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Review

Surgical Techniques of Gastrocnemius Recession and Achilles Tendon Lengthening (Descriptive Review Article)

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Abstract: This paper aims to review the various surgical techniques for gastrocnemius–soleus recession and Achilles tendon lengthening, with a special focus on the treatment of clubfoot and cerebral palsy (CP) equinus contracture. This descriptive review article comprehensively explores different techniques for gastrocnemius recession, including the Hoke percutaneous triple hemisection, Baker's method (Tongue-in-Groove Gastrocnemius–Soleus Recession), the Vulpius method, the Baumann procedure, and the Strayer procedure (Gastrocnemius Recession). The objective is to present a detailed analysis of these methods, covering their indications, procedural nuances, relevance in clinical practice, and outcomes.

Keywords: Achilles tendon lengthening; clubfoot; equinus contracture; cerebral palsy

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1. Introduction

Achilles tendon lengthening is a surgical procedure that can be used to treat various foot and ankle pathologies characterized by equinus contracture in patients with neuromuscular disorders such as cerebral palsy (CP) and other comorbidities including clubfoot, neuropathic foot ulcers, and toe walking [1–3]. If left untreated, these conditions can cause problems in gait, lack of normal equilibrium, and ankle instability [1,2].

In the context of treating equinus deformity, various surgical procedures for Achilles tendon lengthening are utilized, as depicted in Figure 1. As presented in Table 1, each technique is tailored to address the specific characteristics and severity of the deformity. The choice of procedure depends on factors such as the patient's age, the extent of the deformity, and underlying pathologies. These surgical methods aim to correct the limited ankle dorsiflexion associated with these conditions, thereby improving gait and reducing complications. The selection and application of a specific Achilles tendon lengthening technique is a crucial decision in the effective management of an equinus deformity.

The Silfverskiöld test is widely used to identify equinus attributable to isolated gastrocnemius contracture by evaluating ankle dorsiflexion with the knee extended and flexed. The test aims to identify isolated gastrocnemius–soleus complex pathology requiring lengthening of the Achilles tendon and determines whether isolated gastrocnemius recession or tendo-Achilles lengthening is required [4].

Patients undergo tendo-Achilles lengthening if the ankle cannot be dorsiflexed to zero degrees while the knee is in flexion [5]. This indicates a negative Silfverskiöld test suggesting that a fixed Achilles contributes to the equinus deformity instead of a gastrocnemius contracture, which is resolved through tendo-Achilles lengthening [6]. If the equinus resolves with a flexed knee, it is an indication of a positive Silfverskiöld test and that the

gastrocnemius is contributing to the equinus deformity, concluding that a gastrocnemius recession procedure should be performed [6].

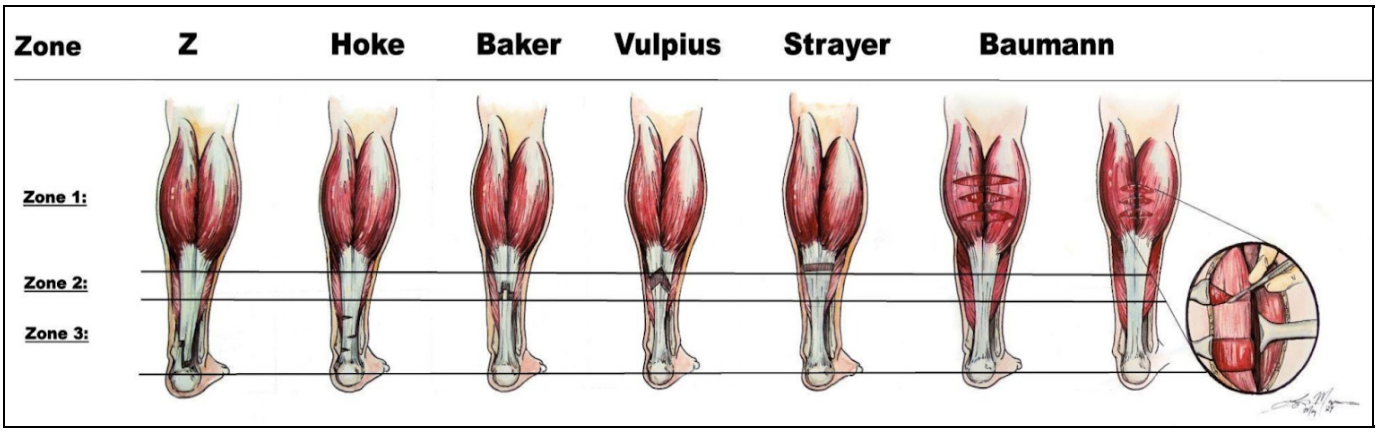


Figure 1. Illustrations depicting the commonly used Achilles tendon and gastrocnemius–soleus lengthening procedures, as well as their position along the posterior superficial compartment of the leg used for the treatment of equinus deformity. (Reproduced, with permission, from Elizabeth M. Mazepa, Peri-Operative Care, Realism Portrait Artist RPN).

Table 1. Considerations Influencing choice of procedure: procedure name, zone description, selection criteria, advantages, and disadvantages/complications.

Procedure	Zone	Selection Criteria	Advantages	Disadvantages/Complications
Baumann	Zone 1: Isolated deep Gastrocnemius recession	Positive Silfverskiöld test Mild to moderate equinus Isolated gastrocnemius contracture Spastic and nonspastic flatfoot with mild to moderate equinus Neuromuscular disease (diplegic CP), where over-lengthening causes crouch gait Athletic individuals, where preserving muscle mass and strength is preferable Pediatric patients, where preserving the musculotendinous junction is crucial for growth and reducing developmental risks	Controlled, selective and stable intramuscular recession Conservative lengthening reduces risks of over-lengthening Avoids calf weakness by conserving muscle integrity and power Preserves gastrocnemius–soleus tendinous complex, origin, and insertion Enhanced cosmesis Minimal risk to sural nerve Minimal lifestyle disruption, immediate postoperative mobility Effective in multi-level surgery Decreased wound and scarring complications compared to TALs and Strayer GR Reduced risk of muscle rupture Improves muscle belly-to-tendon ratio No risk of gastrocnemius muscle proximal migration	Less lengthening compared to TALs Calf muscle atrophy in 0–20% Potential for recurrence of equinus (10%), especially in neurological patients (24%) Complications associated with injury to the sural and saphenous nerves, greater saphenous vein at the incision site
Strayer	Zone 1 Isolated Gastrocnemius recession	Positive Silfverskiöld test Isolated but moderate gastrocnemius equinus Diagnosis of common chronic foot conditions such as symptomatic adult flatfoot deformity, hallux valgus and plantar fasciitis, foot ulcers, metatarsalgia and Haglund's deformity It should be used when multiple procedures are performed with supine patients	Performing an isolated gastrocnemius recession decreases the risk of Achilles tendon over-lengthening or rupture Stable and straightforward procedure Lowest risk of skin-related complications when compared to other Zone 1 procedures	Sharp dissection is often needed and increases the risk of iatrogenic sural nerve and saphenous vein injury if not identified and protected during the procedure Release on the lateral side is difficult Risk of recurrence if postoperative care is inadequate Over-lengthening may result in excessive ankle dorsiflexion and an incorrect gait cycle

Table 1. *Cont.*

Procedure	Zone	Selection Criteria	Advantages	Disadvantages/Complications
Baker	Zone 2 Isolated Gastrocnemius recession	Positive Silfverskiöld test Primarily indicated in cerebral palsy, with associated isolated moderate/severe pes equinus or spastic hemiplegia It should be used when multiple procedures are performed with a prone patient	Not selective, but facilitates greater lengthening of the combined gastroc–soleus aponeurosis and fascia when compared to Zone 1 procedures Low risk of Achilles tendon over-correction The dissection of the soleus aponeurosis eliminates the stretch reflex and decreases the risk of clonus	Visible scar (poor cosmesis) Most risk of sural nerve injury Undercorrection and high recurrence rates of the equinus deformity require repeat surgery if the patient is under 5 years of age
Vulpius	Zone 2 Combined gastroc–soleus recession	Negative Silfverskiöld Neuromuscular disease (CP) Ineffective non-operative treatments Contracture involving both the gastrocnemius and soleus muscles Clubfoot treatment after equinus despite initial Ponseti protocol treatment Adjuvant to selective tendon lengthening based on ulcer location in neuropathic foot ulcers	Lengthening similar to TALs, but with more precise control Preserves function and avoids over-lengthening Effective in severe contractures Effective in multi-level surgery No delays, nonunion, or increased contracture due to prolonged immobilization often seen in TAL procedures Immediate weight bearing Minimal lifestyle disruption	Risk of gastrocnemius muscle proximal migration when there is complete gastrocnemius release Longer skin incision Risk of injury to the lesser saphenous vein and the sural nerve Potential for improper correction
Z-Lengthening	Zone 3 Achilles tendon	Negative Silfverskiöld test Neuromuscular disease (CP) Severe equinus contracture > 20° Patients with clubfoot requiring significant lengthening Adjuvant to Ponseti casting for clubfoot	Simple technique Allows for strong tendon connections after significant lengthening	Recurrence of ankle equinus Difficulty measuring required lengthening, potentially leading to over-lengthening, calcaneus deformity, and crouch gait in CP patients with diplegia Open procedure risks damaging soft tissue and blood supply, leading to scarring, adhesion, and pain Risk of adhesions between the tendon and soft tissues, leading to loss of function of the Achilles tendon
Hoke	Zone 3 Achilles tendon	Negative Silfverskiöld test Neuromuscular disease (CP) resulting in severe spastic equinus deformity Recurrences of structural Achilles tendon shortening after >6 months of conservative treatment Manage residual contracture during ankle arthroplasty or post-Vulpius treatment Severe idiopathic and rigid neurogenic clubfoot	Highly effective procedure with optimal recovery duration Significantly greater lengthening of the Achilles tendon when compared to Zone 1 or Zone 2 procedures Minimally invasive when compared to other TAL procedures—small incisions with reasonable lengthening	Not selective or stable and carries the greatest risk of overcorrection of the Achilles tendon (may result in crouch gait) Blind procedure (not precise, which is generally the case with minimally invasive procedures) May cause push-off weakness during the gait cycle Ideal for the first treatment of equinus deformity, but not for revisions

In this study the authors outline the Hoke, Z-lengthening, Baker, Strayer, Baumann, and Vulpius techniques of Achilles tendon lengthening and gastrocnemius recession. This includes indications, surgical technique, perioperative care, and potential complications associated with each. These procedures are categorized based on three anatomical zones of the gastrocnemius–soleus complex, allowing the selection of the most appropriate technique based on specific clinical requirements. The authors present a wide range of evidence that substantiates the perceived benefits and drawbacks of performing each procedure within different anatomical zones.

In Zone 1, the lengthening procedures target the proximal part of the gastrocnemius–soleus complex. These can be selective, affecting only the gastrocnemius, or differential, impacting both the gastrocnemius and the soleus to varying degrees. The Baumann and

Strayer procedures are performed in this zone. These procedures are noted for their stability, but offer limited degrees of lengthening.

In Zone 2, lengthening techniques, such as the Baker and Vulpius procedures, target the distal part of the gastrocnemius aponeurosis combined with the soleus fascia. These techniques are not selective but ensure greater stability and provide significantly more lengthening than Zone 1 interventions.

Procedures in Zone 3, like the Z-lengthening and Hoke percutaneous triple hemisection, target the actual Achilles tendon and are characterized by their non-selectivity and instability, but result in the greatest degree of lengthening compared to the other zones. These techniques are essential for cases requiring substantial correction of tendon length.

Table 1 presents a summary of the considerations that may influence the choice of procedure. Table 1 includes each procedure name and a description of the zone which corresponds to it. Additionally, Table 1 highlights certain selection criteria, advantages, and disadvantages associated with each lengthening procedure. Figure 1 presents an illustration depicting the Achilles tendon and gastrocnemius- soleus lengthening procedures discussed in this article, highlighting their position along the posterior superficial compartment of the leg. The magnified portion of Figure 1 offers a more detailed analysis of the surgical incisions made in the Baumann procedure.

This paper aims to highlight the indications for each technique, the procedural intricacies involved, expected outcomes, potential complications, and challenges inherent in these procedures. By presenting a comprehensive analysis of these surgical methods, this paper seeks to enhance the understanding of gastrocnemius recession, combined gastroc–soleus recession, and Achilles tendon lengthening in treating equinus deformity, providing valuable insights for orthopedic surgeons and clinicians in optimizing treatment strategies for affected patients.

2. General Management

Preoperative examinations were critical in finalizing the choice of procedure. Considerations included surgical site infections, bone-related dorsiflexion deficits, and isolated shortening of the gastrocnemius muscles, notably accompanying underlying diplegic cerebral palsy as contraindications for the triple hemisection procedure [7]. Detailed preoperative physical examinations to understand the motor and sensory function of the areas of operation were performed [8]. Additionally, a Silfverskiold test was employed in several studies across all procedures to distinguish between Achilles tendon and isolated gastrocnemius contracture [4,9–11]. A recent review by Santacaterina et al. on the surgical management of Achilles tendinopathy highlighted that post-operative management generally includes two phases. The first phase is the initial healing phase, which begins immediately after the operation and typically lasts for the following 14 days. This phase involves early mobilization of the ankle joint while "avoiding the functional overload of the tendon". The authors suggest this may be achieved by allowing the patient to use a splint and walk using crutches. Subsequently, the second phase begins and involves daily passive and active mobilization exercises of the ankle joint with possible weight bearing [12].

Thus, it may be concluded that earlier motion post-operatively in all procedures would help sustain the tendon length achieved intraoperatively to allow for earlier weight bearing.

3. Zone 3 Procedures: Hoke: Percutaneous Triple Hemisection

3.1. Hoke: Percutaneous Triple Hemisection

3.1.1. Overview

Dr. Michael Hoke first introduced the triple hemisection technique in 1931 for correcting equinus contracture, and it was described in further detail by Hatt and Lamphier in 1947 [12]. Today, it is used to surgically treat severe idiopathic ankle joint deformity or contracture of both the gastrocnemius and the soleus exceeding 30° with no improvement in ankle dorsiflexion upon knee flexion [8,12,13].

The surgical procedure requires the patient to be supine, with the leg extended and foot maximally dorsiflexed. The Hoke technique requires three equidistant incisions to be made along the Achilles tendon, separated by no less than 3 cm. This distance is to ensure that the blood supply between each incision remains unaffected [2,3]. A sharp blade is then inserted into the midline of the Achilles tendon, rotated transversely, and used to complete the medial and lateral incisions. Under mild tension of the Achilles tendon, the surgeon carefully controls the blade depth to incise approximately 50% of the tendon with each cut. Proximal and distal cuts are performed medially, and the middle cut is performed laterally to reduce the risk of injury to the sural nerve [2,3].

The goal of this procedure is to permit the lengthening of the Achilles tendon with the foot in the dorsiflexed position by allowing it to slide on itself before immobilization and healing [12,14].

3.1.2. Preference and Indications

The Hoke technique is less invasive when compared to other tendo-Achilles lengthening (TAL) procedures, but it is powerful and carries the greatest risk of over-lengthening the Achilles tendon [15]. Thus, age, desired level of activity, underlying pathologies, and postoperative rehabilitation are to be considered. The Hoke procedure is commonly used to treat equinus in patients with cerebral palsy, preferably over 5 years [7,14]. The indication includes patients presenting with symptomatic equinus accompanying Achilles tendon contracture who are independent of underlying disease, and those with recurrences of structural Achilles tendon shortening exceeding 6 months where conservative measures were attempted first [7]. Finally, it may be used to correct the equinus during an ankle arthroplasty and manage residual contracture following treatment with the Vulpius technique, which will be discussed later [1].

Hoke triple hemisection is applicable in the treatment of equinus associated with cerebral palsy, with cerebral palsy subtype and age at index surgery being the two most important variables for post-operative functional outcomes [16,17]. Dietz et al. demonstrated the use of the Hoke procedure in spastic ankle equinus in ambulatory patients with cerebral palsy [16]. Katz et al. have also reported functional advantages when using the Hoke percutaneous triple hemisection in children aged 4–7 with spastic diplegia cerebral palsy. Additionally, Hoke triple hemisection is also indicated in patients with severe idiopathic and rigid neurogenic Clubfoot [18,19]. The surgery aims to improve ankle joint function and appearance while avoiding complications such as skin infection or necrosis.

3.1.3. Management

Notable pre-operative measures including weight-bearing radiographs, magnetic resonance imaging, and neural electromyography were performed on the ankle joint and Achilles tendon [8]. Plaster was used under anesthesia and casting occurred on the first postoperative day, followed by pain-adapted full weight bearing and discharge [7]. A nerve block, epidural anesthesia, or general anesthesia was also used with a thigh tourniquet [8,14]. When comparing the studies of Struwe and Zhang, both noted that the strategy of percutaneous complete Achilles tendon lengthening should be between 5 and 7 cm (proximal to middle to distal) [7,8].

Post-operatively, Struwe and colleagues suggest cast application with the foot in a neutral position (less than 5° dorsal extension) and reinforcement by wrapping a synthetic support bandage on the first postoperative day. Then, patients are to spend four weeks with a circular lower leg cast with full, pain-adapted weight bearing. This period is followed by mobilization through physiotherapy. Inpatient discharge was between the first and second postoperative days upon independent mobilization on stairs and around wards [7].

Similarly, Bleck et al. emphasize the vitality of the application of postoperative plaster while the foot is in neutral dorsiflexion only [20]. To restore strength, the tendon should not be over-lengthened by forcing the foot past neutral dorsiflexion. The use of a long-leg plaster for six weeks and a below-the-knee plaster after three weeks has also been suggested.

Patients were permitted to walk with weight bearing to tolerance on the first postoperative day. Children typically took two postoperative days. Crutches and walkers were only used for postural stability [7,20]. A post-operative, non-weight-bearing period has also been observed, where the leg is protected in a boot for 4–6 weeks to prevent accidental rupture of the Achilles tendon [1].

3.1.4. Surgical Outcomes

Struwe et al. followed 104 patients between 2 and 73 years old who were operated on with the modified Hoke achillotenotomy. They reported 62% of cases as the sole intervention and 38% of cases involving both limbs. There was no infection, overcorrection, or Achilles tendon rupture. There was one case of postoperative relapse due to a broken cast [7].

The study by Dietz et al. employed both the Hoke triple hemisection and coronal Z-Z-lengthening, which were both performed 56 times in patients with cerebral palsy. Of the 79 patients who underwent 114 complete Achilles tendon lengthening procedures, the results were best in hemiplegic and non-hemiplegic patients requiring single-leg surgery. However, there was no significant difference in the outcomes between the Hoke triple hemisection and Z-Z-lengthening procedures [16].

The functional outcome of the Hoke TAL was assessed by Katz et al., who performed 52 triple hemisections which showed an average of 19.2% recurrence in a 5–10-year follow-up period. Recurrence was 16.2% in diplegic feet and 26.6% in hemiplegic feet, and 80% of recurrence appeared in children who had operations between 3.5 to 5 years [21]. Borton et al. performed and reviewed 195 isolated calf-lengthening procedures in 134 children: 45 with hemiplegia, 65 with diplegia and 24 with quadriplegia. The recurrence was similar to that of Katz et al. at 22%, with the Hoke method being the "least predictable" in diplegia [9,21]. The type of surgery did not influence the outcome in patients with hemiplegia or quadriplegia [9]. One may argue that there are other factors to consider before employing Hoke triple hemisection in cerebral palsy. These include the type of cerebral palsy/severity, female gender [9], age at operation (<8), and presence of aponeurosis muscle lengthening.

Similarly, Zhang et al. investigated the recurrence rate of Achilles tendon contracture following triple hemisection percutaneous complete Achilles tendon lengthening in 33 patients with an average age of 25.2 years. Postoperative treatment involved the use of plaster cast and rehabilitation training. In this study, all patients were followed up with an average period of 56.31 months, and the recurrence rate was 5.7% (foot drop), with one case of mild valgus ankle joint [8]. In the treatment of congenital right clubfoot in a 27-year-old female, the results showed improved ankle function and no recurrence of Achilles tendon contracture 3 years postoperatively [8]. Given these varying outcomes, clubfoot must be treated along with ankle joint rehabilitation in patients with clubfoot. While some patients had restored plantigrade, recurrence was not completely omitted from these results [8,18].

3.1.5. Complications

Risks include an imbalance of the soft tissue strength in cases of Achilles tendon contracture among adult populations, where the dorsiflexion strength is weaker than the plantarflexion strength [8]. This was significant in the avoidance of contracture recurrence. Thus, the proximal incision was to be located deep in the tendon area of the gastrocnemius muscle, near the soleus muscle tissue. Zhang et al. cut most of the gastrocnemius tendon tissue to weaken the Achilles tendon without affecting the function of the ankle joint post-operatively and reported no incision or infection complications in the group that received the Hoke triple hemisection. Additionally, follow-up MRI results showed continuity of the Achilles tendon and a homogenous signal in this group, along with fusiform-shaped tendon thickening post-operatively [8].

Lengthening the Achilles tendon in diabetic patients increases the risk of foot ulceration [22,23]. Hoh et al. reported postoperative superficial surgical site infections in

a 69-year-old male with a history of type 2 diabetes mellitus [23]. This complication of percutaneous complete Achilles tendon lengthening is rare, but important to consider as patients with diabetes are commonly affected by a loss of elasticity and tensile strength of the Achilles tendon, leaving them prone to ankle joint equinus. Additionally, patients with chronic diabetic foot ulcers are at a higher risk of developing infection and must be treated with appropriate measures in place.

4. Zone 3 Procedures: Z-Lengthening

4.1. Z-Lengthening

4.1.1. Overview

Tendo-Achilles Z-lengthening is a surgical procedure intended to correct severe cases of equinus contracture [6]. The technique is characterized by a staggered Z-shaped cut transecting the Achilles tendon that allows for a strong connection between the distal and proximal ends after significant lengthening [6,24,25]. Z-lengthening is traditionally carried out as an open procedure utilizing a longitudinal posteromedial incision; however, a method involving a percutaneous approach has been proposed as well [26,27]. For the open procedure, the longitudinal cut is performed down the center of the Achilles tendon. The tendon is then divided medially and laterally or anteriorly and posteriorly. Then, the knee is extended, the ankle is dorsiflexed, and the foot is placed in the neutral position. For the alternative open procedure, transverse cuts are performed, and the ankle is forced into dorsiflexion. Finally, the Achilles tendon fibers may slide into the desired position and are sutured under tension [2].

4.1.2. Preference and Indications

Z-lengthening of the Achilles tendon is preferred for patients exhibiting equinus deformity exceeding 20 degrees and a negative Silfverskiold test [6]. As per the age criteria, Tirelli et al. suggest postponing Achilles lengthening surgery, if possible, until the patient reaches seven to ten years old to minimize recurrence risks [28]. Indications for Z-lengthening involve treating equinus contracture in children with cerebral palsy, especially in cases requiring more significant lengthening [24]. The surgery aims to improve gait by allowing for a sufficient range of motion in the ankle [5]. Additionally, Z-lengthening is incorporated into the treatment of clubfoot in conjunction with other forms of management, such as Ponseti casting [29].

4.1.3. Management

Prior to partial or complete Achilles tendon lengthening, the patient's history should be considered for factors contributing to the equinus deformity, such as a heritable neuromuscular disease like cerebral palsy, idiopathic toe walking, or post-traumatic occurrence [6]. During physical examination, lower extremities should be assessed for related issues, and the range of motion of the ankle should be evaluated using the Silfverskiold test to discern whether the equinus deformity is due to Achilles or gastrocnemius contracture [6]. Additionally, gait analysis is performed in ambulatory patients to evaluate sagittal plane abnormalities [6].

Regarding intra-operative care, meticulous care must be taken to preserve the deep fascia, fat pad, and paratenon to prevent surgical complications [25]. Kim et al. modified the Z-lengthening technique to minimize complications to the soft tissue by using one or more small transverse incisions in the skin creases above the Achilles tendon, similar to the percutaneous sliding technique, and lengthening the Achilles using Z-lengthening. This modified method resulted in accurate tendon lengthening and a low recurrence rate while minimizing soft tissue damage and maintaining high cosmetic satisfaction [25].

Post-operatively, a short leg cast is applied with the ankle in neutral dorsiflexion, or, for cases with significant lengthening, in slight plantarflexion. Casting is maintained for six weeks with periodic cast changes, after which the patient is transitioned to an ankle–foot orthosis and should commence physical therapy [6].

4.1.4. Surgical Outcomes

Lofterod and Terjesen studied the local and distant effects of Z-lengthening and gastrocnemius recession in children who have spastic cerebral palsy with either hemiplegia or diplegia [5]. The results showed proper equinus correction and improved ankle push-off power in hemiplegia and diplegia [5]. Effects on distant joints were predominantly seen in diplegia, exhibiting significant gait improvements concerning various parameters, while the hemiplegia group showed considerably fewer improvements [5]. Regarding the type of surgical procedure, ankle dorsiflexion improved to the normal range in the Z-lengthening group and gastrocnemius recession group, although the magnitude of correction was significantly greater in the Z-lengthening group as a result of more severe initial equinus [5]. Overall, these findings indicate substantial gait improvements in diplegic cerebral palsy patients as a result of Achilles lengthening or gastrocnemius recession; however, further research must be conducted, as the comparison is somewhat uncertain due to the small sample size [5].

Tendo-Achilles Z-lengthening has also been effective in cases of untreated clubfoot. Wong et al. presented a case of an eleven-year-old female suffering from bilateral clubfoot exhibiting adduction, cavus, varus, and equinus deformity [29]. Treatment included nine weeks of Ponseti casting to correct the clubfoot and an Achilles Z-lengthening procedure to correct the equinus deformity [29]. After treatment, the patient attained 10 degrees of dorsiflexion and 45 degrees of plantar flexion and gained the ability to walk without pain or discomfort [29]. Similarly, Oesman and Sari report a case of neglected neurogenic clubfoot in the right foot of an 18-year-old female [30]. The patient presented cavus varus and equinus deformity. The patient underwent a two-part corrective procedure to address the deformity, including Z-lengthening of the Achilles tendon and various subsequent surgical interventions [30]. Following the procedure, the patient experienced outstanding results, with an improved ankle range of motion and the ability to walk without difficulty [30].

4.1.5. Complications

The Z-lengthening technique is traditionally performed through a longitudinal posteromedial skin incision, which can often damage soft tissue blood supply, leading to incision complications such as scarring, adhesion, and pain [25]. However, the most common significant complications are improper tendon lengthening and ankle equinus recurrence following surgical intervention [26,31].

Determining the magnitude of tendon lengthening typically involves intraoperatively positioning the ankle at the desired dorsiflexion angle. This can often lead to over-lengthening, resulting in crouch gait, or under-lengthening, causing recurrent equinus [26]. Ozyalavac developed a preoperative technique utilizing cosine theory to calculate the magnitude of Z-lengthening needed based on the severity of equinus contracture. The calculation is defined as the magnitude of Achilles tendon lengthening (x) = $\sqrt{2d^2(1 - \cos(\alpha))}$, where "d" represents the distance between the ankle's sagittal center of rotation and the insertion of the Achilles tendon at the calcaneus and "α" represents the degree of equinus contracture. This approach showed a significant correlation between the calculated amount of lengthening and the performed amount of lengthening [26].

Ozyalvac and Akpinar compared the preoperative calculation using the cosine method to traditional Z-lengthening with intraoperative determination of the lengthening magnitude and the Garbarino method, in which the lengthening amount is defined as half of the distance between the bottom of the heel and the floor under forced dorsiflexion with the knee extended [28]. There was no statistical correlation between the Garbarino and the other two methods. However, the performed magnitude of Achilles lengthening showed a significant relationship between the preoperative calculation approach and the intraoperative approach, signifying its value in presurgical planning and accurate calculation of the amount of Achilles tendon lengthening [27].

Regarding the recurrence of equinus following the Z-lengthening procedure, significant factors may include age and the severity of equinus deformity [31]. Studies discuss

age as a primary contributor to recurrence, stating that most cases occur when the patient is under six years of age at the time of surgery. Khatri et al. reported recurrence rates after performing the Z-lengthening technique in a group of 37 children with a mean age of 7.43 ± 2.10 years, with hemiplegic or diplegic spastic CP. Patients with a history of surgery on equinus deformity were excluded. Following surgery, 41 (78.8%) feet achieved pain-free plantigrade feet. Recurrence occurred in 11 (21.2%) cases with insufficient correction, which was evident in a progressive increase in equinus during follow-up [4].

Chung et al. argued, however, that there is no statistically significant relationship between age and likelihood of recurrence. Instead, their results showed that the only significant contributor to recurrent equinus was the severity of the deformity prior to surgery [31].

5. Zone 2 Procedures: Baker: Tongue in Groove Gastrocnemius–Soleus Recession Overview

5.1. Baker Technique: Tongue in Groove Gastrocnemius–Soleus Recession

5.1.1. Overview

In 1956, Dr. Lenox Baker first described a modified approach to gastrocnemius–soleus recession (GSR), which was optimal for patients with cerebral palsy, to lengthen the gastrocnemius tendon to correct triceps surae dysfunction and restore normal gait [32,33]. The surgical technique created by Baker requires a longitudinal midline incision to be created from the lower belly of the gastrocnemius to the proximal portion of the Achilles tendon. The surgeon then creates an inverted "U" incision through the aponeurosis of the gastrocnemius. Then, the incision is extended medially and laterally [2]. The middle portion of the "U" incision is then dissected completely from the soleus muscle. The surgeon then dorsiflexes the ankle, allowing the distal portion of the Achilles tendon to slide, with the remaining four corners of aponeurosis each secured with a suture. The deep fascia, subcutaneous tissue, and skin are then closed with intradermal sutures [2].

In 1974, Fulp and McGlamry were the first to perform the alternative Baker technique (BT) on non-spastic cerebral palsy patients. Their technique requires a non-inverted "U" incision, with the tongue distal and the groove proximal to the gastrocnemius aponeurosis. Using this method, no suturing is required where the Achilles tendon fibers overlap [33].

5.1.2. Preference and Indications

Indications for the BT include cerebral palsy, with equinus exceeding 10°, altered gait or standing ability [9], a positive Silfverskiold test indicative of gastrocnemius contracture [9,34], and spastic pes equinus, particularly in children between 3 and 18 years [34] with low risk of Achilles tendon overcorrection [34]. Equinus is the most common deformity in children with cerebral palsy, and Baker's method was originally intended for its treatment in the younger population [32,33]. Age, subtype of cerebral palsy, ambulatory status, and preferred surgical zones are all indications for the use of the BT [35]. In the pediatric population, the BT is optimal in ambulatory patients above 6 years of age with diplegia [10,32].

5.1.3. Management

Rodda et al. recorded measurements of joint contractures, muscle strength, spasticity, selective motor control, and osseous rotational abnormality. Additionally, the authors included preoperative gait analysis, measurements of fixed flexion deformity at the hip and knee, and measurements of hamstring contracture as demonstrated by the popliteal angle [11]. Borton et al. distinctively included preoperative and postoperative physiotherapy dependent on the level of disability. All of the studies mentioned included the Silfverskiöld test, likely due to its reliability, in the preoperative stages [9–11].

Postoperatively, an above-the-knee cast may be applied with maximum dorsiflexion. Then, sutures are removed on day 12 and patients are to wear a below-the-knee cast with maximum possible dorsiflexion for 6 weeks. They are advised to ambulate in the cast.

Ankle–foot orthoses are applied for 3 months for weight bearing along with physiotherapy, including ankle mobilization exercises and gait training [35].

5.1.4. Surgical Outcomes

The BT is advantageous in controlled lengthening with sliding of the tendon to the appropriate length [36]. Firth et al. noted that mean lengthening of the gastrocnemius–soleus complex was significantly greater with the Baker and Vulpius methods ($p < 0.001$) when compared to Baumann and Strayer's methods [37]. Yu and colleagues concluded that the BT did not result in any residual muscle weakness when the aponeurosis of the gastrocnemius muscle was not over-lengthened [38]. Datta et al. monitored 20 patients with 37 cases of equinus deformity due to cerebral palsy who had received Baker's method of aponeurotic gastrocnemius lengthening [35]. From the prospective study from 2005–2007, the mean patient age was 5 years, 9.6 months (SD +/− 2 years 4.97 months). There were 3 (15%) unilateral and 17 (85%) bilateral cases. After 4–28 months, 34 (92%) feet retained the plantigrade correction [35].

5.1.5. Complications

The greatest complications of the BT are the risk of damage to the small saphenous vein and sural nerve, as well as a prominent scar [37]. Weight bearing of 40 kg and under carries less risk of rupture of the Achilles [39]. Rodda et al. noted ten surgical complications in four patients, including superficial wound infection at the sites of four incisions and partial separation at the sites of two hamstring incisions. They were resolved with a combination of oral antibiotics and wound care. Two patients with knee flexion deformations of 22° and 28° experienced paresthetic pain, which was treated by removing the knee immobilizers, reducing the degree of knee extension, and gradually extending the affected knee over two to three weeks postoperatively [11].

6. Zone 2 Procedures: Vulpius: Gastrocnemius–Soleus Recession

6.1. Vulpius Procedure: Gastrocnemius–Soleus Recession

6.1.1. Overview

In 1924, Vulpius and Stoffel reported the first gastrocnemius recession, initially indicated for treating equinus contracture in neurologically impaired children [40]. Today, the procedure is commonly used in the adult population with equinus contracture arising from a range of etiologies, including idiopathic cases and those related to other underlying pathologies [41]. The procedure is utilized both as an adjuvant and as a standalone treatment for foot and ankle pain when non-operative lengthening measures fail [41].

The VP, aimed at the aponeurosis of the gastrocnemius–soleus complex, involves an incision at the back of the leg in the distal third portion where the gastrocnemius turns into a tendinous structure [3,41]. This procedure is characterized by making a transverse incision through the superficial side of the gastrocnemius tendon and incising the deep fascia and the median raphe of the soleus muscle. The muscle fibers of the soleus should be left intact. The deep fascia is then sutured, and the skin is closed. The foot is placed in the neutral position, and a cast is applied for 4 weeks [2].

It is important to note that during this procedure, the gastrocnemius aponeurosis is not detached from the underlying soleus muscle.

This technique is particularly effective for patients with plantar flexion contractures which involve both the gastrocnemius and soleus muscles, indicated by a negative Silfverskiöld test during physical examination [37,41]. It does not cause differential lengthening between the gastrocnemius and soleus muscles [37]. The incision is placed below the gastrocnemius aponeurosis insertion into the soleus fascia, preserving the muscle fibers. Post-surgery, the deep fascia is carefully sutured, followed by skin closure [42].

6.1.2. Preference and Indications

The Vulpius procedure (VP) is versatile and applicable regardless of whether the contracture is in the gastrocnemius muscle, the soleus muscle, or both [43]. Its effectiveness in lengthening the calf muscles is comparable to that of TAL procedures, but with more precise control and it's performed higher in the calf [43]. The necessary degree of GSL for correcting equinus deformity can be determined through musculoskeletal modeling [44].

The VP is advantageous as it is not associated with delays, nonunion, or increased contracture due to prolonged immobilization often seen in TAL procedures [45], facilitating a quicker return to daily activities and making it a preferred choice for patients requiring minimal lifestyle disruption [45]. An open or endoscopic VP is favored for treating gastrocnemius–soleus contractures that only show partial correction with knee flexion [1]. The Hoke procedure is recommended to address any remaining contracture following the VP [1]. VP applies to specific conditions like clubfoot, diabetic foot ulcers, and cerebral palsy. Clinical data indicate success in using the VP for clubfoot treatment after initial Ponseti protocol treatment. Of 32 cases with residual or relapsed equinus deformity, 22 feet in 17 patients saw effective correction with VP, highlighting its role as an effective surgical option for equinus deformity, especially when relapse occurs, which has been reported in 11% to 41% of cases [46–48].

Though the VP only corrects the tight Achilles tendon—one of several tight posterior structures that may cause equinus contracture in clubfoot—it is, however, the most impactful. It is considered a preferable choice for correcting residual equinus deformity rather than repeating the Ponseti protocol, as it avoids re-entering the scarred area of a previously lengthened Achilles tendon. Younger patients, known for their more flexible tissues, are often better candidates for this procedure [48].

The VP is effective in treating neuropathic plantar forefoot ulcers, particularly in diabetic patients, as demonstrated by Laborde et al. [49]. This technique addresses the Achilles tendon or gastrocnemius–soleus tightness, a common factor in these ulcerations [22]. Laborde's research showed its ability to heal and prevent recurring ulcers at the metatarsal head with minimal complications [49]. He chose the VP for its immediate weight-bearing capability, reducing over-correction and incision issues, and benefits he previously observed in cerebral palsy treatments [49,50]. In diabetic patients, combining the VP with selective tendon lengthening based on ulcer location led to successful healing in most cases and a significant reduction in recurrences [49]. The study included specific surgical adjustments based on the ulcer's location: for ulcers under the first metatarsal head, the peroneus longus tendon was lengthened, and for those under the fifth metatarsal head, the tibialis posterior tendon was lengthened [49].

Out of 20 ulcers treated in 17 patients, 19 healed successfully, and the 3 recurrences responded positively to repeated lengthening [49]. Additionally, applying this technique to treat neuropathic midfoot ulcers without total contact casting resulted in a 91% healing rate [49], further highlighting its efficacy in complex diabetic foot conditions. The most common of the musculoskeletal deformities in ambulant children with CP is equinus, caused mainly by gastrocnemius spasm, or contracture, which can be managed through a gastrocnemius–soleus recession [45,51–54]. Such an intervention can be conducted as a standalone procedure or be integrated into multi-level surgery that addresses additional musculoskeletal deformities [55–58].

Takahashi et al. successfully utilized the VP in a study involving 230 adult CP patients recovering from cerebrovascular accidents, including 98 individuals with diabetes. This approach enabled the patients to stand in a brace the following day without any wound- or tendon-related complications [45]. Immobilization of the leg and bedrest can be forgone postoperatively if the VP is performed under local anesthesia, allowing for effective correction and early rehabilitation [45].

6.1.3. Management

Post-surgical management involves placing the foot in a neutral-position cast for one month [3,42,43,59]. If the VP is the sole intervention, patients are generally permitted to walk and bear weight during this recovery phase [42,43]. The need for additional bracing and night splints is determined by the patient's post-surgery ankle movement; if there is active voluntary ankle dorsiflexion, it is unnecessary, except when full-control ankle–ankle–foot orthotic braces are needed for walking. For those without active voluntary ankle dorsiflexion, consistent use of ankle–foot orthoses during their growth period is recommended [43].

Javors' study on a cohort of CP patients highlighted that, in cases of recurrent equinus contracture in patients with moderate to severe hemiplegia ~5 years postoperatively, a subsequent VP may be considered [43].

6.1.4. Surgical Outcomes

When comparing TAL to the VP, it was observed that both surgeries led to increased gastrocnemius tendon lengths in most patients, correlating with favorable kinematic outcomes [60]. The degree of muscle tendon elongation was found to depend more on individual lengthening requirements than the type of surgery or the patient's specific diagnosis [60]. Additionally, no significant differences were indicated in the effects of these surgeries between patients with CP and idiopathic toe walking, demonstrating the procedures' uniform efficacy across these patient groups [60].

6.1.5. Complications

The risk of proximal migration of the gastrocnemius muscle is one of the complications associated with the VP when there is complete gastrocnemius release. This risk is less prevalent with the Baumann or Strayer procedures, where the aponeurosis is reattached [1]. Drawbacks include longer skin incisions and potential risks such as injury to the lesser saphenous vein and the sural nerve, along with the likelihood of prominent scarring [32,50,61,62]. Gastrocnemius–soleus lengthening in CP patients can lead to overcorrection or undercorrection; while it addresses plantar flexor contractures, it might not enhance dorsiflexor function, causing foot drop, impeding gait by causing tripping, and necessitating ankle–foot orthoses [63]. Tibialis anterior tendon shortening is sometimes combined with GSL to improve gait and reduce AFO dependence. Predicting which children will benefit from TATS post-GSL remains challenging [63].

7. Zone 1 Procedures: Strayer: Gastrocnemius Recession

7.1. Strayer: Gastrocnemius Recession

7.1.1. Overview

The Strayer procedure is a distal gastrocnemius tenotomy (DGT), which aims to correct gastrocnemius equinus by lengthening the gastrocnemius tendon with no subsequent sural nerve injury [15]. It is the most widely used Zone 1 procedure and was first described by Luther Strayer in 1950 to relieve spastic contracture of the calf muscles [10,64]. Early reports indicated that the Strayer procedure was confined to the pediatric population, in patients with cerebral palsy and associated gastrocnemius equinus contracture. More recently, several authors have recognized gastrocnemius contracture as a predisposing factor to several chronic foot conditions in the adult and pediatric population, which must be corrected using the Strayer procedure.

The surgical technique created by Strayer separates the gastrocnemius and soleus muscles proximal to their aponeurosis. This permits the retraction of the gastrocnemius muscle body. A longitudinal incision is then performed at the gastrocnemius–soleus junction either medially, laterally, or over the midline [2]. Dissection occurs through the subcutaneous tissue to the deep fascia, and the sural nerve should be identified and protected, either superficially or deep to the fascia. The deep fascia is then opened longitudinally, and the gastrocnemius tendon is cut transversely. The soleus tendon prevents the gastrocnemius

tendon edges from retracting by more than 2 cm. After the gastrocnemius tendon release, with the ankle in the neutral position, the gastrocnemius fascia will be sutured back to the soleus fascia to reinforce the strength of the gastrocnemius and soleus complex [2].

A comprehensive understanding of the surgical anatomy of this procedure is relevant because the saphenous vein and sural nerve may be located deep or superficial to the gastrocnemius fascia. Once dissected, they must be protected during the procedure to prevent injury.

7.1.2. Preference and Indications

The Strayer procedure is indicated in patients with a positive Silfverskiold test indicating isolated gastrocnemius equinus for isolated lengthening of the gastrocnemius with preservation of the soleus muscle. Preoperative diagnoses which can be attributed to the gastrocnemius equinus are symptomatic pes planus, hallux valgus and plantar fasciitis, adult pes planovalgus, plantar fasciitis, neuromuscular equinus, clubfoot, and foot ulceration secondary to diabetes mellitus [65,66]. Gastrocnemius equinus is a factor in the etiology of these conditions due to subsequent mechanical overload of the Achilles tendon, resulting in a lack of ankle dorsiflexion exceeding 10 degrees past neutral with the knee straight [1,67]. Furthermore, the Strayer procedure may also be used to treat refractory, symptomatic non-insertional Achilles tendinopathy.

7.1.3. Management

Preoperatively, each patient's degree of ankle dorsiflexion was recorded using an electro goniometer. The patient's strength of plantarflexion was also assessed using manual muscle testing, with each affected lower extremity being compared to the contralateral side [67].

Postoperative care for spastic contracture was groin-to-heel casting. The knee was extended, and the ankle remained in a neutral position for 4 to 6 weeks. After this, patients were instructed to wear an ankle–foot orthosis for 24 h for approximately 6 weeks following their operation. With the ankle dorsiflexed at 10 degrees, full weight bearing was permitted. Then, the orthosis was removed, and patients could return to sports after 3 months. One year after the operation, all patients participated in a physical examination to assess for Achilles tendonitis and thickness and a Silfverskiöld test for recurrence of gastrocnemius contracture [4,67]. Various studies advocate for the casting of the ankle in hyper-dorsiflexion, but state that long-leg casting can be shortened if patients can maintain their knee extension independently [21].

7.1.4. Surgical Outcomes

Following the one-year postoperative assessment, all 14 patients involved in the study by Duthon et al. were reported on. The mean degree of ankle dorsiflexion was 7 (range 5–10). Plantarflexion strength was equal bilaterally. All clinical scores (Ankle–Hindfoot score, FFI, and SF-12 physical component score) significantly improved 1 year after the procedure. Nine patients reported no pain, five had occasional pain, and three of those five had developed bilateral Achilles tendinopathy. This study reported no postoperative complications, disturbed wound healing, infection, DVT, or sural nerve injury, and significant improvement in foot and ankle function was achieved, particularly concerning ankle dorsiflexion [67]. Pinney et al. noted the sural nerve to typically be located 46 mm from the medial border of the gastrocnemius tendon. In 57.5% of cases, the nerve was deep to the fascia. This information is useful in highlighting the risk for direct sural nerve injury if it is not identified and protected with a retractor, specifically during tendon release [65]. Lastly, Groves et al. reported that the Strayer technique provided effective elimination of contracture, minimal risk (limited repositioning), and good cosmesis in the pediatric population with non-spastic gastrocnemius equinus [67].

7.1.5. Complications

Due to the position of the sural nerve nearly posterior to the gastrocnemius insertion site, injury by direct trauma or excessive stretch is a common complication of the Strayer procedure. Additionally, poor cosmesis due to excessive incision is a disadvantage to this technique. This could likely be avoided with good surgical technique [65]. Another disadvantage is the risk of disabling the gastrocnemius muscle. This is because, in the Strayer gastrocnemius recession, the gastrocnemius is to be completely detached from the soleus muscle, and it is assumed that the aponeurosis will adhere to that of the soleus muscle while in the lengthened position. Blitz et al. suggested a modified technique, where the gastrocnemius insertion is preserved and may exert a weakened effect on the foot. The authors suggested that this may preserve some muscle function and reduce the risk of calf atrophy as a complication of the Strayer technique [66].

8. Zone 1 Procedures: Baumann: Deep Gastrocnemius Recession

8.1. Baumann Procedure: Deep Gastrocnemius Recession

8.1.1. Overview

The Baumann procedure, introduced in 1989 by Baumann and Koch, is defined as an isolated intramuscular recession of the gastrocnemius muscle executed in the deep interval between the soleus and gastrocnemius muscles [3,68]. Primarily developed for treating patients with cerebral palsy, its goal is to enhance ankle dorsiflexion hindered by gastrocnemius contracture (revealed through a positive Silfverskiöld test) [3].

8.1.2. Preference and Indications

The Baumann procedure (BP) is an intramuscular recession of the gastrocnemius muscle, ideal for patients with mild to moderate equinus deformities or mild isolated gastrocnemius contracture, particularly in CP (associated with quadriceps weakness and normal soleus muscle) and athletic individuals requiring preserved muscle strength [1,3,69,70]. BP only releases the muscle-portion aponeurosis proximally, where the thicker skin heals better, preserving the gastrocnemius–soleus tendinous complex, its origin and insertion, the soleus muscle, and the MTJ. This preservation offers enhanced cosmesis (scar along medial calf) with minimal risk to the sural nerve [3,59,70,71].

The surgical technique utilized in the BP effectively manages the anterior gastrocnemius aponeurosis, distributes tension across multiple incisions to reduce the risk of muscle rupture, and preserves muscle power post-operation [71]. Its stability reduces overlengthening and calf weakness risks, which are common in the Strayer technique [2,3,70]. It facilitates a controlled, selective sequential lengthening of the gastrocnemius muscle to achieve the desired correction levels [72].

In this procedure, the patient is supine with the leg in a figure-of-four position. A small longitudinal incision is made at the distal portion of the leg, posterior to the posterior edge of the tibia. The deep fascia is opened, and the gastrocnemius and soleus muscle bellies are separated using blunt dissection. The knee is extended, the foot is dorsiflexed, and the gastrocnemius fascia is divided. The intramuscular septum of the gastrocnemius muscle is identified and cut. Ankle dorsiflexion should result. Then, additional fascia divisions are performed and separated. Closure is performed in separate layers and the foot is dorsiflexed. A posterior splint is then applied, and patients may begin bearing weight 2 weeks post-operatively [2].

The intramuscular approach and minimal invasiveness of BP render it ideal for patients requiring precise muscular corrections with minimal lifestyle disruption [3]. BP can be performed with the patient in a supine position with their leg externally rotated and bent, without the need for special positioning or an assistant, simplifying the surgical process [3,69].

The BP is versatile and is effectively applied to conditions such as idiopathic foot pain in adults, diabetic foot ulcers, pediatric flatfoot, and cerebral palsy. BP is a treatment for isolated gastrocnemius contracture (IGC), which is common in foot and ankle pathologies,

notably metatarsalgia, found in 65–88% of non-neuropathic midfoot or forefoot patients, 25% of asymptomatic individuals, and 57% of plantar fasciitis patients [41,73]. Chen et al. favor isolated gastrocnemius recession (IGR) to relieve plantar fasciitis for patients with gastrocnemius contracture (GC) and a low arch [40]. There is reasonable evidence supporting the use of BP in treating midfoot–forefoot overload syndrome, non-insertional Achilles tendinopathy, and diabetic foot ulcers, but not enough to recommend it over other treatment options [10,22,74,75]. For diabetic plantar forefoot ulcers, the BP, a safer alternative to TAL, reduces over-lengthening risks, but may have a higher re-ulceration rate (16%) [22]. BP is recommended to treat IGC in pediatric patients [70]. It addresses contractures mainly in the muscle portion of the musculotendinous complex and facilitates more than 10% muscle lengthening post-aponeurotomy with new aponeurotic tissue formation while preserving the crucial musculotendinous junction for muscle growth, thereby reducing developmental risks in pediatric flatfoot cases [70]. In a study with 22 diplegic CP children, BP, used in multilevel surgery, effectively improved gait and ankle movement, as confirmed over two years post-surgery [76]. BP is preferred in children with diplegia/bilateral CP as it provides stable correction of equinus deformity without the risks of over-lengthening and the resultant crouch gait [10,70,76]. Over a 10-year study, BP consistently showed positive results for diplegic CP [77]. Patients with spastic and non-spastic flatfoot with mild to moderate equinus benefit from BP [70].

8.1.3. Management

In BP, preoperative strategies include dorsiflexion of the ankle at each aponeurosis division, moving proximally to distally evenly while avoiding distal cuts in the gastrocnemius aponeurosis to prevent muscle tears [71]. In severe equinus, apparent under-correction post-maximum division typically resolves by the 3-week cast change [71]. Intraoperatively, if the initial recession does not yield adequate ankle dorsiflexion, further recession may be carried out through the same incision [3]. Meticulous dissections and layered closure lower morbidity rates and promote favorable outcomes [78]. When BP is an adjuvant to other procedures, their postoperative protocol will be followed [69]. Otherwise, for the first two weeks, patients engage in assisted weight-bearing activities using a cast brace or a walker boot [42,59,69,73]. Until week four, patients walk in athletic shoes to regain normal gait and strength. Calf stretches, isometric exercises, and the use of a night splint to maintain the ankle at 90 degrees are also advised during this period [42,73]. By week six, patients transition to wearing supportive shoes and resume daily activities [42,59,69,73]. This structured approach aims to balance mobility with the healing process, ensuring a steady return to function.

8.1.4. Surgical Outcomes

Generally, any surgical tendon lengthening reduces muscle strength, but the BP reduces that loss [70,79]. Compared to TALs, BP provides limited lengthening, but is more stable [37]. Cadaveric adult studies show an average of 2.1 mm lengthening from the BP, but greater increases are seen in pediatric patients [10,37,76]. Stability decreases from proximal to distal as lengthening effectiveness rises [37]. When treating equinus in CP patients with BP, simultaneous hamstring lengthening improves the outcome, as its contracture causes equinus recurrence [71,80]. A study involving 37 BP in adult patients found a decrease in ankle dorsiflexion of 17° (108° to 91°) [75]. In Rush et al.'s study, all patients who received IGR could adequately perform five single-limb heel rises at 6 months postoperatively [78].

Baumann and Koch's pioneering study on children with spastic CP presenting with equinus ranging from 5–50° introduced the concept of intramuscular lengthening of the gastrocnemius muscle as an effective treatment approach. Over a 10-year study, BP consistently showed improvement in ankle function in spastic diplegic CP with equinus gait [77]. It showed low over-lengthening rates and recurrence rates that aligned with those of other procedures. It is more functional and safer for the correction of mild fixed equinus deformity in children, as it improves the muscle belly-to-tendon ratio, and over-lengthening

(which leads to crouch gait and calcaneus deformity) is less likely [77,81]. Longer follow-up periods have reported higher rates of calcaneus gait, as some of the changes in ankle kinematics observed are influenced by natural growth and the increasing weight of pediatric patients [16,17,77]. Typically, equinus decreases and ankle dorsiflexion increases as children grow through adolescence. Therefore, not all observed changes in ankle function can be solely attributed to the surgery [77]. BP was also always part of multilevel surgery, influencing ankle function results [77].

BP was employed for the treatment of 20 limbs of 15 ambulant children with fixed gastrocnemius–soleus contracture in spastic CP with an 80% success rate, 10% recurrence, and under-correction [71]. The mean degree of preoperative equinus deformity was 53° (ranging from 30° to 75°). Hamstring lengthening and less severe hip flexion deformity preoperatively positively influenced the results [71].

8.1.5. Complications

General complications of gastrocnemius recession (GR) include sural nerve injury, weakness, unfavorable cosmesis, and calf muscle atrophy, at a rate of 0–20% [73,78,82,83]. The upper medial incision for the BP may cause injury to the sural and saphenous nerves, greater saphenous vein, and unfavorable cosmesis [70]. Post-BP equinus recurrence rates are 10% for non-neurological patients and 24% for neurological patients [70,84–86]. Compared to TALs and Strayer GR wound and scarring complications, as well as weakness from overcorrection, they are of lesser significance [70,71,77,84]. The aponeurosis is reattached in BP so that there is no risk of the gastrocnemius muscle proximally migrating [1].

9. Conclusions

There is a wide range of evidence supporting surgical treatment for foot and ankle pathologies characterized by equinus contracture. This is especially true in addressing the needs of patients with neuromuscular disorders such as cerebral palsy and other pathologies, including clubfoot, diabetes, neuropathic foot ulcers, and idiopathic toe walking. The Hoke, Z-lengthening, Baker, Strayer, Vulpius, and Baumann procedures can be performed within three different anatomical zones as they relate to the gastrocnemius–soleus complex and Achilles tendon. As discussed in this article, the type of procedure chosen should be reflective of the presenting pathology, Silfverskiöld test, and functional requirements of the patient.

Assessing the degree of gastrocnemius contracture is a crucial part of the foot and ankle assessment and should be considered in every case. Although there is no clear consensus on optimal post-operative care, there are other procedures that may be performed in conjunction with those discussed in this article. Thus, post-operative rehabilitation planning will be influenced by these procedures. Surgical correction of equinus deformity may be associated with calf weakness, nerve damage, poor cosmesis, and contracture recurrence. To prevent the various complications discussed in this descriptive review, a thorough perioperative care strategy should be created.

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