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Guided Growth in Lower Extremities

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Abstract: Guided growth is a surgical option of increasing use for the correction of angular deformities of the lower extremities in skeletally immature patients. It is possible to perform in multiple planes or segments, with excellent results. Its most frequent use is in deformities of the coronal plane around the knee. Permanent epiphysiodesis can be performed in patients within 2 years before the end of longitudinal growth of the segment to be treated, considering temporary epiphysiodesis for patients with more than 2 years of remaining growth. In mild to moderate cases, the success rates reach even 100% in some series, while patients with Blount's disease, obesity, advanced skeletal age or severe deformities are less likely to achieve a complete correction. Regardless of the surgical technique, adequate preoperative planning, family education and strict follow-up are necessary to minimize complications and allow excellent correction of the deformity with minimal morbidity.

Key words: growth plate; genu valgum; genu varum; lower extremities

1. Introduction

Numerous pathologies alter growth in the long bones of the lower extremities, causing aesthetic and functional problems [1]. These problems can modify the biomechanics of gait, with angular deformity of the lower extremities in the coronal plane being one of the main causes of knee osteoarthritis due to overload [2].

Causes of lower extremity axis disturbances include sequelae of trauma, infection, tumor pathology, skeletal dysplasia, or metabolic disease [3]. Proper medical management of any of these conditions can help achieve a good outcome and is an essential part of treatment. However, it does not always obviate the need for surgical correction.

One of the methods developed for the correction of these alterations is "guided growth". This aims to modify the longitudinal development of the physis in long bones by blocking or slowing its growth rate, in order to progressively correct deformities of the anatomical axes or length differences in the extremities in patients with growth plate with active function. There are currently multiple surgical techniques to carry it out, each one with advantages and disadvantages, without an ideal technique.

2. Physiology

The physis or growth plate is a zone of specialized cartilage tissue located at the ends of long bones, between the epiphysis and the metaphysis. It consists of three cellular layers with different properties [4]: a) reserve or germinal zone, continuous to the epiphysis, consisting of resting cells; b) proliferation or columnar zone, where cell division, chondrocyte proliferation and matrix synthesis are initiated; c) hypertrophic zone, which ensures longitudinal growth towards the metaphysis by chondrocyte maturation and hypertrophy (increasing up to 5 times its size). Next, there is the zone of provisional calcification, in which vascular invasion, matrix mineralization and replacement of cartilage tissue by osteoblasts take place. In addition, there is the zone of Ranvier, surrounding the physis, which confers the transverse growth of the segment. This entire structure has a peripheral support composed of perichondrium, the Lacroix ring at the physiological level and periosteum at the metaphysiary level [4].

The longitudinal growth of long bones is a product of the activity of all zones of the physis, especially the hypertrophic zone. The percentage of total length of each bone segment contributed by the physis is variable. Approximately 30% of the length of the femur is given by proximal physis, while 70% will be from the activity of the distal physis. At the tibia level, 60% will be given by the activity of the proximal physis, while 40% by the distal physis [4]. This growth potential is the result of the phenotypic expression capacity that can be achieved through the activation of an endocrine axis at the local and systemic level.

The local axis consists of a complex interaction, partially known, involving the Indian Hedgehog signaling pathway (IHH: Indian Hedgehog Homologue Protein) as the main regulator of growth activity [5]. Chondrocytes would be activated by parathyroid hormone-related peptide (PTHrP), produced at the periphyseal and perichondral level at the ends of long bones, producing their proliferation. As long as this proliferation is maintained, IHH signals remain inhibited. Once these pre-hypertrophic chondrocytes move away from the proliferation zone, IHH production begins, signaling cell hypertrophy and, subsequently, osteoblast activation and ossification. By signals not yet defined, IHH would stimulate the production of PTHrP in the bone ends, thus regulating the local axis. Other regulatory signaling pathways include fibroblast growth factors (FGF) and bone morphogenetic protein (BMP). The former decreases chondrocyte proliferation and inhibits IHH production, limiting columnar height. The second increases columnar height by stimulating HHI expression and thus chondrocyte proliferation. These two pathways are therefore considered antagonistic.

The systemic axis is constituted by the regulatory activity of thyroid hormones, which stimulate growth hormone, responsible for cell activation at the germinal zone level, and IGF-1 (Insulin Growth Factor like-1), responsible for stimulating cell proliferation. Following this longitudinal growth, bone tissue changes its internal and external structure in response to the mechanical forces acting on it, known as "Wolff's Law". For immature bone, longitudinal bone growth is inhibited by sustained compressive loads and accelerated by physiological loads or traction. This is known as the Delpech-Hueter-Volkmann Law [6].

Based on this growth potential, different methods of guided growth have been developed. However, the histological changes evidenced experimentally after its application are disparate, including complete disorganization of the physis and formation of bone bridges, which demonstrates the complex biological and signaling process yet to be studied [7].

3. Surgical Techniques

The option of inhibiting growth at the physiological level of long bones was introduced in 1933 by Phemister [8], who resected a bone block including metaphysis, physis and epiphysis, and then rotated and reinserted it, generating a bone tissue bar, which produced a growth block at the level of the physis. The disadvantages were the long postoperative recovery time and the permanent inhibition character it produces. The technique was modified in 1984 by Bowen [9], by performing a percutaneous peripheral curettage, which reduced the surgical invasion, but it is still a definitive process, so it is preferably used in the last months of growth of the segment to be operated.

In 1949, Blount [10] proposed reversible physiodesis by periphyseal stapling, which is applicable for both angular correction and longitudinal growth inhibition. Among its problems are the need for a wide approach to the operative site and the failure of the fixation material, with extrusion or breakage of staples. It is also reported a "rebound" of restricted growth, which occurs in children with greater remaining growth, so a brief over-correction is recommended when used in such cases. Finally, the risk of achieving definitive physiodesis after a period of physial fixation longer than two years has been defined as a risk of this technique [11].

In 1998, Métaizeau [12] described the use of screws as a method of fixation of a segment of the physis, blocking its longitudinal development, which further improved postoperative rehabilitation times by being a less invasive surgical technique and without compromise of the joint capsule. The use of cannulated screws, decreasing the risk of inadequate perforations, has been fundamental in its diffusion (Figure 1). However, the osteosynthesis material crosses through the growth and produces a direct compression of it, which can generate an irreversible physiodesis, so it is still of choice in a precise age range, close to the end of physiological growth.

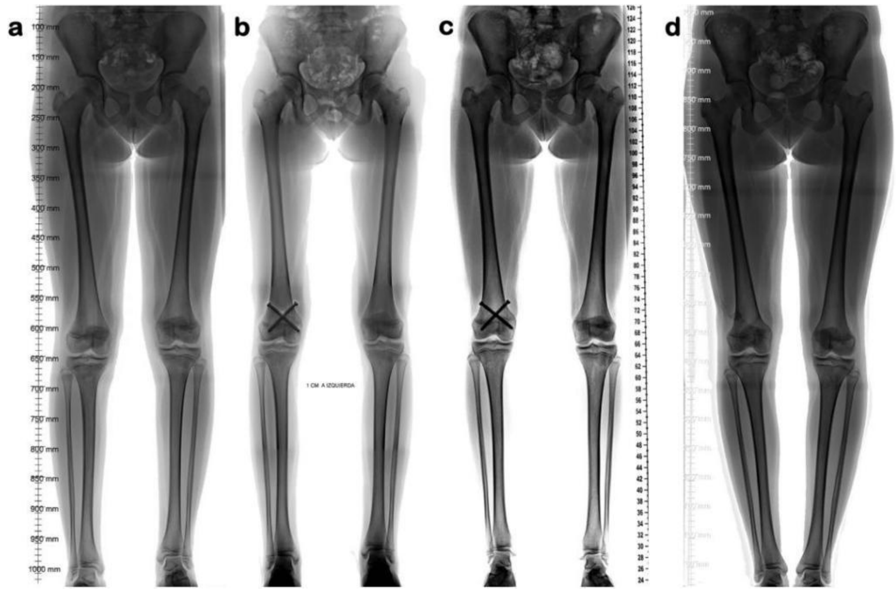

Figure 1. (a) Radiological study of a 12-year-old girl with a difference in length of the lower extremities showing a difference of 2 cm. (b) Physiodesis with percutaneous screws is performed. (c) Control at 9 months shows correction of the length difference. Given the potential of remaining growth, the screws are removed. (d) Radiological control one year after screw removal confirms symmetric growth, without length difference.

The term "guided growth" was first described by Stevens [1], using a plate with two screws around the physis (Figure 2), seeking to overcome the problems of staples. Based on the tension band principle, it gradually transforms the distracting force of physiological growth into compression at that level, altering growth. In this way, through a less invasive method and without direct involvement of the physis, a gradual correction was achieved, with a reversible effect.

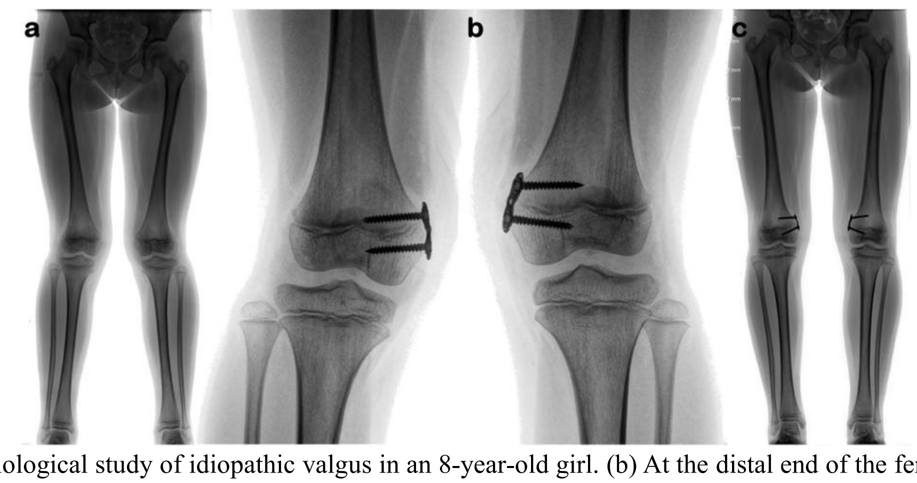

Figure 2. (a) Radiological study of idiopathic valgus in an 8-year-old girl. (b) At the distal end of the femur. (c) Correct the axis 15 months after surgery.

By using plate and screws as a tension band applied in a hemiepiphysiodesis, the fulcrum point is located outside the physis, as compared to stapling, where the fulcrum point is located on the cross bar of the staple [1, 6]. This achieves faster angular correction, avoiding prolonged fixation and the risks of definitive physiodesis. These advantages have led to this technique becoming a frequently used medical treatment option in clinical practice. Its disadvantages include the costs associated with medical implants and the need for a second surgery for implant removal.

In 2019, Martinez [13] describes the use of a tension band surgical technique with extra-periosteal suture for the correction of pathologic genu valgum, with results comparable to the use of plate with screws. This would be a lower cost technique, based on the same principles of tension banding with plate and screws.

4. Evaluation

Acquired angular deformities of the lower extremities may present in the coronal, sagittal or axial plane, or a combination of these. Severe deformities that cause pain, cosmetic or functional problems will usually require surgical management [14].

For the clinical analysis of coronal plane alterations, the intercondylar distance (in cases of genu varum) or intermalleolar distance (in cases of genu valgum) can be measured, with normal values of 0-5 cm and 0-7 cm, respectively. In those patients who exceed these measurements, in relation to age, a pathological cause should be sought: progressive deformity, unilateral, asymmetric, family history of skeletal dysplasia, short stature, history of trauma or bone infection. These situations require a complete evaluation to determine the need for medical treatment [15].

The clinical diagnosis should be complemented with a standardized imaging study (Figure 3). In this way, an adequate analysis of the axes of the lower extremities in both planes, the compensatory mechanisms present, and the establishment of the frontal and sagittal mechanical axis of the lower extremities can be performed.

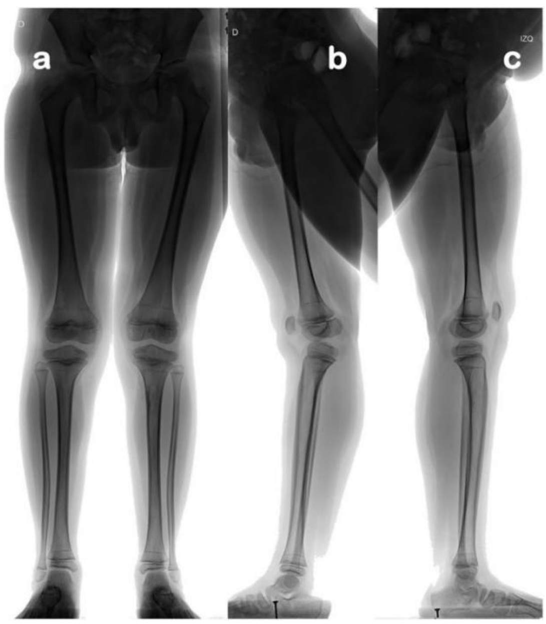

Figure 3. Standardized radiological study for the evaluation of lower extremity axes, with pelvis and patellae in front (a), lateral in right (b) and left (c) with maximum extension.

Once a pathological deformity has been diagnosed, its apex must be established. For the coronal plane, the calculation of the deviation of the mechanical axis gives us an idea of the type and magnitude of the deformity, while the measurement of the bony joint angles allows us to establish the affected bone segment [17]. For the sagittal plane, the analysis of the anterior cortical line in femur and tibia should be added, in order to diagnose deformities established in flexion or extraosseous extension [18, 19].

In those patients with closure or absence of growth plate, the longitudinal growth process of the bone segment is already completed, so guided growth will not be a valid therapeutic option. This also applies in deformities secondary to altered physiological function, such as a physiological bar, where blocked physiological growth is the cause of deformity and cannot be corrected through guided growth. In these cases, other therapeutic options should be considered, with segmental osteotomy being the most common correction method, which carries greater morbidity and surgical invasiveness.

5. Guided Growth in Lower Limb Length Difference

The presence of a length difference between the lower extremities can be of varied etiology, from congenital to acquired, and can be static or progressive. Treatment options for the management of anisomelia include: bone lengthening by callus distraction of the short segment, acute shortening of the long segment, growth inhibition of the longer segment. These methods can be used in combination when the estimated length difference at the end of growth is significant [20]. In general, when the estimated length difference at the end of growth is greater than 4 cm, bone lengthening is recommended, when the difference is between 1.5-4 cm, physiodesis is suggested, and when it is less than 1.5 cm, no further treatment may be required. Multiple factors should be taken into account for this decision, including the patient's final height, etiology, available resources and the expectations of the patient and parents.

The physiodesis technique chosen will depend on patient characteristics and remaining growth. The prediction of final limb length is based on skeletal age. Methods that assess skeletal age can estimate the optimal timing of surgical intervention. The Greulich and Pyle atlas and Green-Anderson charts have been replaced by tools such as the Moseley straight-line graph and, more recently, the Diméglio graph and the Paley multiplier method [20]. Macarov [21] determined that the Multiplier method is the least accurate in prediction, and that the Rotterdam modification of the straight-line chart, the Anderson-Green and White-Menelaus methods produced clinically relevant and comparable predictions of the physiodesis effect and the length of both limbs.

Irreversible physiodesis procedures are ideal for those patients close to physiological closure, where the length difference will have little variation and the calculation of the difference at the end of growth is more accurate. Among the most commonly used techniques are peripheral curettage [9] or percutaneous drilling [22]. Both techniques have excellent esthetic results, but require time to protect the traumatized area. The use of percutaneous screws [12] is another option, described as reversible, but because they invade the physis, they are preferred for use near the end of growth.

The use of tension band plates has the advantage of being predictably reversible as long as there is remaining growth (Figure 4), as opposed to irreversible procedures that may result in overcorrection if performed early, or undercorrection if used late [20]. Comparative studies between percutaneous procedures with tension band plates have shown that both methods are effective in correcting limb length differences. However, percutaneous physiodesis would present greater corrective power, with fewer complications and less need for additional surgical procedures [23, 24]. Therefore, it is recommended to consider a latency time of one year when choosing a tension band plate for the correction of length differences [25].

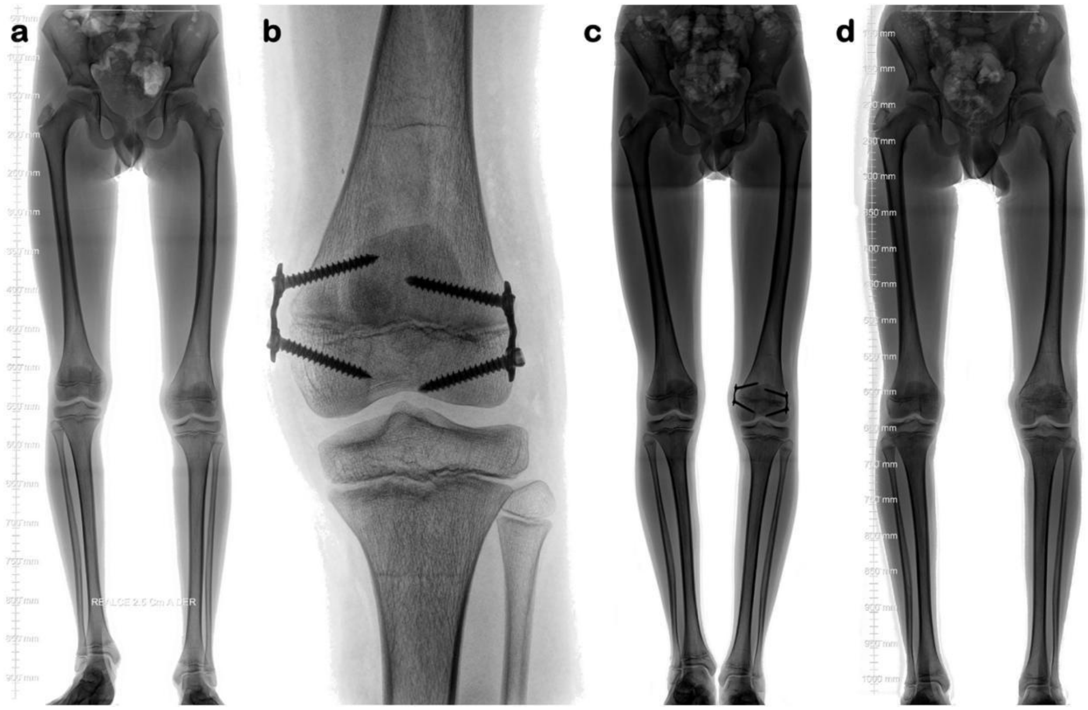

Figure 4. Radiological study of a 13-year-old boy, with a difference in length of the lower extremities (a) showing a difference of 2.5 cm. Physiodesis is performed with tension band plates (b). Radiological control at 6 months showed a length difference of 1 cm (c). At 23 months complete correction is achieved, and plates and screws are removed (d).

6. Guided Growth in Different Parts of the Lower Limbs

6.1 Guided growth in hip deformities

There are numerous reports of the use of guided growth to correct deformities in the coronal plane of the hip with success.

In the case of a coxa valgus, partial physiodesis can be performed by inserting a cannulated screw with entry under the greater trochanter in the direction of the inferomedial quadrant of the femoral head epiphysis. This has been shown to be effective in controlling progressive hip subluxation in children with cerebral palsy, decreasing the need for major reconstructive surgery [26]. In those with severe subluxation and an acetabular deficiency, guided growth combined with an acetabular procedure could improve outcomes [27].

In the case of dealing with a coxa vara of an early patient, the use of tension band plates in the lateral proximal femur has been described, by installing a plate with a screw in the epiphysis of the greater trochanter and a screw under its physis [28].

6.2 Guided growth in coronal plane knee deformities

Angular deformity of the lower extremities in the coronal plane is one of the main causes of knee osteoarthrosis (OA) [2]. A varus deviation of the mechanical axis increases the load in the medial compartment, while a valgus deformity shifts the load to the lateral compartment of the knee, and this overload is associated with the risk of developing OA [29]. The most frequent causes of coronal plane deformity are idiopathic, Blount's disease and a variety of skeletal dysplasias [28].

The correction of these alterations can be achieved by hemiphysiodesis, which can be temporary or definitive (Figure 5). Correction is achieved by blocking or reducing physiologic growth on one side of the cartilage ring. Undercorrection or overcorrection is a common problem. For this reason, careful preoperative planning and adequate follow-up are imperative to achieve accurate deformity correction with minimal morbidity.

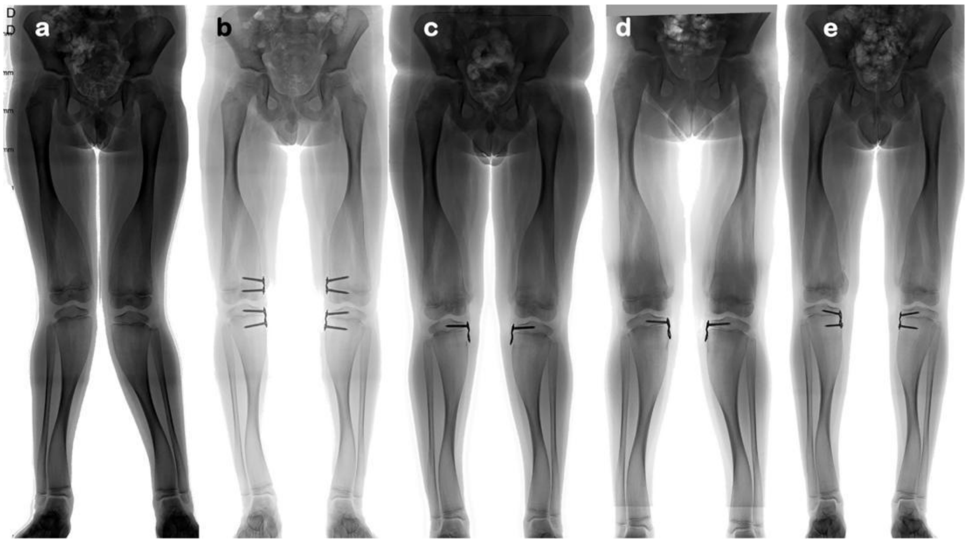

Figure 5. Radiological study of a 6-year-old boy with pathological genu valgum secondary to Pyle's disease (a). He underwent surgery using a guided growth technique with a tension band plate. Axial correction was achieved 8 months after surgery (b). As it is a skeletal dysplasia with high risk of recurrence, it is decided to over-correct and partial removal of osteosynthesis 12 months after treatment (c). Nine months after partial removal, recurrence of valgus deformity was observed (d), so a new guided growth procedure was performed, achieving correction after 12 months (e).

Ballal [30] described an average correction rate of 0.7° and 0.5° per month in femur and tibia respectively, using a tension band system with plate and screws. When guided growth was performed on both bones at the same time, the correction rate was 1.5° per month. The correction was faster in children younger than 10 years. Aslani [31] reported the use of 3.5 mm reconstruction plates with cortical screws, achieving complete correction in 86% of cases, decreasing costs. Martinez [13] described the use of a tension band system with two screws and a suture loop to replace the metal plate, achieving effective correction of pathologic genu valgum, without differences with the comparison group that used plate and screws, with a lower associated cost.

Patients with a high body mass index, severe deformity and less than nine years of age are more likely to have implant failure. The most predictable outcomes occur in patients with idiopathic etiology. Whereas patients with Blount's disease have higher screw breakage rate [28].

6.3 Guided growth in deformities around the knee in the sagittal plane

Fixed knee flexion deformity is a common disorder in children with neuromuscular diseases, arthrogryposis and cerebral palsy [32]. Patients develop muscle contractures and bone deformities, with the consequent decrease in strength and gonalgia, significantly altering gait kinematics, decreasing the efficiency of ambulation [33].

The usual surgical procedures include distal femoral extension osteotomies, an arthrodiastasis with external fixator and soft tissue release. These procedures have a high complication rate. In 2001, Kramer and Stevens [34] described temporary anterior distal femoral hemiphysiodesis using staples or tension band plates, being a less invasive option, with lower risk of complications, and without the need for postoperative immobilization. Stiel [35] reports improvement of fixed knee flexion deformity from 21° to 8°, with a correction rate of 0.44° per month, with an average follow-up of 15 years. Slight overcorrection (approximately 5°) is recommended in patients with substantial growth potential at the time of implant removal to avoid recurrence [28].

The disadvantages of using plate are the need for medial and lateral parapatellar arthrotomy for insertion, and its prominence under the skin, which limits tolerance. Remaining growth must always be considered to avoid undercorrection [36].

6.4 Guided growth in ankle deformities

An axis alteration with a valgus ankle is found in association with neuromuscular disorders, skeletal dysplasias, post-traumatic, infectious, among others [37]. This deformity is usually progressive, causing altered dynamic alignment, with abnormal loading on the lower extremity joints, leading to pain and early ankle osteoarthritis [38].

Guided growth with temporary hemiphysiodesis with a medial malleolar screw rapidly corrects the deformity (Figure 6). Its problems are the symptomatic prominence of the osteosynthesis, and the difficulties involved in its removal. For these reasons, hemiphysiodesis with a tension band plate has recently been recommended as an alternative [39].

Figure 6. Radiological study of an 11-year-old boy with severe ankle valgus (a) corrected by guided growth with percutaneous cannulated screw as a method of hemiphysiodesis (b) at 8 months post-operatively.

7. Complications

Guided growth is a surgical method with few problems and minimal complications. Hemarthrosis and joint effusion have been reported in 2-6% of cases, which resolves spontaneously within three weeks [40]. Infection is reported in less than 6% of cases, with no differences for the different methods, corresponding to superficial infections of management with oral antibiotics [41]. Although the incidence of staple migration and extrusion is high, those requiring reinsertion range from 2%-8% [42]. Undercorrection can be minimized with close follow-up. Physiologic arrest is uncommon given the extraperiosteal insertion of the most commonly used hemiphysiodesis devices, which are generally temporary and with strict follow-up at the time of implant removal [41].

8. Conclusion

Guided growth is a surgical option of increasing use for the correction of lower extremity angular deformities in skeletally immature patients, limiting the need for major procedures. This procedure can be performed in any plane or extremity. Given its high incidence, its most frequent use is in coronal plane deformities around the knee, but its usefulness has been demonstrated in other segments.

Permanent epiphysiodesis can be performed in patients within two years prior to reaching skeletal maturity or end of longitudinal growth of the segment to be treated, considering temporary epiphysiodesis for patients with more than two years of remaining growth. In mild to moderate cases, success rates are as high as 100% in some series, while patients with Blount's disease, obesity, advanced skeletal age or severe deformities are less likely to achieve complete correction.

Regardless of the surgical technique, the growth process is relatively unpredictable, so adequate preoperative planning, education of parents or caregivers, and strict follow-up are necessary to minimize complications or problems and allow correction of the deformity with minimal morbidity.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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