Strayer[2] used the Silfverskiöld's concept to perform a selective release of the fascia of the gastrocnemius for an equinus correction. The objective was not only to obtain correction of the equinus but to avoid significant weakening of the triceps surae. This idea represented an improvement in the correction of the spastic equinus and it was then used by other authors who described other variations of the Strayer's techniques.

Relevant anatomy

Relevant anatomical details of the triceps surae have gained interest with the different surgical techniques to treat the spastic equinus. The gastrocnemius-soleus complex is a muscular unit whose primary function is to act at the ankle and to plantar flex the foot. The muscle also makes significant contributions at the knee maintaining the static and dynamic posture. The gastrocnemius-soleus securely inserts on the calcaneus, via the Achilles tendon. The triceps surae occupies the posterior compartment of the leg. The gastrocnemius comprises two heads that originate from the posterosuperior region of the femoral condyle. About 70% of the force of the gastrocnemius is generated by the the medial head[6]. A sesamoid bone, the fabela, occurs in 10% to 30% of the population and is found in the lateral head's tendon[7]. The medial head glides on a serous membrane which is in contact with the knee joint, and the bursa of the semimembranous muscle[8]. The two heads of the gastrocnemius converge to form a large aponeurosis that merges with the soleus aponeurosis. The identification of this fusion area is important for some selective lengthening techniques. In the popliteal region branches of the tibial nerve penetrate separately into the medial and lateral heads to innervate the gastrocnemius.

The third component of the triceps surae is the soleus which is formed by a large and voluminous muscle mass that lies deeply in relation to the gastrocnemius. It has both tibial and fibular origins in the proximal portion of the leg. In this region, the tendinous fibers converge to form a fibrous arch that provides passage to the tibial pedicle. The aponeurosis of the soleus occupies the anterior face of this muscle and thickens distally. It then fuses with the aponeurosis of the gastrocnemius to give rise to the calcaneus tendon[9]. The soleus is the most powerful muscle of the ankle and it represents more than twice of the entire flexion force[6]. The aponeurotic faces of the gastrocnemius and soleus are in contact and provide a slipping surface between the two muscles.

The calcaneus tendon is formed by the union of the aponeuroses of the gastrocnemius and soleus. It is a strong structure that is inserted onto the posterior tuberosity of the calcaneus. Although it is the largest tendon of the human body, it is also one of the most prone to degeneration and rupture[10]. Its blood supply comes from vessels originating from the posterior tibial artery that supplies the proximal and distal portions of the tendon. The less vascularized middle portion is supplied by branches arising from the fibular artery. Spatially, the Achilles tendon is twisted clockwise on the left side and counterclockwise on the right side[11]. Figure 1 illustrates the applied anatomy.

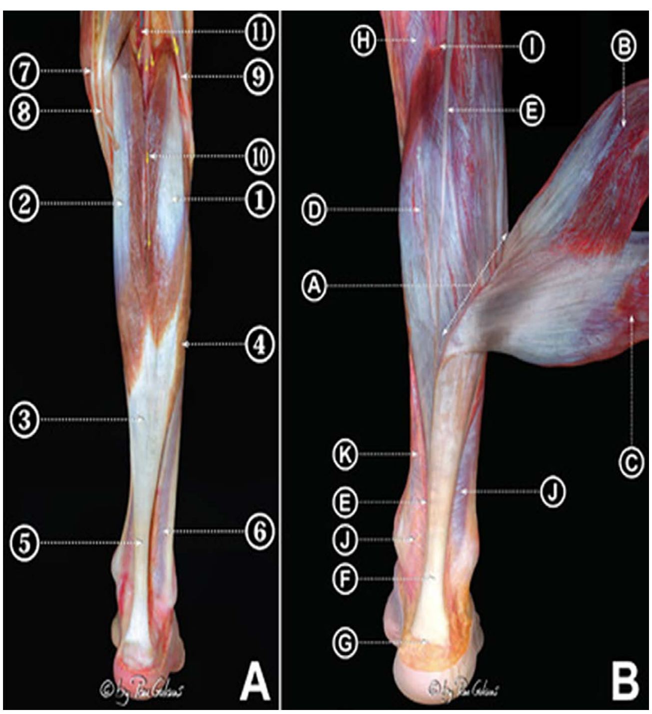

***Figure 1.** Relevant muscle-tendon anatomy of the calf. A) Posterior view of the superficial muscular layer: 1- lateral portion of the gastrocnemius, 2- medial portion of the gastrocnemius, 3- aponeurosis of the gastrocnemius, 4- soleus, 5- calcaneus tendon, 6- posterior deep fascia, 7- sartorius, 8- gracilis tendon, 9- common fibular nerve, 10- sural nerve, 11- tibial nerve; B) Separation of the gastrocnemius and soleus, illustrating the aponeurotic faces of the two muscles that are in contact. (A) fusion region of the gastrocnemius and soleus aponeurosis, (B) gastrocnemius lateral head, (C) gastrocnemius medial head, (D) soleus aponeurosis, (E) plantar tendon, (F) calcaneus tendon, (I) fibrous arch of the soleus, (J) deep posterior fascia of the leg, (K) medial intermuscular septum. Reprinted with permission of Dalmau-Pastor et al.[9].*

Clinical evaluation of the equinus deformity

The observation that the position of the knee influences the degree of dorsal flexion of the foot has been presented independently by Vulpius and Nutt, in 1913 (*apud* Singh[4]), and others[2]. However, the clinical test that differentiates the origin of the equinus secondary to the retraction of the gastrocnemius from that of the whole triceps, is associated with Silfverskiöld[4]. For this test, with the patient in the supine position, the foot is maintained in inversion to lock the mediotarsical joints and, with the knee in extension, dorsiflexion of the foot is forced, and the equinus quantified. Then, the knee is flexed. If there is significant increase in dorsiflexion, the retraction is mainly caused by the gastrocnemius. If there is no equinus change with the flexed or extended knee, the entire triceps surae is shortened (Figure 2).

For the spastic hemiplegic, Winters *et al.*[12] described four walking patterns. In Group I, there was equinus only in the swing phase. In Group II, there was triceps contracture, with equinus in weight bearing. The Group III was similar to Group II, but with knee involvement. In Group IV, besides the involvement of the knee, there were also changes in the hip.

However, it is in the diplegic patient that the evaluation of the equinus is more critical because these individuals are more vulnerable to iatrogeny. The equinus may not be fully apparent and may be associated with a flat valgus foot. Therefore, the evaluation should be performed with the foot in inversion to lock the mediotarsal joint. In addition, knee conditions, such as flexion deformities, hamstring retraction, and quadriceps strength should be carefully considered. Finally, the strength of the triceps surae should be carefully evaluated, since there may be an equinus deformity with weak triceps (retraction), and in this case, lengthening would worsen the gait.

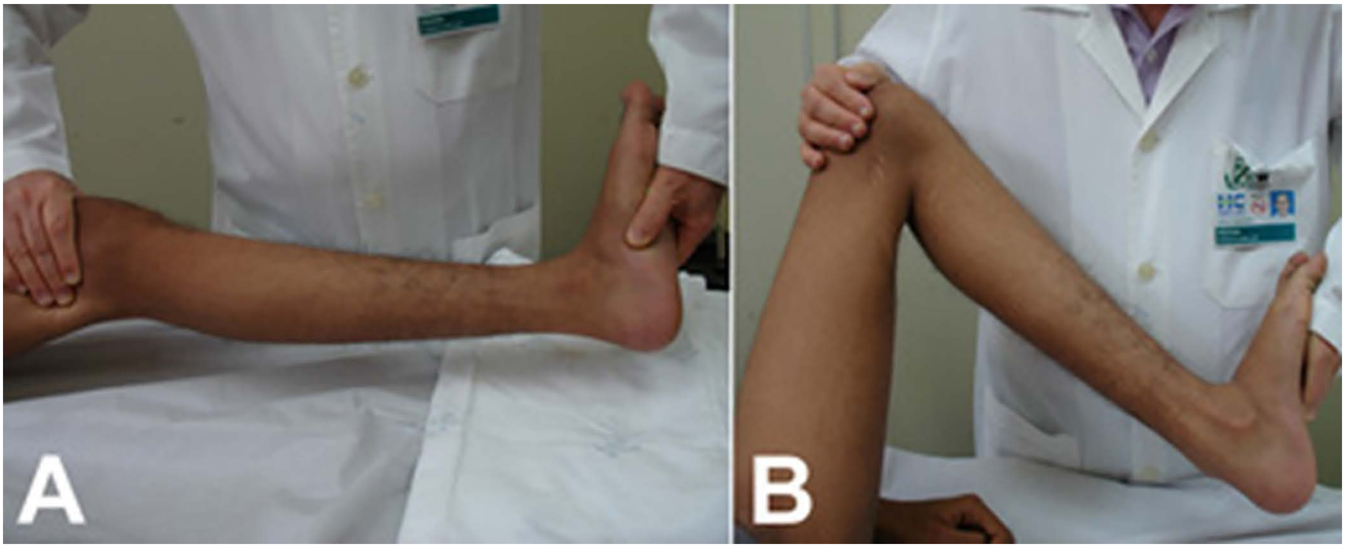

Figure 2. *Silfverskiöld test to differentiate flexion contracture caused by the gastrocnemius or by the whole triceps. (A) With the knee in full extension, forced ankle dorsiflexion reaches neutral (90°); (B) However, when the knee is flexed, the equinus disappears and the ankle can be brought in considerable dorsiflexion, which indicates that most of the gastrocnemius retraction is the cause of equinus. If there is no change, the whole triceps is shortened.*

METHODS

Using classical orthopedic books, we conducted a search for the most common surgical techniques to correct the equinus, and also looked for the original articles. Then, we searched the databases for the last ten years.

RESULTS

Surgical interventions for equinus correction

The gastrocnemius contracture is well documented in patients with neurological sequelae[4]. More recent studies suggest that isolated retraction of this muscle may be present in neurologically intact individuals[13] and be causal factor of afflictions of the foot, such as plantar fasciitis[14], mechanical metatarsalgia[15], and plantar ulcers in non sensitive feet[16]. Due to this diversity of conditions, the surgeon seeks to use the most appropriate technique to correct the equinus, taking into account the etiology, degree of deformity, patient's profile, and physical examination.

Postoperative immobilization should be performed for a short period of time, usually three to four weeks, and supplemented by orthosis. Gait and weight bearing during the immobilization period should start early.

The surgical techniques on the gastrocnemius-soleus-Achilles complex can be performed at five levels[17], as shown in figure 3. The correction capacity is greater for more distal releases, with maximum correction when performed at the Achilles tendon. However, the greater the elongation, the weaker the muscle becomes. The possibility of developing harmful secondary changes then increases. The time of immobilization is longer for more distal surgeries. Procedures in zones 3 and 4 require three weeks of immobilization and early walking.

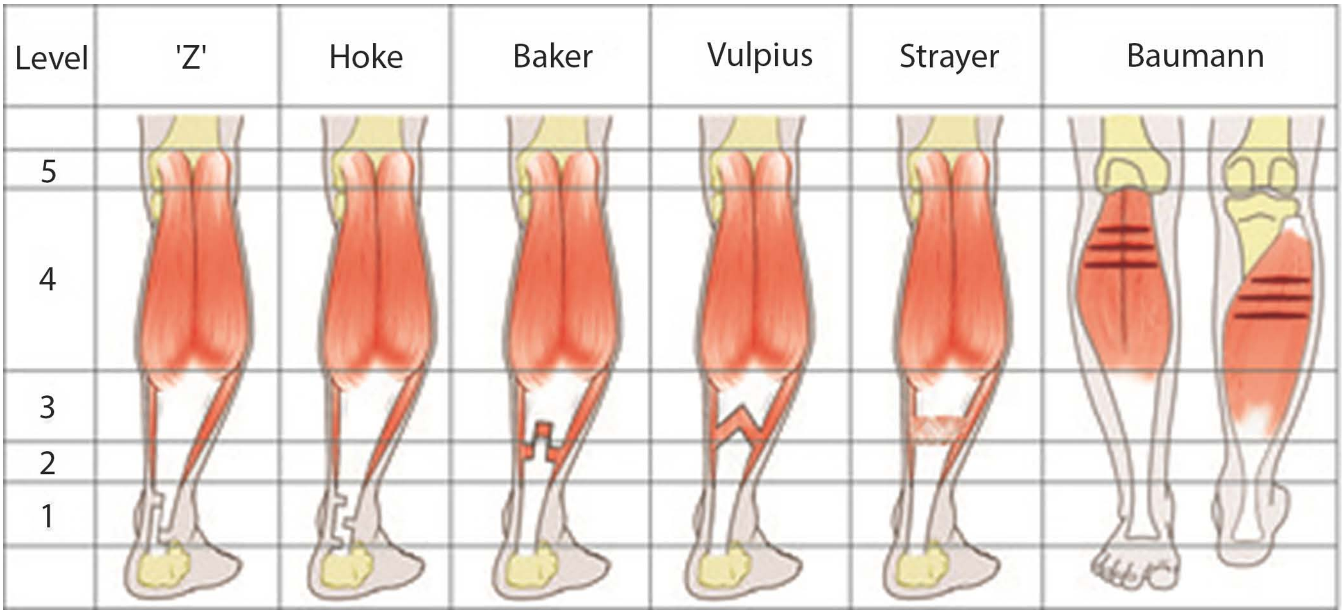

Figure 3. *Illustration of the anatomical levels of the triceps surae and the most common surgical procedures at each level for the equinus correction. Reprinted from Firth GB et al.[17], with permission, and adapted.*

1) Interventions in zone 1: Achilles tendon

These techniques affect both the gastrocnemius and soleus and they weaken the whole muscle complex. In the 1930s, in the United States, Achilles percutaneous tenotomy was abandoned because of its potential deleterious effects, such as crouching, calcaneus gait and weakening at the knee and hip[18]. However, at that time, tenotomies comprised a complete transection of the tendon and the etiology of the deformity was not taken into consideration. For this reason, open tendon lengthening in a "Z" fashion was preferred. Hatt and Lamphier, in 1947[19], showed good results with the triple percutaneous hemisection of the Achilles tendon and credited to Hoke with originality of the idea. Later, Bleck[20] performed the triple hemisection of the tendon, performed openly as a way to treat the spastic equinus and avoid hypercorrections.

Complete percutaneous Achilles tendon section

This technique is currently used for the equinus correction for patients with congenital clubfoot treated by the Ponseti method. The tendon section can be performed with a delicate surgical blade or a large gauge needle[21]. In cerebral palsy it may be indicated for the most severe cases (Grade V Gross Motor Function Classification System – GMFCS V), with the purpose of adapting to orthoses, shoes or wheelchairs. The complete Achilles transection is formally contraindicated for ambulatory patients, due to the risk of triceps weakening, with severe consequences at the ankle, knee and hip[22]. The transection is performed at the narrower portion of the tendon, which corresponds to its hypoascularized region (Figure 4).

The Achilles "Z" lengthening

The Achilles "Z" lengthening is a classic technique, but currently it has limited use. It can be performed as a procedure associated with neglected congenital clubfoot[23], or in the hemiplegic spastic child (GMFCS I or II), with significant deformity, taking care not to cause excessive correction and weakening of the triceps surae.

A straight cutaneous incision is made over the medial border of the tendon and its posterior aspect is exposed while avoiding injury to the adjacent soft tissues that carry the vascularization.

After longitudinal cut in the tendon, the surgeon performs the proximal and distal hemisections. Dissection of the two arms of the "Z" must be avoided. The foot is dorsiflexed until 90° so that the two hemisections slide in relation to each other. They are then sutured together (Figure 5). One potential complication is the wound dehiscence as the skin is this region is poorly vascularized, especially in adults.

Triple hemisection technique (Hoke[24])

Although the triple hemisection technique of the calcaneus tendon has not been the subject of a specific publication by Hoke[24], it appears in an article by this author on flat foot treatment. It may be performed by an open approach, as reported by Bleck[20], or percutaneously, as a relatively safe technique[25]. With the patient in the supine position and the extremity of the foot forced against the body

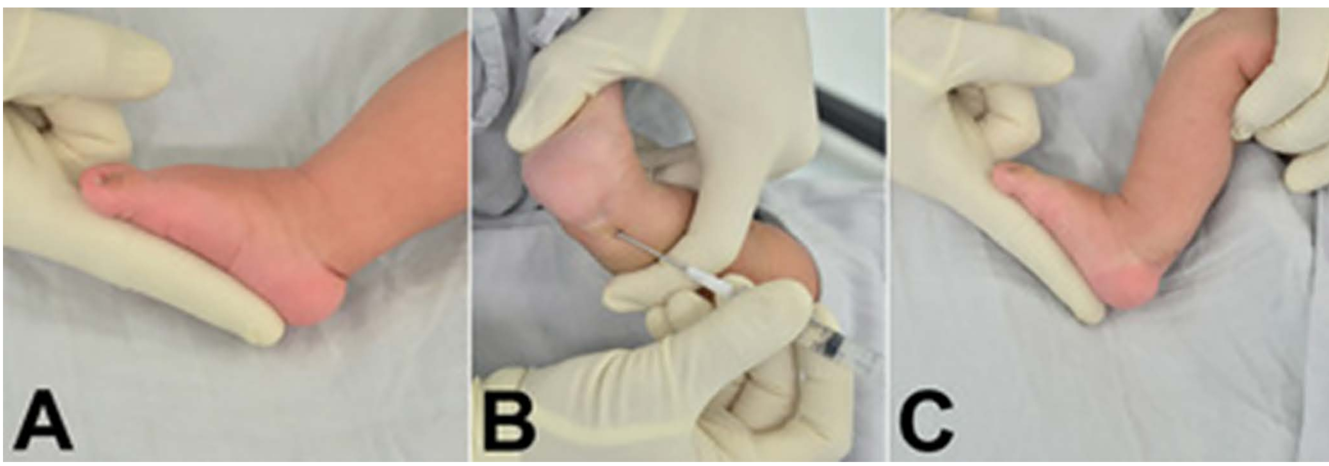

Figure 4. *Percutaneous section technique of the calcaneus tendon in congenital clubfoot. (A) The equinus is evaluated and the narrower portion of the tendon is identified, as well as its lateral and medial borders; (B) The scalpel blade or a thick needle penetrates at the medial border of the tendon which is completely transected; (C) Illustration of the obtained correction. Signs of complete section are the ankle dorsiflexion, the appearance of a depression in the cut region, and the lack of plantar flexion when squeezing the calf (Simmonds or Thompson's Sign).*

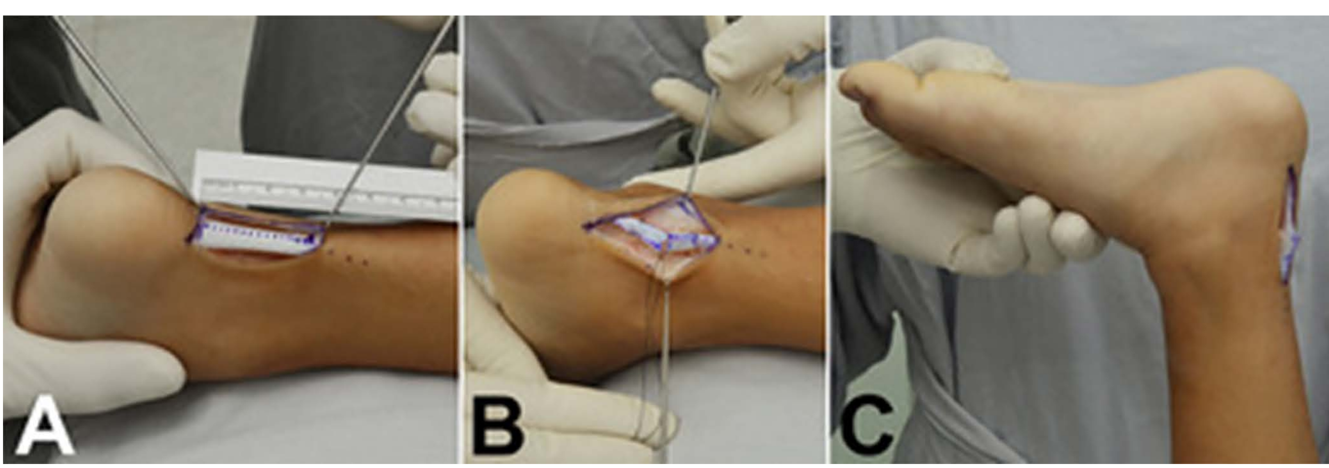

Figure 5. *Technical steps for "Z" lengthening of the calcaneus tendon. (A) Only the posterior aspect of the tendon is exposed, and the "Z" is drawn; (B) The tendon stumps are sutured in the neutral position of correction (C).*

of the surgeon, the borders of the calcaneal tendon are identified by palpation. Three cuts are made through the skin: the most distal is near its insertion, from the tendon center, to its medial border. The intermediate cut is made one inch above the distal cut, from the center of the tendon to the its lateral edge. Finally, the third cut is one inch proximal to the middle cut, from the center of the tendon to its medial border (Figure 6). In children, instead of using an inch (2.5cm), the length of the distal phalanx of the patient's own thumb is used.

The tendon hemisections are made percutaneously and then the foot is forced into dorsiflexion, which will cause the tendon to stretch, thus lengthening (Figure 6). Bleck[20] reported a large use of this technique, with no cases of overcorrection. Potential complications by the closed technique include injury of neighboring structures (sural nerve, tibial nerve and tendon of the flexor hallucis longus), and rupture of the cuts[26].

2) Interventions in zones 2 and 3: selective lengthening

Selective lengthening interventions in zones 2 and 3 are preferred for spastic equinus correction, when the Silfverskiöld test shows gastrocnemius retraction and little or no soleus involvement.

Vulpius technique[17]

With the patient in the supine position, the muscle-tendon junction is identified by palpation and a longitudinal midline incision is performed. Close to the muscuotendineous junction, an inverted "V" section is made through the layers formed by the aponeuroses of gastrocnemius and soleus, with the apex of the cut located at the midpoint of zone 2. The median raphe is also sectioned. The ankle is forced in dorsiflexion with separation of the cutting edges that expose the soleus muscle, which is maintained intact (Figure 3).

One variant is the Baker lengthening[27], which is performed in the same region of the Vulpius technique, but the cut is made in an inverted "U" shape. Dorsiflexion is applied by promoting the separation of the horizontal arm of the "U" shape[28]. The Baker and Vulpius procedures are similar and differ only in relation to the cut shape. Although the Vulpius lengthening is often associated with an inverted "V" cut, in the author's original description the cuts may also be horizontal or diagonal[17] (Figure 3).

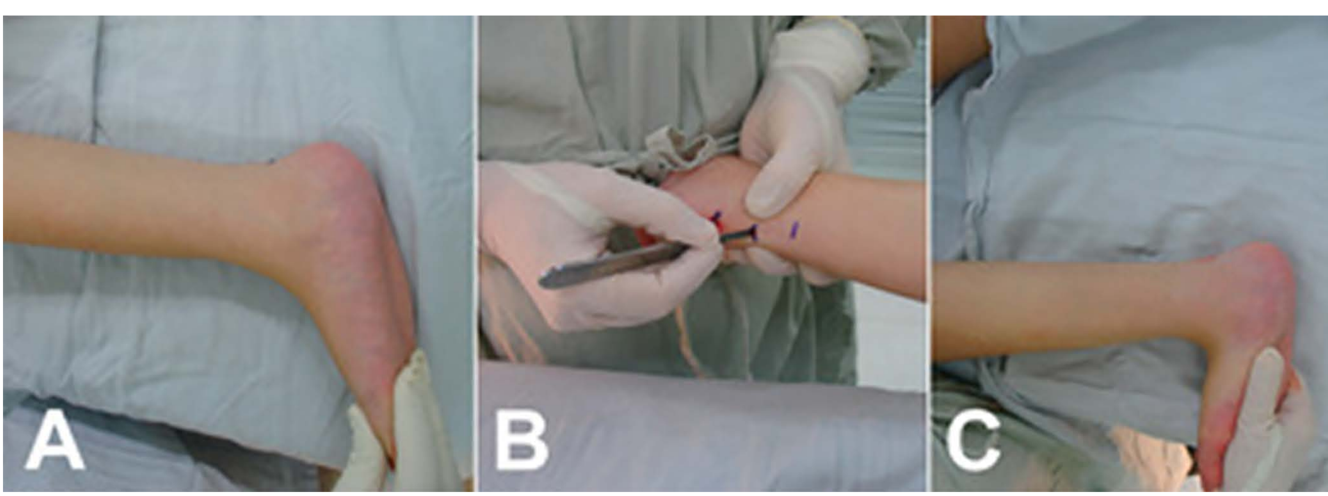

Figure 6. *Illustration of the technique of the triple percutaneous Achilles hemisection (Hoke). (A) The equinus is evaluated; (B) The forefoot is forced against the surgeon's body to thighten up the calcaneus tendon. The tendon borders are identified by palpation. The tenotomies marks are made on the skin. The more distal cut (near the calcaneus) is made from the center of the tendon to its medial edge. The next hemisection is made at the second mark, from the center of the tendon to its lateral edge. The most proximal hemisection is made from the center of the tendon to its medial border; (C) With the knee extended, the foot is carefully forced until 10° of dorsiflexion is obtained. Overcorrection is avoided.*

Strayer technique[2]

The Strayer lengthening[2] is often used in the treatment of spastic equinus. It is especifically indicated when the Silfverskóld test is positive. The tendon is approached with the patient in the prone position, through a median straight incision on the muscletendon junction identified by palpation (Figure 7). As the sural nerve crosses the region, it must be identified and protected. The anatomical separation between the aponeuroses of gastrocnemius and soleus is dissected and the former is cross-sectioned in zone 3. The ankle is then dorsiflexed, promoting equinus correction. If the correction is incomplete, the aponeurosis of the soleus may be sectioned. If residual equinus is still present, the median raphe is dissected and sectioned under direct vision. Some people refer to these last complementary procedures as a modified Strayer[29].

One of the drawbacks of performing the classic Strayer technique is that the skin scar becomes very apparent and sometimes retracts and adheres. The same surgery can be conducted by a medial access, with the advantage of being performed in the supine position, which may facilitate other procedures when performing corrections at multiple levels. Special care should be taken to spare the sural nerve.

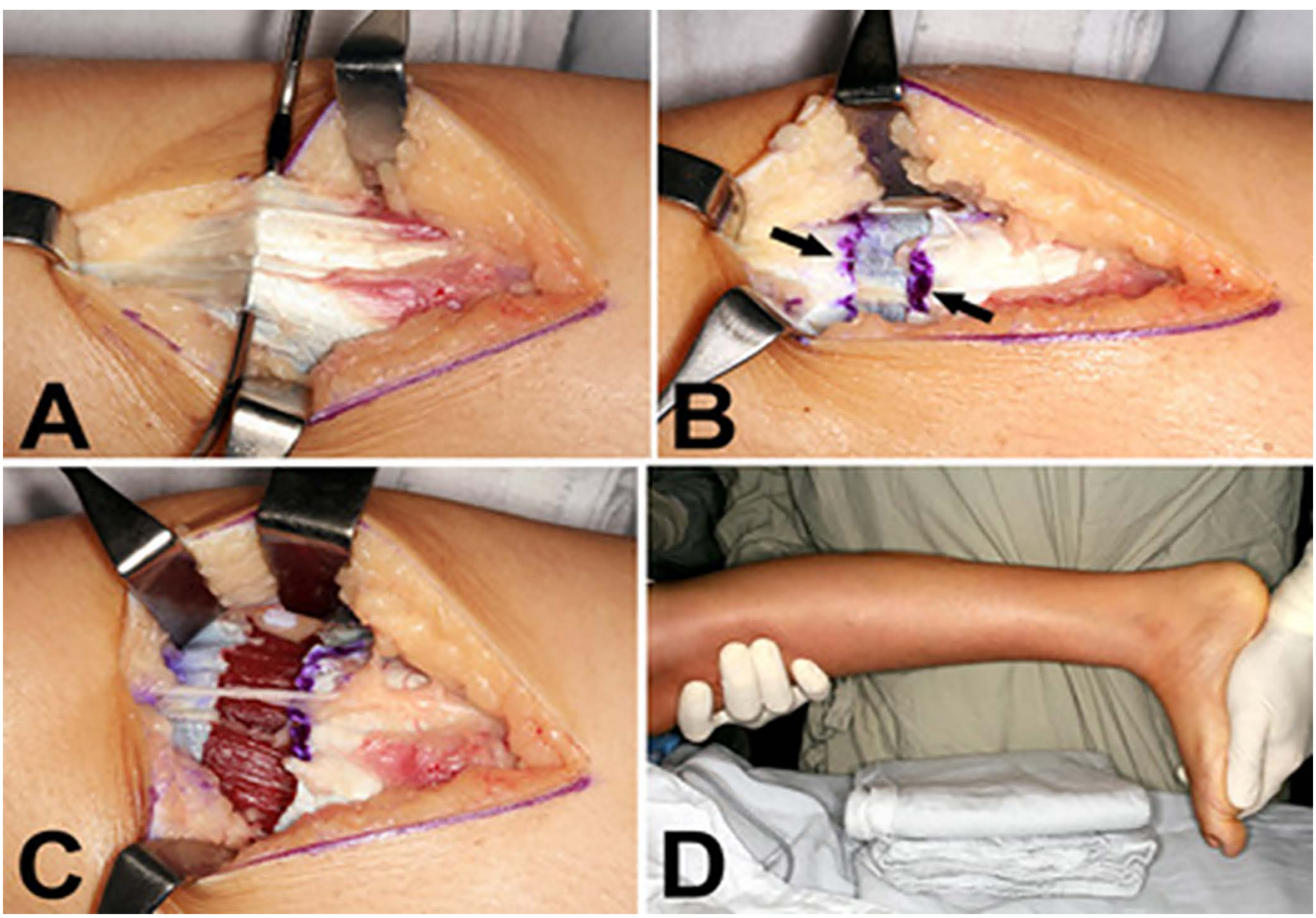

Figure 7. *Main surgical steps for the Strayer selective lengthening. (A) Through a median incision on the posterior aspect of the calf, the gastrocnemius is approached and its aponeurosis is detached from that of the soleus; (B) After the section of the gastrocnemius aponeurosis, the foot is dorsiflexed and the extremities of the sections move away from each other (arrows). Deep into the incision, the aponeurosis of the soleus is observed; (C) The aponeurosis of the soleus can also be sectioned to increase the correction. Notice the sural nerve crossing the surgical field. If the nerve is stretched, paresthesia may occur; (D) Correction obtained.*

Some authors and even textbooks do not differentiate the Strayer's techniques from the techiques described by Vulpius and Baker. However, they are different procedures, because in the Strayer technique the release is sequential and even with section of the aponeurosis of the soleus, the lengthening levels between the two muscles are different, as shown in figure 6. In contrast, in the Vulpius and Baker procedures, on the other hand, there is a section of both aponeuroses on the same level they retract equally and may cause further decrease in the plantar flexion power[30].

3) Interventions in zone 4

Technique of Baumann and Koch[31]

According to Firth *et al*.[17], this lengthening technique provides the least correction compared to the others. It takes advantage of the anatomical relationship of the aponeuroses of the gastrocnemius and soleus which are in contact, and slide one over the other (Figure 1). The triceps surae is approached by an 8.0-12.0cm-long incision on the inner side of the middle third of the leg. Care is taken not to injure the saphenous vein. The space between the muscles is dissected and three incisions are made in the aponeurotic portions of each one. These sections should lie at different levels between the two muscles to avoid adhesions (Figure 3). The equinus is corrected by forcing the dorsiflexion.

4) Interventions in zone 5

Fasciotomy of the medial head of the gastrocnemius

This intervention is indicated in painful affections of the foot, such as metatarsalgias and fasciitis. Through a small transverse posterior incision, the medial head of the gastrocnemius is approached and its fascia is sectioned. Care should be taken not to impair the muscle innervation, especially by forced removal of soft tissues.

FINAL CONSIDERATIONS

In anatomical terms, the triceps surae can be divided into five zones, and interventions on each level lead to varying degrees of equinus correction, as well as to different side effects. Over time, several techniques have been described and, as a general rule, the more distal the correction, the greater is the corrective effect, but it is associated with greater muscle weakness. The orthopedist should be familiar with one technique at each level. The choice of the technique should take into account not only the corrective effect, but also the etiology, degree of deformity, associated deformities, profile and the age of the patient. Currently, for a spastic patient who walks, there is a preference for the selective techniques that release the distal aponeurosis of the gastrocnemius, with preservation of the soleus, in order to maintain the main power in plantar flexion.

R E S U M O

A deformidade em equino leva a diversos transtornos da marcha, ao causar alterações no apoio do pé e afetar regiões anatômicas mais distantes, como o joelho, quadril e tronco. Geralmente é secundária à retração, encurtamento ou espasticidade do tríceps sural, de modo que algumas intervenções cirúrgicas podem ser necessárias para corrigi-la. Trata-se de um dos procedimentos mais antigos da Ortopedia, antes realizado apenas no tendão calcâneo e que, ao longo do tempo, evoluiu com técnicas diferentes de acordo com o grau de deformidade, doença de base e perfil do paciente. Busca-se corrigir a deformidade, com a menor interferência possível na força muscular e, com isso, diminuir a incidência de complicações, como marcha agachada, arrastada e pé calcâneo. Do ponto de vista anatômico, o tríceps sural apresenta cinco regiões que podem ser abordadas cirurgicamente para correção do equino. Em virtude da complexidade do paciente com equino, os ortopedistas devem ter experiência com ao menos uma técnica em cada zona. Neste texto são abordadas e analisadas criticamente as técnicas mais importantes para correção do equino, principalmente de modo a evitar complicações. Foi realizada uma busca sobre técnicas cirúrgicas mais comuns de correção do equino em livros clássicos e identificação e consulta aos artigos originais. Em seguida, fez-se uma busca em bases de dados nos últimos dez anos.

Descritores: *Pé. Articulação do Tornozelo. Tendão do Calcâneo. Revisão. Pé Equino.*

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