Longitudinal epiphyseal bracket

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Abstract Longitudinal epiphyseal bracket or bracket epiphysis is an uncommon disorder of growth. Alternatively known as a delta phalanx, it is due to an anomalous secondary ossification center that extends longitudinally along the diaphysis. Although rare, longitudinal epiphyseal bracket most commonly manifests in the hands as clinodactyly and in the feet as hallux varus. Previously, longitudinal epiphyseal bracket has been treated with angular osteotomy, but we recommend early surgical physiolysis. We describe this uncommon disorder, our current recommendation for treatment, and present three illustrative cases.

Keywords Longitudinal epiphyseal bracket · Bracket epiphysis · Delta phalanx · Hallux varus · Clinodactyly · Physiolysis

Introduction

Longitudinal epiphyseal bracket is an uncommon disorder of ossification of the tubular bones in the hands and feet, which is due to an abnormal continuous physal tissue along the diaphysis (Figs. 1, 2). Longitudinal epiphyseal bracket most commonly presents in the middle phalanx of the small finger of the hand as clinodactyly, which is radial angulation in the radio-ulnar plane (Figs. 8, 9a). It also

occurs in the foot as hallux varus, where the pathology occurs on the medial aspect on the first metatarsal of the first proximal phalanx. The “D”-shaped metatarsal is usually associated with polydactyly (Fig. 5a). Less commonly, longitudinal epiphyseal bracket can occur in other small long bones in the hands and the feet, and in the tibia as Nievergelt syndrome [1]. It can also be present on both sides of a bone, which is known as a duplicated longitudinal epiphysis or “kissing bracket” [2].

Other commonly used terminology for longitudinal epiphyseal bracket include bracket epiphysis and delta phalanx. Delta phalanx was originally described by Jones in 1964 [3]. Other less commonly used terminology referring to the same phenomenon include delta bone [4], longitudinal bracketed diaphysis [5], and congenital angular deformity [6].

Etiology and pathophysiology

The etiology of longitudinal epiphyseal bracket is not completely understood, but is thought to result from incomplete development of primary ossification centers [7]. The typical metatarsal longitudinal epiphyseal bracket has been shown on histological examination to be a composite epiphysis connecting proximal and distal epiphysis [7]. A typical metatarsal only has a proximal epiphysis, but with a bracket, there is a continuous proximal, medial, and distal epiphysis. The metatarsal cannot elongate normally because of the abnormal epiphysis bracketing the bone.

Epidemiology and associated conditions

In the hand, it is typically inherited in an autosomal dominant fashion with variable penetrance, and is often bilateral [8]. Longitudinal epiphyseal bracket is commonly associated

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Fig. 1 Diagrammatic representation of longitudinal epiphyseal bracket. Note the abnormal secondary center of ossification along the diaphysis connecting the normal proximal and distal physis

with other conditions in both the hand and the foot. A list of common but non-comprehensive associations for longitudinal epiphyseal bracket include polydactyly [6] (Fig. 7a), cleft hand or foot [9], and mild tibial hemimelia [10], along with a variety of other deformities and syndromes.

Radiographic staging of bracket epiphysis

A radiographic staging of the longitudinal epiphyseal bracket has been described in plain radiography [11, 12] (Fig. 3). The first stage (I) is a delta shaped diaphysis with a radiolucent cartilaginous epiphysis. The second stage (II) includes the appearance of secondary ossification centers at the proximal and distal ends. At the third stage (III), complete ossification of the longitudinal bracket epiphysis occurs along one side of the diaphysis. The fourth (IV) and final stage is the closure of the physis. These stages are related to the patient's bone age, and, therefore, may present in different patients at different ages. Staging of the longitudinal epiphyseal bracket has implications for the surgical treatment, as we will discuss below.

Fig. 2 Longitudinal epiphyseal bracket presenting as hallux varus. Three-dimensional reconstruction of foot CT of patient at age three with hallux varus demonstrates longitudinal epiphyseal bracket from both the (a) superior view and (b) posteromedial view of the foot

Fig. 3 Radiographic classification of longitudinal epiphyseal bracket. Stage I is an ossified diaphysis with a radiolucent cartilaginous epiphysis. Stage II includes the appearance of secondary ossification centers at the epiphysis proximal and distal. In stage III there is ossification of the bracket epiphysis along the diaphysis. Stage IV, the final stage is closure of the bracket epiphysis

The diagnosis can be made with plain radiographs early on because of the wedge-shaped diaphysis of the little finger middle phalanx (Fig. 9a) or the “D”-shaped metatarsal (Fig. 5a). Although magnetic resonance imaging (MRI) has been described in the literature for the diagnosis of longitudinal epiphyseal bracket [13, 14], in the experience of the senior author, it is not often necessary. We typically do not use MRI when radiographs are diagnostic and no other deformities are present, as it rarely aids diagnosis, and typically does not alter treatment strategies (Fig. 5b). However, it may be more useful in the setting of duplicated and unusual digits with possible brackets [2].

Computed tomography is not commonly used for longitudinal epiphyseal brackets, but it may help in stage III digits when the entire bracket epiphysis is ossified (Fig. 2a, b).

Treatment

Historical perspective

Prior to 1987, the primary treatment of a longitudinal epiphyseal bracket typically involved osteotomy of the

affected bone. Various opening and closing wedge osteotomies were described [3, 7]. A disadvantage of osteotomy without physiolsis is that it does not address the pathological physeal tissue, thus increasing the risk of recurrence [7, 10]. Additionally, the use of bone graft risks fusion of the bracket epiphysis, creating a epiphyseal/metaphyseal bar. However, osteotomy remains an important tool for the treatment of longitudinal epiphyseal bracket in older children after closure of the bracket epiphysis or after physiolsis to lengthen or correct angulation of the involved bones.

In 1987, Vickers [8] described an alternative treatment for delta phalanx. It involved the resection of the mid-zone of the epiphysis along with the underlying physis and replacement with a fat graft in the middle phalanx of the little finger. This procedure was modified from the description of bony bar resection by Langenskiöld. The advantage of this simple procedure was that the technique addressed the pathological tissue while sparing the proximal and distal physis. It also eliminated the need for pin fixation, as no osteotomy was performed.

This surgical technique for the ossified bracket in the first metatarsal of the foot was described by Mubarak et al. in 1993 [10]. Later, Shea et al. described a different technique for the unossified bracket of the first metatarsal [11].

Timing of physiolsis

Surgical physiolsis is recommended as early as feasible. With more growth of the phalanx or metatarsal, there is more correction of the angulation and more longitudinal growth. Also, the timing of physiolsis also impacts the need for and type of interpositional graft in the space vacated by the excised pathological physis.

Choice of graft material

There has been a variety of graft materials as well as non-graft techniques described to fill the void of surgical excised bracket epiphysis. The procedure was initially described by Vickers [8] with the use of fat graft as interposition material to prevent recurrence. Subsequent papers have alternatively recommended polymethyl methacrylate (PMMA), especially in cases of delayed presentation and an ossified bracket [10]. The senior author initially tried fat for bony bracket epiphysis; however, fat poorly attaches to the diaphysis. In several cases, a peripheral bar resulted at the proximal metaphyseal–epiphyseal junction. This causes a recurrence of the varus deformity. We have not had similar problems since using PMMA. If surgical excision of the bracket is completed early, before the diaphysis epiphysis is ossified, an interposition graft is not necessarily required.

Surgical technique

Early presentation: unossified epiphyseal bracket of the phalanx or metatarsal of the foot

These patients usually present with a short great toe and polydactyl. The clinical appearance and radiographs are quite classic (Fig. 5a). As stated above, if the epiphyseal bracket has not yet ossified, we would recommend physiolsis of the first metatarsal and removal of the extra digit for the infant <6 months of age.

The patient should positioned supine, and prepped and draped in with a non-sterile thigh tourniquet. The incision is made over the medial aspect of the first metatarsal at the dorsal aspect of the flexor crease from the tarsometatarsal to the metatarsophalangeal joint. Dissection is made down to the diaphysis, identifying the cartilaginous portion of the epiphyseal bracket there. Ragnell retractors are used to preserve both the dorsal and plantar neurovascular bundles. Under direct visualization, the edges of the bracket should be marked with a 21-gauge needle both proximally and distally. Fluoroscopy should be used at this time to verify their placement at the border between the proximal and distal extent of the bracket (Figs. 4a, 5c). The primary purpose of this step is to protect the proximal and distal physis from damage during the procedure and excise the abnormal diaphyseal bracket.

Fig. 4 Diagrammatic representation for surgical physiolsis. **a** The border between the bracket and the proximal and distal epiphysis are marked with a small gauge needle and placement is checked on fluoroscopy. **b** The border of the bracket are sharply severed. **c** The bracket is excised, keeping normal epiphysis on the ends

Next, the physiolsysis is performed. A beaver blade is used to cut through the abnormal epiphysis between the two needles (Fig. 4b). The central cartilaginous bracket is then excised, typically with the Beaver blade scalpel and small curettes (Fig. 4c). In these very young infants with unossified brackets, no interpositional graft is required and the wound is irrigated and closed in layers.

Although treatment of the pathology is definitive, from the perspective of cosmesis, it is important to inform the

patient's family that the digit will gradually normalize over the remaining years of growth (Fig. 5d, e).

Later presentation: ossified epiphyseal bracket of the phalanx or metatarsal of the foot

In late presentation, ossification of the epiphyseal bracket will occur at stage III of the disorder (Figs. 6a, 7b). In this case, simple physiolsysis will not be sufficient to treat this

Fig. 5 Early presentation: unossified epiphyseal bracket. **a** A 3-month-old male presents with a longitudinal epiphyseal bracket and unilateral hallux varus. Plain films demonstrate the D shaped metatarsal and polydactyl. **b** A MRI demonstrates the epiphyseal bracket. **c** At 4 months of age, he underwent excision of longitudinal

epiphyseal bracket in the manner described. This intra-operative radiograph demonstrates the needles placed to mark the bracket resection area. Clinical and radiographic correction is noted at **d** age 2 years. At age 14 years his radiographs demonstrate his right first ray is nearly equal to his normal left side with normal alignment

Fig. 6 Later presentation: ossified epiphyseal bracket. Illustration of an **a** ossified bracket with **b** initial treatment with bracket excision with Kirschner wire fixation and polymethylmethacrylate (PMMA)

and **c** restoration of length and alignment with subsequent growth (From Mubarak et al. [10])

Fig. 7 **a** A 2-year-old female with foot preaxial polydactyly. She underwent excision of bilateral preaxial polydactyly and reconstruction of the great toe at nineteen months. **b** At age two the patient is noted to have a bracket of the proximal phalanx with early ossification. The patient then underwent excision of the hallux bracket epiphysis. **c** Intra-operative fluoroscopy demonstrating placement of two needles at edges of bracket. **d** Following excision of the bracket, a Kirschner wire was placed which transversely through the proximal phalanx. **e** PMMA was then placed around the Kirschner wire

more angulated digit and to prevent physeal bar. In these cases, the cartilaginous and bony epiphysis are excised (Fig. 7b). In the surgical technique of the ossified bracket, the initial approach and resection is the same as for the unossified bracket. Fluoroscopy should be used to verify the proximal and distal extent of the bracket (Figs. 4a, 7c). Next, the physiolyis is performed. The abnormal epiphysis is removed between the two needles. Small rongeurs, curettes, and osteotomes may be needed to remove the ossified epiphysis.

After longitudinal epiphyseal bracket resection, a threaded Kirschner wire is placed in the center of the metatarsal diaphysis from medial to lateral. The placement of the Kirschner wire is checked under fluoroscopy (Fig. 7d). This wire is then cut flush with the cartilaginous portion of the normal physis. PMMA is then mixed and prepared in the usual fashion. The PMMA is then placed in around the threaded K-wire, flush with both the proximal and distally epiphysis, and allowed to harden (Fig. 7e). If needed, the toe can be re-aligned and fixed with a smooth Kirschner wire placed in a retrograde fashion. If needed, osteotomy can be utilized at a later date for the correction of a misaligned ray.

Clinodactyly of the little finger: bracket epiphysis of the middle phalanx

Most cases of clinodactyly of the hand involve the middle phalanx of the little finger. They are usually bilateral and, often, multiple family members are affected (Fig. 8). Bracket epiphysis involving the hand are treated similarly to the foot; however, typically we prefer the physiolyis when the child is at least 2 years of age due to the small size of the involved middle phalanx of the little finger (Fig. 9a).

Under general anesthesia, the patient is positioned supine with an arm board and tourniquet. The limb is prepped and draped. The incision is made over the radial aspect of the middle phalanx at the dorsal edge of the flexion crease from the proximal to distal interphalangeal joint. Dissection is carried down to the bracket, and a Freer elevator is used to elevate tissues on either side to avoid injury to neurovascular structures. 21-gauge needles are placed both proximally and distally with fluoroscopic guidance just inside the proximal and distal physis. Then, a beaver blade scalpel is used to cut just inside both of the needles transversely through the bracket (Fig. 4a–c). The cartilaginous bracket is excised between the needles, being careful to remove the entire cartilage tissue from dorsal to the palmar side of the diaphysis. No interpositional fat or material is needed in these young children. The wound is then closed in layers and dressed with a soft dressing. With time, correction of the clinodactyly will occur as the child approaches maturity (Fig. 9c).

Conclusion

Longitudinal epiphyseal bracket is an uncommon disorder causing deformity of the hands or the feet. This disorder of aberrant physeal cartilage extending along the diaphysis interferes with normal longitudinal growth. There remains some variability in treatment strategies, but we recommend

Fig. 8 Clinical image of a family (parent and three children) demonstrating clinodactyly associated with longitudinal epiphyseal bracket of the hand little finger bilaterally

Fig. 9 Surgical treatment of bracket of the finger in a 2-year-old female. **a** Radiographs of the left little finger note the short wedge middle phalanx. **b** Skin incision is marked along the radial aspect of the finger at the dorsal edge of the flexor crease from the proximal to distal interphalangeal joint. **c** Follow-up 3 years later shows improvement in length and less deformity

early physiolsysis to achieve optimum growth of the digits with minimal deformity. Recognition of the typical clinical and radiographic appearance of these digits allows for early excision of the bracket by a fairly simple technique, with minimal difficulty for the child.

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