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REVIEW ARTICLE

A New Eclectic Open Surgical Management of Recurrent, Residual, or Neglected Clubfoot in Children: An update on old and new in the field

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ABSTRACT

Background context: All patients with clubfoot, regardless of age, are treated by the Ponseti or Bensahel technique as the first conservative therapeutic method. These techniques have greatly increased the success rate, which still remains at a good level even if the recurrence rate has recorded an increase from 5% to 40%. Thus, interventions for medial and dorsal release have also increased in number. When the decision to treat complications is resumed, it is good to start with one of these methods to ensure tissue flexibility and consolidate favorable outcomes.

Purpose: The purpose of the new eclectic procedure is to reduce or eliminate recurrence and obtain a stable and pain-free foot. The article presents a new eclectic technique to analyze the outcomes of medial and dorsal release using this surgical technique for recurrent, residual, or neglected clubfoot in children 6 months to 8 years of age. The study aims to standardize an effective treatment solution for clubfoot after the treatment of choice and non-idiopathic feet in genetic syndromes. The therapeutic orientation focuses on the medial and dorsal approach and establishes the limits between this approach and the use of an external fixator.

Design: This is a project study that analyzes statistical data from three graduation theses. The paper is actually a meta-analysis that compares various published procedures and presents the results obtained from both independent studies conducted by various authors and our own study to illustrate the most relevant data.

Patient sample: All patients included in the study were personally operated on in two periods of time as follows: 2008-2016, in public clinics, and 2018-2022, in private clinics.

Outcome measures: The preoperative evaluation was performed after completion of the Ponseti or Bensahel technique and consisted of an X-ray examination (CT and 3D-CT). After this scan, those who needed CT and MRI were selected.

Methods: Radiologically measured talonavicular-cuneometatarsal 1 alignment was invariably fixed on the splint within the talus range and restored the tibial radius of the foot. The plantar arch was normal, and the talocalcaneal divergence in the coronal and sagittal planes was within normal limits.

Results: The mentioned results showed an excellent correlation between the plantar arch configuration and the three essential clinical elements of the foot: shape, direction, and position. In the support phase, the operated foot moves normally from the contact point on the calcaneus to the digital support phase. The comparison with the normal foot indicated a similarity of 89%, meaning 25 out of 28 feet.

The results of the study can bring improvements to the statics and dynamics of children with severe complications after the initial treatment but especially to non-idiopathic deformities.

Conclusions: The properly aligned and reconfigured tibial (medial) radius of the foot allows the biomechanics of the foot to regain a mobility pattern that is almost similar to that of the normal foot.

Keywords: medial and dorsal release, transposition of plantar insertions of the tibialis posterior to the navicular, syndesmolysis, musculoaponeurotic plantar disinsertion, reconfiguration of the plantar arch on the talonavicular-cuneometatarsal 1 splint

1. INTRODUCTION

Congenital foot deformity is the most common malformation encountered in pediatric orthopedics. It accounts for about one-third of all congenital osteoarticular deformities. Among them, clubfoot or talipes equinovarus has the highest incidence rate (85%).

The treatment of choice for clubfoot is conservative. The Ponseti technique, Bensahel technique, or the hybrid method is used. The results obtained and preliminary evaluated deteriorate over time, and the deformity reappears in different forms.

Initial short-time studies conducted on patients treated by the Ponseti method showed that only 2% of them ended up being operated, as indicate Charles and al's[1], and then, approximately 3% to 5% upon according Willis and al's[2]. Later, Morcuende and al's[3] stated that the recorded rate was 20%, and subsequent literature revealed a medium-term recurrence rate in 20% to 41% of cases, according Bergerault[4]. According to a 2022 study made by Van Schelven[5], after initial clubfoot correction through Ponseti treatment, recurrence rates range from 26% to 48%. The recurrence rate after using the Bensahel technique is similar to that reached after using the Ponseti technique. Although this rate has constantly increased, the results obtained after applying these methods are indisputably much better than those achieved before their implementation in medical practice.

The widespread use of the treatment methods developed by Ponseti and Bensahel has considerably decreased the number of operated cases and the extent of surgical interventions. Thus, extensive surgical interventions performed on young children, who sometimes resulted in deep retractile scars, stiff joints, and extensive muscle atrophy, were eliminated according to studies carried out by Wenger[6] and Coplan[7]. Until the application and generalization of these methods, only moderate and mild forms responded to operative treatment. Ponseti[8] described that 71% of the treated feet were normal looking, functional and pain-free, while 28% remained with slight residual deformity. In 1992, Ponseti[9] reported a success rate of 85% to 90%.

After the non-operative treatment standardized by Ponseti, it is necessary to perform Achilles tendon lengthening in 90% of cases, tibialis anterior tendon transfer in 15% to 40% of patients, and iterative Achilles tendon lengthening or plantar fasciotomy, as Eidelman and al's[10] claim. Azarpira and al's[11] suggest that relapses occur more frequently in non-idiopathic clubfoot. Late recurrence 8 years after correction is very rare but possible. Although it is estimated that most relapses occur due to insufficient correction, as indicate Dobbs and al's[12], a relapsed clubfoot must be treated.

Even if the number of operative interventions for extensive surgical release has been reduced, this intervention is performed on a large scale and is an effective way of treating recurrent, neglected, or residual clubfoot in special circumstances as it results from the studies carried out by Kuo and Smith[13].

The constant increase in the number of relapses recorded over a longer period of time has also led to an increase in the number of surgical interventions for medial and dorsal release.

All medial and dorsal procedures communicated from 1880 to the present are eclectic. They took over some of the operative times used in previous procedures and modified or added other times that brought improvements to make the results more efficient.

2. PATIENTS AND METHOD

The paper is a serial and staged retrospective meta-analysis study that also includes an original study conducted on 92 patients who were initially treated conservatively during the newborn period, and then their recurrent, residual, or neglected clubfeet were operated on. Deformities that required medial and distal release were quantified in 23 patients. All interventions were made according to the technique described in this article.

We analyzed the statistics of the treated patients, as well as the interventions performed personally and reported in the graduation theses prepared by three doctors, Gîrbotei LM, Huzum E, and Mihalache E. The article presents the experience accumulated between 2008-2016 and 2018-2022, when was treated 92 patients (128 feet) as follows: 61 patients (89 feet) with the Ponseti technique, and 31 patients (39 feet) with the Bensahel technique. Treatment using the Bensahel technique was performed by physical therapists and regularly monitored at orthopedic follow-ups.

The deformity relapsed in 28% of cases, meaning 17 patients (25 feet) treated with the Ponseti technique, and in 28.9% of cases, meaning 9 patients (11 feet) treated with the Bensahel technique. Overall, recurrence was recorded in 26 patients (36 feet) of whom 23 patients (28 feet) had an indication for medial and dorsal release.

The inclusion criteria for the 28 operated patients took into account that their feet were rigid and could not be restored or partially repositioned in the anatomical position when the reduction was attempted with the knee flexed at 90 degrees. In these cases, patients presented 3-4 residual components. All patients were aged between 6 months and 8 years.

Three patients who had undergone other interventions were excluded from the study; two of them had only equinus deformity that was correctable on knee flexion and one presented equinus and residual metatarsus varus. No other patients outside the initial group of 92 persons were included in the study.

The study also includes patients from the initial group who have abandoned treatment or not followed the therapeutic program indicated by the Ponseti or Bensahel protocol. Patients who had clubfeet with 3-4 residual components and whose age was over 8 years were also excluded. I treated these patients by implanting the Ilizarov external fixator.

When the relapse had 3-4 components, medial and dorsal release was performed. The four components that we encountered in recurrent clubfoot had the following incidence rates: forefoot adduction in 95% of cases, equinus in 94% of cases, supination in 68% of cases, and protarsus adduction in 42% of cases. Inversion associated with the cavus foot was present in only one case. Recurrence was recorded for 28 feet, of which 16 cases of idiopathic clubfoot and 12 cases of non-idiopathic clubfoot. Non-idiopathic cases involved 5 (5/7) patients with arthrogryposis, 3 (3/6) with Streeter's dysplasia, 2 (2/2) with myelodysplasia, and one each with Larsen syndrome (1/1) and prune belly syndrome (1/2).

Postoperatively, all patients were immobilized with leg casts. The first cast is placed in the position gained after surgery, preferably without reduction or with minimal reduction under pulse oximetry control. Casts are changed every 7 days and are gradually corrected until extension reaches 110 degrees and pronation reaches 10-15 degrees. Correction is achieved within 21-30 days after wearing 3-4 casts.

After removing the last cast, the foot will be protected by an orthosis and walking will be resumed. Rehabilitation treatment mainly focuses on the plantigrade position of the foot, restoration of extension and correction of supination. The alignment rod was removed after 6 months to 1 year for children under 3 years of age and after 8 months to 2 years for children older than 3 years.

3. POSTOPERATIVE GOOD RESULTS

The results were regularly assessed at 30, 60 and 90 days, and then at 6 and 12 months. After 1 year, the recommendation for children younger than 3 years of age was to perform splashing and physical therapy. Older children were recommended to do martial sports, ballet, or swimming.

The plantar arch configuration allowed reconstruction of the plantar vault, and normal shape, direction, and position were obtained in all cases. At 5 years postoperatively, the comparison with the normal foot had a dynamic similarity of 89% for 25 feet out of 28, except 3 feet, 2 with arthrogryposis and one with Larsen syndrome.

In two patients, one with arthrogryposis and the other with Larsen syndrome, the mounting of the screw that fixed the notch deteriorated, which is why other screws were placed, and 8 years postoperatively, the titanium K-wire fractured. In the other patient who had a titanium elastic rod implant, the foot had a plantigrade position but radiologically presented a talocalcaneal synostotic block 10 years after surgery.

4. SURGICAL TECHNIQUE

4.1 Approach

When the operation is performed under tourniquet control, the surgeon has greater comfort, and the duration of the intervention decreases. Medial and dorsal release can be done using a single or double approach. We preferred the double (medial and dorsal) approach, given that the skin flap between the two incisions eliminates the risk of a hypertrophic scar in the area under great tension, in order to restore adduction and the protarsus varus.

4.1.1 Medial approach is done through an arcuate incision (Figure 1).

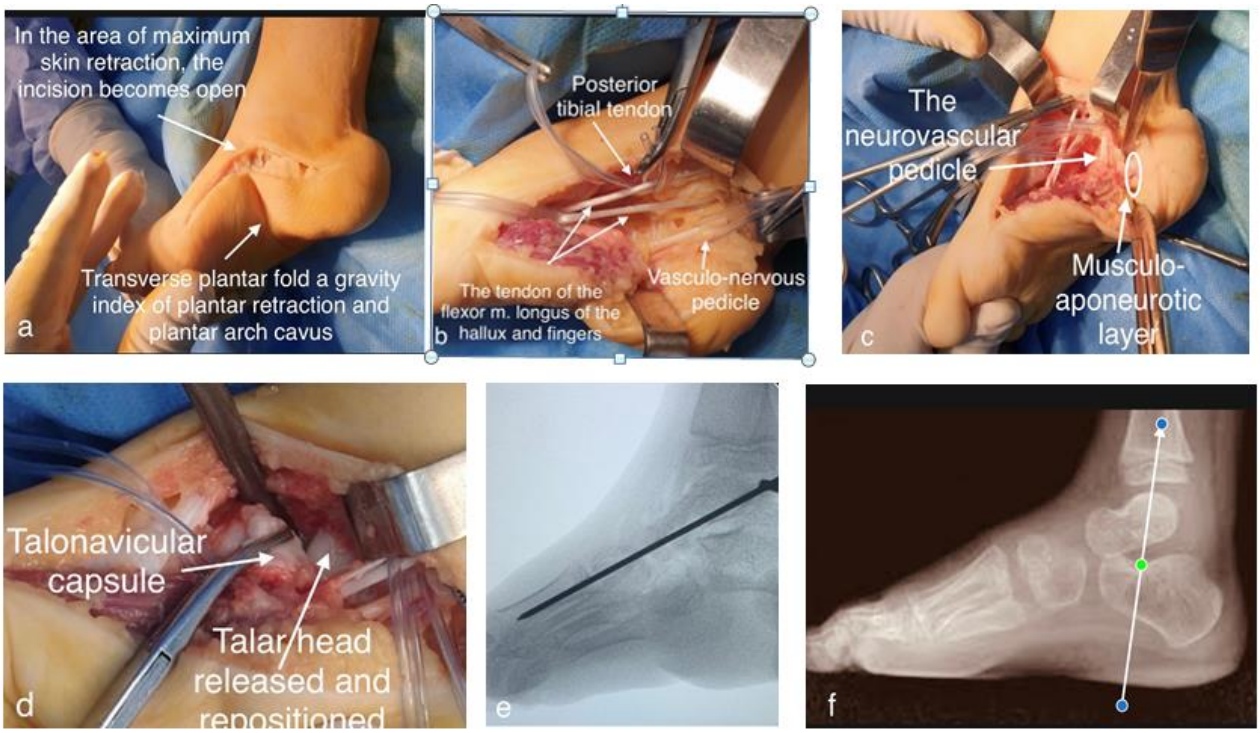

Fig. 1 Images taken during the medial approach: a) Skin incision and arrangement on the medial edge of the foot. b) Tendinolysis of the flexor digitorum longus, hallucis longus, and tibialis posterior muscles, and identification of the tibial retromalleolar neurovascular pedicle. c) Between the neurovascular pedicle, the distal edge of the calcaneus, and the skin, the superficial and deep musculoaponeurotic layers are delimited with two decollators and sectioned (the area delimited by the white ellipse). d) talonavicular syndesmolyis has released the dislocated talar head and is put back into the tibiotalar joint. e) fluoroscopic evaluation illustrates the fixation of the talonavicular-cuneiform 1-metatarsus 1 radius on the splint. f) stabilization of the protarsus varus with a K-wire (represented by the drawn arrow) passed through the calcaneus-talus-tibia

The incision starts from the central point of the medial facet of the calcaneus, ascends towards the apex of the tibial malleolus, and then descends symmetrically to the end of the medial edge and continues distally along a slightly curved path with the concavity oriented dorsally, up to 1 cm distal to the cuboid-metatarsal 1 joint interline.

- the medial edge of the abductor hallucis muscle is revealed and detached, and then the crossing of the flexor hallucis longus and flexor digitorum longus is identified and isolated separately on a cord.

- each flexor is dissected, and the fibrous adhesions are sectioned and partially released from the synovial sheaths; the flexor retinaculum is not sectioned or is partially sectioned to prevent dislocation during reconstruction.

- the posterior tibial pedicle is identified, isolated on a cord and released proximally and distally to prevent its injury and allow safe plantar disinsertion.

- the dissection and release of the tibialis posterior begins with the identification of the navicular tuberosity, the insertion site of the tibialis posterior muscle. The tendon is released from the synovial sheath, which appears obviously thickened. The plantar ramifications of the tendon are identified (Figure 2) and highlighted by digital pressure with the help of a compress.

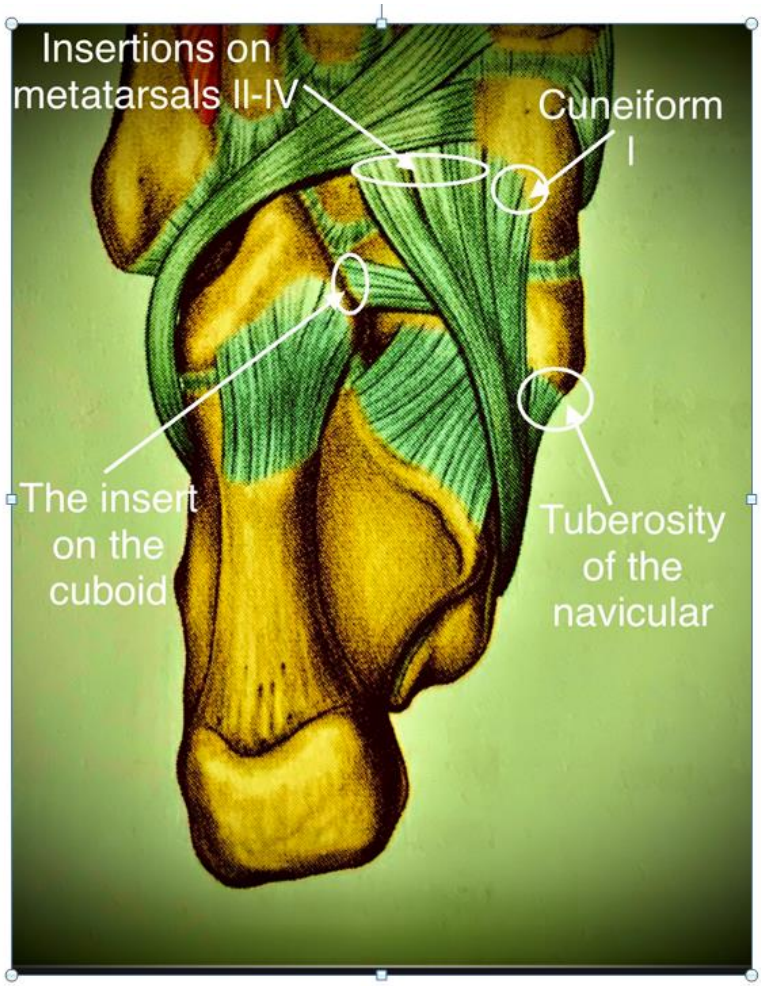

Fig. 2 Medial and plantar insertions of the tibialis posterior. The tibialis posterior lengthens by transposing the plantar insertions to the navicular tuberosity after detachment of the tendon by sectioning the tuberosity insertion

The 3 or 4 plantar digital extensions are sectioned at the level of plantar inserts, the navicular insertion is sectioned, and the tendon is detached; the tendon becomes longer and allows reinsertion of the plantar extremities on the navicular tuberosity. The potential balance of the plantar arch forces is achieved by transposing the plantar inserts to the navicular tuberosity, given that the tensile muscle force does not decrease as much as after lengthening.

4.1.2 Posterior approach consists of a dorsal incision made along the medial edge of the Achilles tendon, and lengthening is done in the sagittal plane while keeping the lateral insertion of the tendon on the calcaneus. Posterior syndesmolysis (or capsulotomy) opens the tibiotalar and talocalcaneal joints.

4.2 Medial syndesmolysis complements posterior syndesmolysis and includes release of the metatarsus 1 radius and protarsal joints.

4.2.1 Syndesmolysis of the metatarsus 1 radius is done dorsally, medially and plantarly for the talonavicular, naviculocuneiform and cuneometatarsal 1 joint. Insertions of the anterior and posterior tibial tendons are important spots for the identification of joint interlines.

Please note! One of the most important mobilizations is ensured by releasing the laterally oriented talar head. Talonavicular syndesmolysis must be done with particular rigor because there is a risk of damaging the joint cartilage due to the convex shape of the femoral head. Therefore, the talar head is visualized with the help of an elevator, without being damaged. The elevator is placed at the level of the talar neck, and moderate traction is applied while sectioning all talocalcaneal connections, including the anterior talocalcaneal ligaments. This release allows the talus to rotate, with the interosseous ligament as its center of rotation. The technique is used in several procedures. Talus mobilization and anatomical repositioning cancels the forefoot inversion and allows reduction of the calcaneocuboid subluxation

by releasing the calcaneus, which is blocked by the talar head. Thus, the talonavicular joint can be reconstructed, and then stabilized on a splint (Figure 1e).

As a splint, it is preferable to use a titanium elastic nail or a titanium K-wire is preferable, with age-appropriate sizes: 1.2-1.4 and more rarely 1.6 as studies performed by Baltatu and al's[14,15,16]. Titanium elastic rods can be maintained for 3 to 6 months. The splint can be passed manually or with a drill using a guide that orients the wire from the lateral edge of the talus (which has been identified through the posterior incision) toward the center of the talar head. The talar splint allows the talus to rotate; if necessary, with the elevator placed at the level of the talar neck, we can control the reduction much better, and the splint is advanced through the navicular, cuneiform 1 and metatarsal 1. The advancement of the splint can be followed at each passage from one joint to another. The axis and arch of the medial radius are reconfigured on the splint.

Arching is done by fixing the splint between two joints with two special clamps and modeling the plantar arch curvature. In younger children, this can be performed by fixing the splint distally and arching the forefoot in equine.

4.2.2 Protarsal syndesmolysis

The cutaneous-subcutaneous flap with an hourglass shape, which is delimited by the two incisions, together with the tibial retromalleolar neurovascular pedicle, is anchored to a cord in order to prevent its damage and facilitate syndesmolysis.

Medial syndesmolysis of the protarsus complements posterior syndesmolysis. Medial sectioning is done carefully and sparingly. This operative time becomes easier if a decollator is inserted through the posterior talocalcaneal and tibiotarsal joints to allow better visualization of the medial capsule and ligaments of the two joints, which are difficult to identify because they are thickened and retracted. Please note! Medial tibiotalar syndesmolysis must not damage the articular surface of the tibial malleolus or the malleolus in order to prevent early arthrosis or heterotopic ossification.

It is preferable to perform talocalcaneal syndesmolysis at the beginning. After opening the talocalcaneal joint, the talus can be aligned much more easily.

If the protarsus varus is corrected and the talar head can be realigned in the axis of the metatarsal 1 during the reconstruction attempt, then tibiotalar syndesmolysis is abandoned. If tibiotalar syndesmolysis is required, the tibiotalar and talocalcaneal joints are opened medially and dorsally when attempting to reconstruct the foot.

Medial and dorsal talocalcaneal syndesmolysis allows opening the joint and anatomically repositioning the calcaneus. If there is instability of the calcaneus, it is provisionally stabilized with a wire inserted through the calcaneus, talus and tibia (Figure 1f).

Exceptionally, in children over 8 years of age with autism, mental retardation, idiosyncrasy, etc. who have no indication for an external fixator implant, medial syndesmolysis allows performing talocalcaneal cuneiform subtalar resection, which results in a synostosis equivalent to an arthrodesis that corrects the varus (Figure 3).

Fig. 3 In a 12-year-old child with autism, the only treatment option for a severe form of recurrent clubfoot after Achilles tendon lengthening and plantar aponeurotomy was medial and dorsal release. Protarsal syndesmolysis for varus correction was followed by talocalcaneal cuneiform resection: the achieved synostosis allowed correction of the deformity. Eight years after surgery, the foot has normal shape, direction, and plantigrade position, and is pain-free

4.3 Plantar vault reconstruction

The released talus has an unstable position, and foot correction by alignment on the splint requires the plantar arch to adopt a flat or overcorrected position while fixing the medial radius to align the first cuneiform and metatarsus in the axis of the splint.

Aligning the talonavicular-cuneiform 1-metatarsus 1 on the splint allows reconstruction of the plantar vault. At the posterior extremity, a notch is configured, which is fixed with a special screw to the calcaneus. The screw has a groove in which the notch of the wire is fixed. The groove positions the wire, allowing the convexity to be fixed dorsally, and the notch does not create talocalcaneal pressure because it is smaller than the groove.

Fixing the wire allows bending it in order to reconstruct the plantar vault. Fixation is very important to maintain the dorsal convexity position of the wire; rotation must be avoided to prevent plantar arch collapse and wire migration.

After applying the splint and releasing the foot in a free position, the foot is partially corrected. In the free position, pulse oximetry usually indicates a saturation level of 85% to 95%. The subcutaneous cellular tissue and the skin are sutured with the foot in anatomical position. The dressing is loose, and the compresses are covered with a cotton bandage but without compressing.

Immobilization is done with a large plaster cast with the foot in the position gained after surgery, without restoring it to the normal position in order to prevent ischemic phenomena. Then, at regular intervals of 7-10 days, progressive reduction of the foot begins until complete restoration of its shape, direction and position. The duration of immobilization is proportional to the patient's age; 4-6 weeks in a plaster cast, a period during which the deformity is gradually reduced, and then in a calf-foot brace.

Physical therapy is very important. Recuperative treatment is simultaneously performed to provide stability of the foot in a normal position, as well as the static and dynamic balance between the flexor-extensor and supinator-pronator muscles but especially between the muscles that ensure eversion and inversion.

5. SHORT HISTORY

Since ancient times, the initial treatment of congenital clubfoot has been conservative. Muscle relaxation maneuvers were performed, and straps or devices were applied to correct the deformity. This stage was followed by a period during which plaster casts were used by Jeffs[17] by applying them successively, without taking into account the components and their degree of manifestation.

Syndesmolysis and lengthening of the posterior, medial and plantar tendons have been done for a long time. The first description found belongs to Phelps, who used them in 1880, as Farill[18] claims.

Until 1970, Kirmisson, Codivila, Nove Josserand, Anzoletti, Leveuf-Bertrand, Kanadel, Von Haelst, Camera, Moroz, Wagner, and many others modified the procedures, provided technical indications and suggested several anatomical, physiological, and surgical technique details. In Romania, Socolescu, Pesamosca, Goția, Mironescu, Stan, and Moldovan made an important contribution in this regard.

In the last 30-40 years, conservative approaches have been outlined; the Ponseti technique, the Bensahel technique, and recently a third way, the hybrid method.

6. THE TREATMENT OF CHOICE

The treatment of choise for congenital clubfoot is initiated early and is done according to the Ponseti technique or the Bensahel technique. Treatment has maximum effectiveness if it starts from the first day of birth.

6.1 Ponseti technique

Treatment of children younger than 8 years of age can start with a Ponseti protocol because many feet that have not previously been treated orthopedically or surgically are sometimes surprisingly supple. Treatment success is inversely proportional to the age at which treatment begins, as Mosca[19] affirm.

Radler and Mindler[20] stated that the first line of treatment consists of a series of cast immobilization procedures, regardless of the severity of the deformity and the patient's age.

The results obtained by Ippolito and al's[21] through the Ponseti method associated with limited posterior release are better than those achieved through medial and dorsal release performed after a period of cast immobilization.

6.2 Bensahel technique

History should never be rewritten, but it can only be served by getting the facts right stated Bensahel and al's[22].

This is a functional therapy method for the conservative treatment of congenital clubfoot. It was implemented and developed in the early 1970s at the Robert Debre Children's University Hospital in Paris. I had the privilege of meeting Prof. Bensahel and talking with him in the period when he was President of EPOS and coordinator of the Journal of Children's Orthopaedics (JCO) together with Prof. Wintrab.

In 1975, he reported his original technique, which was erroneously taken as a French method, at the Tachdjian Course in Chicago organized by the American College of Surgeons.

Mirhan Tachdjian, a renowned orthopedist at the Children's Memorial Hospital in Chicago, knowing Bensahel's experience and being a member of the French Society of Orthopedics, offered Bensahel the privilege of presenting his original technique to the participants. Throughout the years, over 10,000 orthopedic surgeons from more than 60 countries took part in these international orthopedics seminars. Within a short time, the reported technique became widespread and began to be applied in many countries. The results obtained in the long term, until to the end of the growth period and beyond it, were appreciated, and the applicability of the method has expanded. The Bensahel technique is currently applied all over the world.

Bensahel and al's[23] first reported the use of the method in 1990. Good results were obtained in almost 50% of patients. When complementary surgery was performed, the percentage of good results increased to 86%.

6.3 Hybrid method

This therapeutic option combining both methods was called "the third way" by Dimeglio and Canavese[24].

Clubfoot treated with the Ponseti or Bensahel technique shows, at the end of the treatment period, residual deformities that require surgical interventions. The rate of these interventions is similar after both approaches, namely 28% to 29%, according to the statistics of treated cases.

The asymmetry discrepancy between the size of the feet and the circumference of the calves did not show differences until the age of 5 in children with clubfoot treated with the Ponseti or Bensahel technique.

Interventions after using the Ponseti technique were less extensive than after applying the Bensahel method. For this reason, a less extensive selective surgical intervention must be an integral part of both the Ponseti technique and the

Bensahel method. The combined use of both techniques, Ponseti and Bensahel, for patients with correction difficulties helps to cumulate the advantages of the two and maximize the results. So far, the best outcomes have been obtained by Dimeglio[24] through this method, which is why it can be the best approach in the future.

7. DEFORMITIES SUITABLE FOR MEDIAL AND DORSAL RELEASE SURGERY

There are complications that appear progressively after conservative treatment as a result of minimally invasive interventions or simple soft-tissue release. After initial clubfoot correction through Ponseti treatment, recurrence rates range from 26% to 48%, as Van Schelven[5] noticed. In personal case reports, the recurrence rate after using the Bensahel technique was 28.9%, meaning that is was approximately equal to that obtained after applying the Ponseti technique, namely 28%.

7.1 Recurrent clubfoot is an iterative deformity that affects a clubfoot treated only orthopedically and on which surgical interventions, other than medial and dorsal release, have been performed.

Early relapses occur in the first 6-12 months after treatment and usually correspond to ages between 6 months and 2 years. Late relapses occur after two years and correspond to ages between 2 and 8 years. Both early and late simple relapses with 1-2 components are treated by resuming the Ponseti or Bensahel program to facilitate muscle relaxation. If the foot is reducible, Achilles tendon lengthening, anterior tibial transfer, or plantar fasciotomy are used, but other methods are also possible.

When the relapse involves 3 or 4 partially reducible or irreducible components, medial and dorsal release is used if the patient has not previously undergone another medial and dorsal release. This group can also include orthopedically treated patients who have initially received minimally invasive or simple interventions. Patients with recurrent clubfoot who have previously undergone medial and dorsal release benefit from the rule of correction with an external fixator.

7.2 Residual clubfoot is the deformity that has been partially but never completely corrected. Most of these patients have already had at least a soft-tissue release, and therefore there is little hope that another soft-tissue release will improve the situation as Eidelman and al's[25] observed.

The most common residual component is forefoot adduction or residual metatarsus varus. Regardless of the procedure used, several authors, including Li and al's[26], claim that excision of the abductor hallucis muscle is recommended to prevent recurrence of forefoot adduction.

7.3 Neglected clubfoot is a deformity present in a patient who has never been treated, has abandoned treatment, or has not systematically followed the established therapeutic program. The most relevant factor of negligence in the Ponseti technique is non-compliance with the indications for wearing the orthosis, which aims to restore the balance between agonist and antagonist muscles.

8. DISCUSSION

Surgical treatment applied when conservative treatment fails includes minimally invasive, minor, medium, and extensive interventions in its therapeutic arsenal. The best known and most commonly applied techniques are those described by Anzoletti, Codivila, Carroll, McKay, and Simons. The Turco procedure, as a medium extension intervention, is a highly effective synthesis that has brought great benefits to patients. The modifications made by other authors to the Turco procedure adapted the operation for groups of patients and had favorable effects on conceptualizing the technique itself, which is why this approach has been used in surgical techniques from 1880 to the present.

8.1 Extensive procedures

The most extensive procedures are McKay and Simons, which use the Cincinnati incision. In both, the subtalar release is complete and also involves the interosseous ligament.

McKay develops a new concept after assessing 102 clubfeet operated over a 6-year period. The author analyzes and discusses the following issues: correction of horizontal rotation of the talus, early mobilization of the ankle, mobilization of the flexor tendons, and release of the interosseous ligament. He introduced the concept of early mobilization of the ankle joint through an articulated "cable cast" to increase ankle extension by 30-60 degrees, it being limited to 10-15 degrees, as suggest McKay[27]. The complete subtalar release is an extensive soft-tissue procedure for the treatment of clubfoot that has not been corrected by non-surgical methods. It is a more extensive surgical procedure than medial and dorsal release.

Simons mentions that the complete subtalar release produces a greater degree of correction than other procedures and provides superior anatomical alignment between the foot and calf. Simons[28] indicate that the risk of this procedure is a tendency to overcorrection. There is a correlation

between the extent of the soft-tissue release and the degree of functional impairment to the foot joints. In the long term, extensive medial, dorsal and lateral release leads to poor functional outcomes and arthrosis disorders as claims Dobbs[29].

Medial and dorsal release allows correcting the deformity and limits this inconvenience.

8.2 Medial and dorsal release

Medial and dorsal release aims to restore the shape, direction, and plantigrade position of a neglected, recurrent, or residual clubfoot. This medium-extension surgical intervention is still widely used and is an effective way of treating clubfeet in certain circumstances, according Van Schelven[5].

Medial and dorsal release has caused much controversy. However, some of the problems have been elucidated:

- the final result of clubfoot treatment is accurately assessed at maturity;
- if medial and dorsal release does not allow for correction, partial excision of the cuboid is required;
- transposition of the anterior tibial insertion to the posterior side of the foot in podiatrically marked sites is necessary to maintain complete correction.

There are some points of view that still remain in question:

- extensive subtalar release;
- fixation and alignment of the calcaneal-tibiotalar or talonavicular-cuneometatarsal 1 joints;
- sectioning of the deep fibers of the deltoid ligament.

We support the extensive subtalar release only for stiff feet in genetic syndromes, with their fixation using small elastic rods, maintenance until the desired effect is achieved and ablation in the shortest possible time. We have always sectioned the deep fibers of the deltoid ligament and no complications have occurred as a result of total release of the ligament. Reinsertion of the tibialis posterior after lengthening it with plantar extensions and the splint removes this inconvenience.

The selection of cases that have this indication and not another one, such as foot correction by implanting an external fixator or arthrodesis resection, relies on the experience of the surgeon who, depending on the patient's age and clinical evaluation but also the ankle and foot imaging, decides for one of the medial and dorsal release options.

This procedure takes into account the surgeon's ability to associate and understand, as well as their skill and experience not only in foot pathology but also in the knowledge of many techniques and implants that can be used in orthopedics.

The technique and art of solving difficult cases puts the surgeon to a hard test, and in this regard, there are no standard methods or models, but a case that can be solved by doing "as much as needed and what is needed".

The surgeon chooses the most efficient method, which should be, as both the doctor and the patient's family wish, the last operation that will benefit the patient. This is an integrative and innovative concept that is not understood by some resident doctors and young doctors who are eager to simplify everything to minor surgical techniques, regardless of the outcome, in their desire to quickly climb the career ladder, being full of infatuation that they hold the truth. They want to restrict medicine to the rules of a simple addition and subtraction arithmetic or to copy-paste operations.

Certain generally valid principles associated with the laws of growth and development can be adapted while keeping the specific limits and adaptive abilities of the affected structures.

When recurrence occurs after another surgical intervention or multiple interventions, and the foot deformity is associated with marked hypotrophy of the foot or calf, using the Ilizarov fixator is a better indication.

8.2.1 From Anzoletti to Codivila, and then Turco associated with Hendrix-de Marneffe or Lichtblau

The specific therapeutic program for a patient with an indication for medial and dorsal release includes a number of factors, among which an important role is played by age, weight, degree of deformity, severity of each component of the deformity, associated injuries, and social considerations.

Typically, children aged 6 to 12 months underwent surgery when their foot was found to be irreducible after conservative treatment, and retraction and shortening of the Achilles and posterior tibial tendons were highlighted. Of the multiple techniques, the most appropriate was the Anzoletti method, which consisted of lengthening the Achilles and posterior tibial tendons, and sectioning the deltoid ligament with its superficial

and deep layers. The technique specifies that, if there are still obstacles, they are also sectioned.

Codivilla's internal release was indicated between 2 and 5 years of age. It had as an express indication the recurrent foot after conservative treatment and the neglected foot. The procedure was similar to Anzoletti's technique. In addition, it involved lengthening of the flexor hallucis longus tendon, syndesmolysis of the medial radius, and sectioning of the plantar aponeurosis. At the surgeon's discretion, the plantar aponeurosis was sectioned, and the tibialis anterior was transferred to the cuboid to prevent recurrence in supination and adduction. After an intraoperative evaluation, the intervention was complemented by the medial traction of the talar neck with the help of a decollator, and the correct contact between the talus and the navicular was reconstructed to restore the angle between the talus and the calcaneus: 30 degrees from the front and 45 degrees from the side. To maintain this configuration, a wire was passed through the metatarsal 1-cuneiform-navicular and talus from the anterior to the posterior part, and another one from the distal to the proximal surface through the calcaneus, talus and tibia.

Between 6 and 9 years of age, a mixed intervention was performed on soft tissues and the bone. The Codivilla or Turco release procedure was associated with the extraarticular cuneiform resection of the cuboid, as envisaged by de Hendrix and Marneffe. Licthblau[30] combined medial release with lateral excision of the distal part of the calcaneus to reduce the high recurrence rate of the deformity. The operation allows good clubfoot correction, without requiring extensive dissection. In the selected cases, this resection is very useful in the therapeutic arsenal of clubfoot.

8.2.2. The Turco procedure

This is a one-stage method for early surgical correction of irreducible congenital idiopathic clubfoot that has failed to respond to non-operative treatment, or has relapsed after previous soft-tissue surgery.

Turco[31] stated that "the method is derived from the procedures previously described by, among others, Codivilla, Brockman, McCauley, and Bost" (p. 477).

This technique has highlighted three essential elements:

1. a complete correction is best achieved with a one-stage posterior and medial soft-tissue release.
2. a lasting correction is achieved only if the correction at operation is complete and temporarily stabilized by internal fixation.
3. a stress dorsiflexion illustrated by lateral radiograph of the ankle is the most accurate and reliable method of assessing correction of the deformity.

Turco supported calcaneus repositioning through complete medial, dorsal and lateral subtalar release as well as fibular ligament release. Complete posteromedial release in one stage was first described by Turco[31] in 1971.

Turco established the described technique, which was adopted by many practitioners. Some performed it ad litteram, while others modified it with the purpose of adapting it to a particular group of entities.

Attributing this technique to him and adopting it as a Turco procedure is well deserved, and his role is undeniable. Years of experience have led to the refinement of several technical aspects and the improvement of the efficiency and effectiveness of the Turco procedure. Turco's modification of the classic Codivilla operation has led to improved results reported by Turra[32].

8.2.3 Goldner's procedure incorporates a concept and highlights the role of the talus in this foot deformity. According Lejman[33], full correction of the deformity can be achieved only by posterior, medial, plantar and lateral release of the talus.

Goldner[34] also emphasizes correction of the talus rotation as a primary deformity, performs complete release of the tibiotalar joint, including the deep medial deltoid ligaments, and subsequently repairs these ligaments, if necessary, to correct talus rotation in the ankle joint. Subtalar capsulotomy is minimized in order to prevent valgus overcorrection.

8.2.4 Carroll's procedure stressed the importance of sectioning the plantar fascia and performing calcaneocuboid syndesmolysis, which he considered responsible for the real cavus; however, these elements were overlooked by Turco, noticed Burnei[35].

Carroll described a method of releasing the calcaneocuboid joint through a dual skin incision approach allowing easy access to plantar medial and posterolateral structures. Porat and Kaplan[36] critically analyzed 33 clubfeet operated with Carroll's procedure. Four years after surgery, 82% satisfactory and 18% unsatisfactory results were reported. The double-incision approach offered the advantage of plantar, medial, and posterolateral release. The calcaneocuboid joint was released and emphasis was also placed on releasing the lateral soft sides, which provide the ability to resist the surgical reduction attempt.

In this procedure, sectioning of the plantar fascia is also accompanied by distal sectioning of the abductor hallucis muscle to decrease forefoot adduction. Talonavicular syndesmolysis enhances adduction correction.

In all children with irreducible clubfoot when passive reduction is attempted, the bone architecture is deformed. According to the Delphes law, the subluxated anterior part of the talus grows excessively and can no longer fit into the tibiofibular joint. In this way, Nelaton and Adams protuberances appear in the resistant foot and oppose correction, as Pesamosca[37] and al's noticed.

In the untreated or relapsed feet, the lateral malleolus is displaced posteriorly, the talar head is oriented laterally, and the subluxated navicular is directed medially toward the medial malleolus. Carroll[38] takes into account these modifications and describes an operative technique to restore normal alignment of the talus in the tibiofibular-talar joint, of the navicular and talus, but also of the talus in relation to the calcaneus.

8.2.5 Burnei's new eclectic procedure

A variety of surgical procedures and techniques have been described to achieve the goal of complete anatomical restoration, as noticed Hering[39].

Goldner[40,41], a famous American surgeon, predicted in 2016 that, in the next phase, the surgical techniques necessary for treating numerous categories of deformities would appear. An etiopathogenically targeted operation performed early, correctly and which will be sufficiently thorough can decrease the recurrence rate and will not result in overcorrection or limited aseptic necrosis of the talus.

Burnei's medial and dorsal release aims to correct a foot that is irreducible or partially reducible to passive maneuvers. In the case of a recurrent or residual clubfoot, retractions or scar tissues may also be present, causing technical difficulties. All recurrent, residual or neglected clubfeet show retraction and shortening of the intrinsic and extrinsic muscles of the foot, as well as deformed bones accompanied by thickening and shortening of the posteromedial joint capsules, presented by Caroll[42]. This eclectic procedure strictly addresses these modifications.

At the age of 6 moths, clubfeet with moderate or severe deformities show significantly altered surfaces of the joint cartilage. That is why the preferable age for surgery on recurrent, residual, or neglected clubfoot is between 3 and 6 months, generally under the age of 9 months, so that the child can walk at 1 year. The results after a longer period of time are clearly superior claims Pesamosca[37].

In the mild forms, the cartilage is less altered, and surgical treatment allows restoration of cartilage quality until the age of 8. Medial and dorsal release for children under 3 years of age has a smaller extent and allows appropriate selection of operative times. The more severe the foot deformity, the more difficult the surgery and the more extensive the medial and dorsal release required to achieve correction, as Burnei[35] studied.

This surgical intervention selects the most appropriate operative times from among various techniques and adds the following: lengthening of the posterior tibial tendon by sectioning the plantar insertions and transposing them to the navicular tuberosity; plantar disinsertion instead of plantar fasciotomy; alignment of the metatarsal 1 radius on the splint; reconfiguration of the plantar arch.

The intervention takes into account Goldner's[43] recommendations and excludes some of the factors known as the cause of overcorrection, especially the extensive subtalar release and the tenotomy of the tibialis posterior tendon, without the possibility of reinsertion that ensures the maintenance of the plantar vault.

The posterior tibial tendon is shorter and retracted, and to rebalance the forces that maintain the plantar arch, the action force is better maintained by transposing the plantar insertions to the navicular insertion site.

The technique of the designed procedure involves sectioning the deltoid ligament. There is no need for its reinsertion if limited subtalar release is used and tibialis posterior efficiency is maintained in the plantar arch balance. Moreover, splint placement provides safety.

In this procedure, not only the plantar aponeurosis and the abductor hallucis muscle, but also the plantar muscles are sectioned. Musculoaponeurotic disinsertion is performed, which involves, besides the abductor hallucis, the flexor digitorum brevis and abductor digiti minimi from the superficial layer, as well as the quadratus plantae. Plantar musculoaponeurotic disinsertion facilitates restoration of the Lombard balance between the agonist muscles responsible for forefoot adduction and supination and the antagonist muscles. The relaxation effect for correcting this adduction is complemented by medial syndesmolysis, which involves the talonavicular, naviculocuneiform, and cuneometatarsal joints to provide reliable potential for complete clubfoot correction. The

arcuate talonavicular-cuneometatarsal 1 splint prevents the plantar arch drop.

Teratological deformities and those caused by genetic syndromes present more advanced lesions than severe forms. An arthrogrypotic, myelodysplastic, or other eponymous foot is difficult to correct surgically and, once operated, is difficult to maintain, as suggests Goldner[40]. Aligning and correcting the plantar vault on the elastic rod reduces or eliminates this inconvenience. The duration of maintaining the splint is longer and, in cases with extreme rigidity, it can be maintained for 2 years. Prolonged retention of the elastic rod can prevent iterative tendon lengthening and ultimately segmental resections and foot shortening.

Residual protarsus varus requires medial and dorsal tibiotalar and subtalar syndesmolysis because it has as its anatomical-pathological substrate the equinus and varus position of the talus associated with an obliquely oriented calcaneus in the plantar and medial planes.

Basically, the talus is subluxated anterointernally compared to the tibiofibular joint, and the calcaneus is lying on its external side. Postoperatively, the foot has the potential for complete recovery, is fully correctable intraoperatively and will be successively repositioned to achieve the anatomical restoration of its shape, direction and position. The Burnei procedure provides safety especially for older children. Without the alignment of the navicular, which can dislocate dorsally, the cavovarus deformity may relapse, and without the curvature of the splint, the foot may lose its plantar arch or be overcorrected into valgus. Reconstruction of the tibial radius induces the reduction of calcaneocuboid subluxation. Intraoperatively, the complete reduction of the deformity is observed when the lateral radius flattens, or in other words, the "Nelaton prefibular protuberance" and the "Adams pretibial transverse bar" disappear. Sometimes, a depression appears in the middle area of the lateral column, which is corrected over time.

Therefore, intraoperatively, the passive reduction completely corrects the medial radius, lateral radius, and forefoot inversion. After placing the splint, the foot left free maintains an improved equinovarus position, the "Nelaton protuberance" is present but is less prominent, the foot is fully reducible, and the lateral column is straight in the reduced position.

In exceptional cases, this can be a solution for children over the age of 8 who have a contraindication to use the external fixator due to social conditions or certain disorders, but there is a risk of arthrosis lesions (Figure 4). However, the intervention is more advantageous than resection-arthrodesis.

Currently, much emphasis is placed on the ideal age to operate on infant clubfoot. The fact that surgical treatment has been successful and is an essential part of general treatment has been confirmed by Turco[31] and Goldner[44]. If the Ponseti or Bensahel protocol is ineffective, rigid and irreducible feet have an indication for surgery. A 6-month delay in performing surgical correction has been shown to be safe and acceptable for restoring the shape, direction and position of the foot.

Fig. 4 The clinical and radiological appearance of the feet of a 32-year-old patient who presented at the age of 9 with recurrent clubfoot after simple soft-tissue release interventions. The patient showed severe retardation and poor communication skills. Implantation of an external fixator was contraindicated. In this context, the only reasonable option accepted by the patient's parents was medial and dorsal release (without cuneiform resection). The left foot was operated on at the age of 9, and for the right foot, the patient presented for surgery at the age of 14. a) and b) frontal and dorsal images reveal a normal static configuration c) and d) frontal X-rays illustrate arthrosis lesions at the talocalcaneal joint and metatarsal 1 radius, which are more evident in the right foot e) and f) during gait, in the support phase of both feet, the plantar movement is outlined but range of motion is missing. Both the stationary position and locomotion are pain-free. The patient is kept in the record for arthrodesis. Medial and dorsal release made it easier to maintain the foot length, being a much better choice than resection-arthrodesis done at 9-14 years of age; if arthrodesis is performed when pain occurs, the foot length will not be affected as in the case of resection-arthrodesis performed during adolescence

The skin is sutured with the foot in a reduced position. The tension induced by the suture must be minimal. The foot will be immobilized with a plaster cast in the position gained after surgery, but without being reduced in order to prevent ischemic phenomena. Foot immobilization immediately after surgery is as important as the operative technique itself because a foot incorrectly positioned in the plaster cast will heal in that vicious position.

9. CONCLUSIONS

Burnei's procedure reconfigures the plantar arch on the splint and reduces the number of complications, uses plantar musculoaponeurotic disinsertion and removes the effect of intrinsic muscles, achieves balance between agonist and antagonist muscles that ensure inversion and eversion, and extends the indication up to the age of 8. In exceptional cases, for children aged over 8 years who are indicated an external fixator but suffer from diseases that contraindicate its use (autism, cerebral palsy, severe psychomotor retardation), subtalar syndesmolysis can be accompanied by resection-arthrodesis with a lateral base and performed using the medial approach.

This operative technique considers biomechanical criteria and is also effective for non-idiopathic clubfoot.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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