

The Orthopaedic Management of Arthrogryposis Multiplex Congenita

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Abstract:

Arthrogryposis multiplex congenita (AMC) describes a baby born with multiple joint contractures that results from fetal akinesia with at least 400 different causes. The most common forms of AMC are amyoplasia (classic arthrogryposis) and the distal arthrogryposes. Over the past two decades, the orthopaedic treatment of children with AMC has evolved with a better appreciation of the natural history. Most adults with arthrogryposis are ambulatory, but less than half are fully independent in self-care and most are limited by upper extremity dysfunction. Chronic and episodic pain in adulthood—particularly of the foot and back—is frequent, limiting both ambulation and standing. To improve upon the natural history, upper extremity treatments have advanced to improve elbow motion and wrist and thumb positioning. Attempts to improve the ambulatory ability and decrease future pain include correction of hip and knee contractures and emphasizing casting treatments of foot deformities. Pediatric patients with arthrogryposis require a careful evaluation, with both a physical examination and an assessment of needs to direct their treatment. Further outcomes studies are needed to continue to refine procedures and define the appropriate candidates.

Key Concepts:

- Arthrogryposis multiplex congenita (AMC) is a term that describes a baby born with multiple joint contractures. Amyoplasia is the most common form of AMC, accounting for one-third to one-half of all cases, with the distal arthrogryposes as the second largest AMC type.
- There are more than 400 different underlying conditions all of which result in fetal akinesia, causing the joint contractures.
- Most adults with arthrogryposis are ambulatory but only a minority are fully independent in their daily activities, usually related to limited upper extremity function.
- Care of the upper extremity is directed to correct elbow extension contractures and shoulder internal rotation contractures and are best performed under 2 years of age.
- The regular use of Ponseti casting for clubfeet, along with the development of techniques for treating hip and knee contractures has improved lower extremity function.

Introduction

Arthrogryposis multiplex congenita (AMC), or simply arthrogryposis, is a term describing a collection of conditions which by definition have congenital contractures of two or more joints in multiple body areas.¹⁻³ Under this

definition, a child born with a clubfoot and a knee flexion contracture would have arthrogryposis but one with just bilateral clubfoot deformities would not. AMC is not a diagnosis of itself but rather a description or sign of the over 400 causative conditions that lead to a baby being born

with congenital contractures.⁴ Most of these conditions are caused by known gene mutations but some are not (e.g., maternal Zika infection or intrauterine crowding), including the most common form of AMC, Amyoplasia, also known as “classic arthrogryposis.” What these 400+ causative conditions fundamentally have in common is a lack of movement during pregnancy (fetal akinesia). This results in joint fibrosis, stiffness, and in extreme cases essentially an immobile fetus during pregnancy.⁵ The term Amyoplasia (capitalized) specifically indicates the nongenetic “classical” arthrogryposis, the most common form of AMC, whereas amyoplasia (not capitalized) is used to describe a generalized congenital lack of muscular development and growth.

Over the past 10–12 years there has been increased understanding and interest in treating both children and adults with arthrogryposis. Some studies group all people with arthrogryposis together, others focus solely on a particular diagnosis or diagnosis group, such as Amyoplasia or Escobar syndrome. As pediatric orthopaedists, our treatment revolves around improving positioning of joints and improving joint range of motion.

Epidemiology, Classification, and Forms of AMC

The estimated incidence of AMC is 1:3000 to 1:5000 live births, with Amyoplasia accounting for one-third of live cases (1:10,000), and up to one-half of cases seen by orthopaedists.⁶ As a group, the distal arthrogryposes make up approximately one-fifth of live cases.⁷ It is assumed that embryogenesis was largely normal initially, yet the underlying lack of intrauterine motion prevents normal joint development and leads to contractures. Although difficult to quantify, there is a high early mortality rate, with stillbirths, termination of pregnancy, and death during first year of life reportedly between 32% and 69%.^{8,9} The life expectancy of most of those that survive is normal.

Developing classification systems for AMC has been difficult given the wide heterogeneity of phenotypes and causative conditions. Since the functions of a classification system are to aid in diagnosis, enhance communication

between stakeholders, guide treatment, and help prognosticate, different classification systems have been suggested for AMC. The three most commonly used strategies categorize by clinical involvement (separate conditions by body areas involved), by cardinal features (grouping conditions by common characteristics), or by etiology of fetal akinesia (separate by the different pathways that result in a lack of intrauterine motion), the latter approach is currently² of limited clinical utility.

Classification by Clinical Involvement¹⁰

Group 1: Primarily limb involvement (e.g., Amyoplasia, distal arthrogryposis type 1 [DA1], Bruck syndrome)

Group 2: Musculoskeletal involvement plus other system anomalies (Freeman-Sheldon [DA2A] and Sheldon-Hall [DA2B] syndromes, DA3, DA4, DA5, DA6, DA7; pterygium syndromes [Escobar, popliteal pterygium syndrome], Mobius syndrome)

Group 3: Musculoskeletal involvement with associated central nervous system dysfunction/malformation, with or without cognitive disability, including the lethal arthrogryposes (Wieacker-Wolff syndrome)

Classification by Cardinal Features¹¹

Typically, when describing the landscape of AMC with new parents, using the cardinal features classification helps them to understand where their child fits within the array of conditions.

Group 1: Amyoplasia—the most common single cause of AMC, nongenetic

Group 2: Distal arthrogryposes—a group of conditions that are autosomal dominant with variable expressivity (except DA5, which is autosomal recessive). Many patients present with de novo mutations. As a group, the second most common cause of AMC. Table 1 lists the most common types.

Group 3: “Everything Else”—the pterygium syndromes, X-linked conditions, teratogenic syndromes, maternal illnesses, intellectual disability, fetal akinesia deforming syndrome [FADS], and lethal conditions

Table 1. Eleven Types of Distal Arthrogryposes Classified by Bamshad

Distal Arthrogryposis Type	Mode of Inheritance	Condition Name	Affected Protein (Gene)
DA1	AD	Classic distal arthrogryposis	TNNI2, TPM2, MYBPC1, MYH3
DA2A	AD	Freeman-Sheldon syndrome	MYH3
DA2B	AD	Sheldon-Hall syndrome	TNNI2, TNNT3, TPM2, MYH3
DA3	AD	Gordon syndrome (short stature, cleft palate, and ptosis)	PIEZO2
DA4	AD	DA with severe scoliosis	
DA5	AR	DA with ophthalmoplegia, ptosis and retinal involvement	PIEZO2, ECEL1 (for DA5 without ophthalmoplegia)
DA6	AD	DA with sensorineural hearing loss and microcephaly	
DA7	AD	Trismus-pseudocamptodactyly syndrome	MYH8
DA8	AD	Autosomal dominant multiple pterygium syndrome	MYH3
DA9	AD	Congenital contractural arachnodactyly/Beals syndrome	FBN2
DA10	AD	DA with congenital plantar flexion contractures	
		Congenital contractures of the limbs and face, hypotonia, and developmental delay (CLIFAHDD)	NALCN
Distal Arthrogryposis with peculiar facies and hydronephrosis	AR	Ehlers-Danlos syndrome, musculocontractural type (EDSMC1)	CHST14

AD: autosomal dominant; AR: autosomal recessive; TNNI2: troponin I subunit; TPM2: tropomyosin 2 or beta-tropomyosin; MYBPC1: myosin binding protein C1; MYH3: embryonic myosin heavy chain 3; TNNT3: troponin T subunit; PIEZO2: piezo type mechanosensitive ion channel component 2; ECEL1: neuronal endopeptidase; MYH8: fetal myosin heavy chain 8; FBN2: fibrillin-2

Amyoplasia

Amyoplasia is the most common and “classic” form of AMC; therefore, it is occasionally mistaken as “the true” form of arthrogryposis, suggesting that all other forms are not actually arthrogryposis. This misunderstanding can be very confusing to families and can complicate treatment decisions. A common pregnancy experience of most babies born with AMC can be a recognition of fetal

akinesia, either by the mother who notices decreased movement, or by unchanging fetal position over serial ultrasounds. The most common ultrasound findings may include limb deformities, such as clubfoot and hand deformities, as well as findings of oligohydramnios and intrauterine growth retardation. If fetal cervical hyperextension is identified, a Caesarian section should be planned for safe delivery.

On physical examination, the face may have a midline congenital hemangioma of the forehead, nose, or chin called a nevus flammeus, which fades with age. Lack of “chewing” during pregnancy may result in an underdeveloped mandible. Some babies are born with a spinal curve that reflects their static intrauterine position. Since there are no structural vertebral abnormalities, it is not a “congenital scoliosis” but a “prenatal scoliosis.” Approximately 30% of patients will have scoliosis.

Contractures of the upper and lower extremities are usually symmetrical. The shoulders are adducted, and usually internally rotated, impeding reach forward of the body plane. Most affected elbows lack flexion, but moderate or severe flexion contractures can occur and often have more severe hand dysfunction than those with extension contractures. The wrists are usually palmarflexed and ulnarly deviated. Thumb-in-palm deformities and finger stiffness is common. The hip contractures are a combination of flexion, abduction, and external rotation known as the “Buddha position.” Congenital hip dislocations occur earlier in pregnancy than idiopathic hip dislocations and are therefore stiffer and more proximally displaced. Both knee flexion and extension contractures can occur with the former more common. Flexion contractures may have an associated mild popliteal pterygium. Clubfeet are extremely common in Amyoplasia and are stiffer and more supinated than the idiopathic clubfoot. The equinovarus foot, a variation of the classic clubfoot with pronounced midfoot cavus but with less heel varus and adduction, is less common.¹² Congenital vertical tali are not associated with Amyoplasia.¹³ Involvement of all four limbs is seen in 46 to 84% of those with Amyoplasia, isolated lower limb involvement presents in 11% to 43%, and upper limb only involvement is less common at 5 to 11%.¹⁴ Dimples over joints (e.g., patellas, greater trochanters) indicate skin tethered down to bony prominences due to lack of intrauterine movement. Umbilical cord wrapping creates a spiral “groove” of thigh or calf soft tissues and is frequently mistaken for an amniotic band.

Although the cause of Amyoplasia is unknown, an association with atrophy or dysgenesis of an affected limb’s anterior horn cells (AHC) seen on autopsy suggests a vascular insult to the developing fetus between the 8th and 11th week of gestation.¹⁴ That time interval coincides with AHC development, and if individual AHC were unable to mature, the function of that particular lower motor neuron would be inhibited which in turn would inhibit development of the target muscle. AHCs mature from cephalad to caudad; therefore, a vascular interruption or insult earlier in the critical period will affect the lower motor nerves of the jaw (8 weeks) and upper extremities (9 weeks) whereas, later incidents affect the lower extremities more (11 weeks).¹⁴ A short vascular disturbance will have more isolated effects compared to an ongoing vascular disturbance which will affect more body parts with more severe contractures. Intrauterine vascular upset may also cause truncated/amputated digits (fingers/toes), bowel atresia, or gastroschisis, all of which are occasionally seen in those with Amyoplasia.

Amyoplasia is a diagnosis of exclusion following a complete genetics workup and a brain and spinal cord MRI. In some centers, such a workup is not needed in an otherwise healthy child with a characteristic appearance.

Distal Arthrogryposis

The distal arthrogryposes (DA) are a group of genetic syndromes with contractures affecting mainly the distal joints (hands and feet). Although there are 19 different recognized types, most discussion is based on the 11 types of distal arthrogryposes classified by Bamshad et al. (2009), the most common of which are DA1 (“classic distal arthrogryposis”), DA2B (Sheldon-Hall syndrome), and DA2A (Freeman-Sheldon syndrome)¹¹ (Table 1). The conditions have variable expressivity and reduced penetrance so that an affected parent and offspring may have different extents of involvement. Many cases result from a de novo gene mutation. Most of the DAs are autosomal dominant conditions other than DA5, which is autosomal recessive.¹⁵

On physical examination, some have facial involvement consisting of a small mouth opening, downslowing palpebral fissures, and/or deep set eyes, particularly seen in DA2A (Freeman-Sheldon syndrome or “whistling face” syndrome), DA2B (Sheldon-Hall syndrome), and DA7 (trismus-pseudocamptodactyly syndrome). Ocular movement is limited in DA5. The distal joints of the extremities are most affected, although proximal and larger joints may also have motion limitations. The wrists often have extension contractures, but flexion deformities can be present, with mild to moderate ulnar deviation. Flexion contractures are often associated with hyperextension of the metacarpalphalangeal (MP) joints. The fingers also are ulnarly deviated and are often clenched and overlapping. Clasped thumbs are the norm with fixed or correctable flexion contractures at the thumb MP joint. In Beals syndrome (DA9), also known as arachnodactyly contractural syndrome, the patient appearance is similar to Marfan syndrome, except that the gracile fingers have proximal interphalangeal (PIP) joint flexion contractures. In the lower extremities, the hips and knees are usually spared, although there are occasional congenital hip dislocations and knee flexion contractures. Both congenital vertical tali and clubfoot deformities occur and occasionally a child will have one of each. Surprisingly, the clubfeet associated with DAs are often stiffer than those seen in Amyoplasia. Scoliosis is associated with Gordon syndrome (DA3), DA5, autosomal dominant pterygium syndrome (DA8) and Beals syndrome (DA9) and can be severe in Freeman-Sheldon syndrome (DA2A) and DA4.

The distal arthrogryposes (DA) are a heterogeneous group both phenotypically and genetically. What was once considered a “one gene-one diagnosis” paradigm has now been found to be markedly less specific with the genotype not tightly linked to the phenotype.² Therefore, one phenotypic form of DA may be caused by different single gene mutations or variants, and a particular gene mutation may result in one of several DAs. Many of the affected genes encode for components of the fast-twitch muscle contractile apparatus (sarcomeric proteins) primarily found in the hands and feet.¹⁶ For example, DA1, DA2A (Freeman-Sheldon

syndrome), DA2B (Sheldon-Hall syndrome) and DA8 may all be caused by a mutation in the embryonic myosin heavy chain (MYH3) gene. Interestingly, MYH3 is expressed only during fetal life (weeks 6-24 of pregnancy) and the myosin subunit encoded by it is replaced with an “adult” protein prior to birth, but the damaged muscles cannot be restored. As such, MYH3 mutations actually result in a fetal myopathy, and various mutation may lead to a spectrum of disease rather than define discrete diagnoses. Mutations in other fast twitch sarcomeric proteins, such as troponin (TNNI2, TNNT3), tropomyosin (TPM2), and other myosin components (MYBPC1, MYH8) also cause forms of DA.⁷

“Everything Else”

More than 400 diagnoses fit under this category. Two of the most common—multiple pterygium syndromes and arthrogryptic conditions with nervous system involvement—will be discussed.

The *multiple pterygium syndromes* (MPS) are usually segregated as lethal conditions (lethal multiple pterygium syndrome) and nonlethal ones (Escobar type or Escobar syndrome). Diagnoses may be made prenatally, with ultrasounds showing decreased fetal movement, foot deformities, and oligohydramnios—all typical signs of arthrogryposis. Other findings suggesting a lethal MPS include hydrops fetalis, cystic hygromas, and hypoplasia of the heart, lungs, brain and kidneys.^{17,18} Most such babies will experience intrauterine demise or die soon after birth. The word pterygium shares a root with pterodactyl and describes webbing or winging of skin on the flexor aspects of joints. The tethering skin is but one of many restrictive elements of the joint contracture along with the musculotendinous structures and the progressive deformity of the joint surfaces themselves. Escobar syndrome is most commonly associated with a mutation in the CHRNG gene.¹⁹ The CHRNG gene codes for the fetal gamma (γ) subunit of the acetylcholine receptor (AChR). The γ subunit is replaced by the epsilon (ϵ) subunit before 33 weeks gestation, forming an intact adult AChR. The contractures and pterygia persist, and there may be permanent muscle weakness, but myasthenic

symptoms are absent later in life. Most MPS forms are autosomal recessive^{19,20} Rare autosomal dominant MPS forms have been identified, including MYH3 (distal arthrogyrosis type 8) and TPM2, a tropomyosin mutation. Rarer still is an X-linked MPS, which is lethal.

Babies with Escobar syndrome may present with either poly or oligohydramnios and often have pulmonary hypoplasia. They have facial dysmorphisms with micrognathia and small mouth, downslanting palpebral fissures, and mild ptosis. The neck may have lateral pterygia, and severe scoliosis develops at a young age in 50%. Axillary and antecubital pterygiums restrict shoulder and elbow motion. The wrists are often dorsiflexed with finger/thumb flexion contractures and interdigital pterygia. Perineal pterygium extends from one medial thigh to the other. Knee pterygia and flexion contractures can limit ambulatory ability; hamstrings and gastrocnemius fascia/tendons are often confluent. Both congenital vertical tali and clubfeet can occur. Intelligence is typically normal, but their milestones may be mildly delayed.

There are many *arthrogryptic conditions with nervous system involvement*. Most are genetic conditions, although babies born with microcephaly and arthrogyrosis following the recent Zika virus outbreak are an example of a nongenetic cause. The prognoses for life expectancy, independent living, and ambulation vary widely even within the same underlying condition. The fetal akinesia may be more profound in the CNS types of AMC, with ultrasonographic findings of hydrops fetalis, cystic hygromas, and oligohydramnios in the more severe conditions. An intrauterine MRI can help identify the presence of structural brain abnormalities.^{17,21} These conditions are rare but some of the more common are ZC4H2 deficiency, perisylvian polymicrogyria, and absent corpus callosum. ZC4H2 is an X-linked condition, known as Wieacker-Wolff syndrome or ZC4H2-associated rare disorder (ZARD).²² Males usually have severe cognitive involvement and most do not develop the ability to sit independently, whereas females are variably affected, some

with mild to moderate deficits ambulate well while others appear similar to the male counterparts. Perisylvian polymicrogyria is a disorder of neuronal migration of the brain. Mild to moderate cognitive deficits are common, but most children learn to walk. The contractures may be mild to moderate, including clubfoot deformities. The diverse group of absent corpus callosum can have cognitive involvement that spans from minimal to nonverbal, yet most will develop the ability to ambulate. Their contractures can range from mild to moderate.

Longer Term Outcomes Studies

Treatment protocols for children with arthrogyrosis have benefitted from recent studies detailing the outcomes in adults. Ambulatory status is relatively common in adults (49–88%), although some report losing the ambulation ability they had as children or began using wheelchairs in the community or for longer distances. Automobile driving is common (48–86%), with only occasional control modifications. Affected upper extremity function is the most common limit to activities of daily living, with only 32–50% having a fully independent lifestyle.^{23–27} Most (95–98%) had undergone orthopaedic procedures for the spine and lower extremities, with patients reporting 7–10 procedures on average, the majority occurring during childhood. Very few had undergone upper extremity procedures.^{23,27} Pain is a common complaint for adults (75–91%), affecting the feet/ankles, knees, spine, and less often the jaw and the upper extremities.^{28,29} It is sometimes chronic and often activity limiting, even in childhood. Pain of the low back and lower extremities tends to be the most disabling, particularly for standing and walking activities. Cumulatively, these studies indicate the significant potential for ambulation and independent living most children with AMC have. However, because surgical options and indications have advanced markedly over the past 15 years, particularly for the upper limb, there is a lag of seeing the effects of these advances in the current adult population. Therefore, treatment should be relatively aggressive to help them realize their full potential yet mitigate the risk of

overtreatment by being judicious and individualized. Measures to prevent pain in adulthood include fewer surgical interventions for foot deformities and an emphasis on standing posture to preclude back pain.

Treatment

Upper Extremities

The prevailing wisdom among the pediatric orthopaedic community is that there is little to be done to help the upper extremities of children with AMC other than the occasional elbow release. The advances in upper extremity surgery have benefited from a richer and more nuanced understanding of surgical indications and timing, more available surgical options, and a more informed and interconnected parent and patient support network. If the hands are functional enough to provide pinch and/or grasp, functional independence is possible for a majority of patients regardless of their shoulder, elbow, forearm, and wrist involvement. Therapy, including early and consistent splinting, passive range of motion, and supervised play is critical to minimize the need for surgery and to optimize the results of surgery.

Hands

We have no surgical techniques to improve finger motion at this time. Thumb in palm, however, can be greatly improved. Most patients will correct over time with splinting and therapy. For the children with persistent thumb in palm deformities, the choice of surgical procedures depends on the joint with the greater flexion contracture. Children with DAs tend to have clasped thumb with contractures of the thumb metacarpophalangeal (MP) joints, whereas children with Amyoplasia tend to have hyperflexed carpometacarpal (CMC) joints. A clasped thumb can be corrected as early as 2-3 years of age, typically with a thumb MP chondrodesis and an index rotation stiletto flap (Figure 1). Because the CMC joint is often the most mobile thumb joint in Amyoplasia, thumb CMC chondrodesis is not an option. Instead, we have advocated a thumb metacarpal base reorientation osteotomy

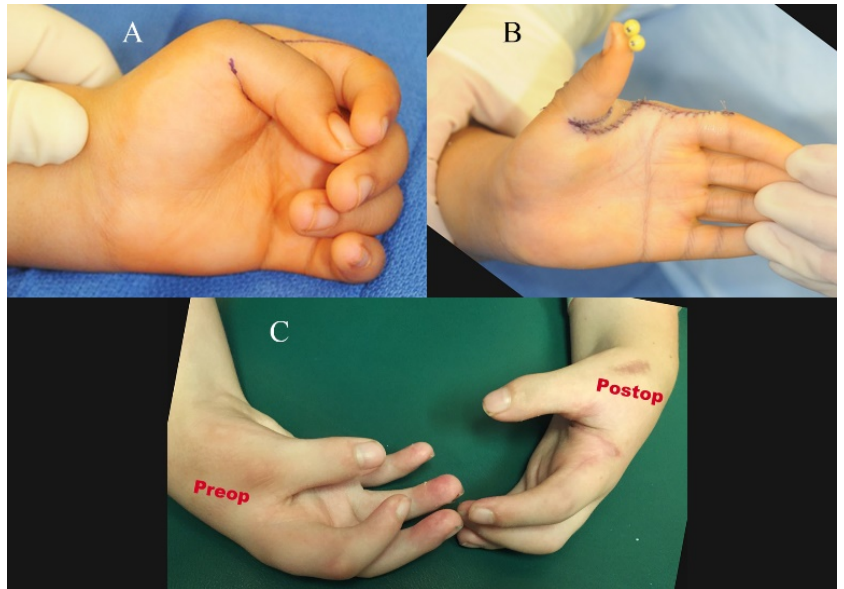


Figure 1. Clasped thumbs A) are common in Distal Arthrogryposes. For fixed deformities, a thumb MP fusion and stiletto flap B) can improve both appearance and function. Children with Amyoplasia C) tend to have a flexion, supination, and adduction deformity of the thumbs (right hand). These are best treated with a thumb reorientation osteotomy and stiletto flap (left hand).

and stiletto flap.³⁰ Camptodactyly is common in all forms of AMC. Multiple procedures and algorithms have been proposed to correct camptodactyly in general but not specifically for children with AMC.³¹ While the results of a Z-plasty and FDS tenotomy are inconsistent, we have found it to be the simplest procedure and the least likely to result in untoward consequences.

Wrist

The wrist remains a controversial topic in AMC. Children with DAs typically have fixed wrist extension contractures which are well tolerated and generally do not pose a functional or aesthetic concern. Children with Amyoplasia tend to have flexion and ulnar deviation contractures of the wrist. The primary deforming force is tethering of the wrist by a flexor carpi ulnaris tendon without muscle. Wrist flexion is beneficial for through the legs perineal care, for reaching the mouth when elbow flexion is limited to less than 100 degrees, and for facilitating finger extension. Some children will also weight bear on the dorsum of a flexed wrist to scoot or

assist with ambulation. Wrist extension tends to improve grip and pinch strength and position, as well as improve the appearance of the hand. The most common operation for correcting flexion contractures of the wrist are the extensor carpi ulnaris (ECU) to extensor carpi radialis brevis (ECRB) transfers with or without a carpal wedge osteotomy.³² Absolute contraindications to wrist surgery to augment extension include reliance on through the legs perineal care, obligate wrist flexion for hand-to-mouth access, weight bearing on dorsum of the wrist, and flexion contractures of the fingers when the wrist is held in maximum passive extension.

Forearm

Contrary to published reports, the forearm in AMC is not always or even commonly fixed in pronation. Internal rotation of the shoulder often creates the illusion of pronation, even when the child has a mild supination contracture. While a supination contracture may be beneficial for hand-to-mouth activities and behind the back perineal care, a pronation contracture can point the wrist away from the face and the perineum making grooming, eating, and wiping impossible. Pronation, however, can be beneficial for through the legs perineal care and for getting dressed. For fixed deformities with minimal forearm rotation, a one bone forearm can place the forearm in a stable position to enhance function.³³ Typically, we place the forearm in neutral rotation, but the position will vary depending on the needs of the child.

Elbow

Most children with Amyoplasia have elbow extension contractures, presumably due to persistence of the triceps muscle and lack of biceps and brachialis muscles. Elbow flexion contractures are more common in the DAs, often with a pterygium. When children are born with less than 15 degrees of elbow flexion, it is difficult to determine the orientation of the elbow. Well-intentioned therapists will attempt to flex the elbow and often bend in the wrong direction, stretching the collateral ligaments and destabilizing the elbow. If the child has not achieved at least 75 degrees of elbow flexion by 1 year of age, an elbow release may be indicated for the dominant arm. Results of an

elbow capsular release, triceps lengthening, and ulnar nerve transposition have been shown to be age dependent, with significantly better results under 2 years of age.³⁴ Bilateral elbow releases are not recommended due to the risk of elbow flexion contractures after surgery and the demands of rehabilitation. After gaining passive elbow flexion with a release, active elbow flexion can be achieved in order of preference by a bipolar latissimus transfer, a monopolar lower pectoralis transfer, a partial triceps transfer, a free gracilis transfer, or a Steindler procedure.³⁵

Elbow flexion contractures with a pterygium are more difficult to manage. The most predictable surgical plan is a trapezoidal posterior closing wedge distal humeral osteotomy to reorient the child's arc of motion into more extension. When the child has a functional brachialis and biceps but no triceps, a biceps-to-triceps transfer can be considered. A pterygium release with anterior 2-flap Z-plasty can also augment extension and improve the appearance of the arm.

Shoulder

There is very little that can be done to gain either passive or active motion of the shoulder. A humeral rotational osteotomy is, however, very effective at reorienting the arc of rotation of the shoulder into a more advantageous position of between neutral and 60 degrees of internal rotation. Provided that the forearms are in a neutral position, the additional external rotation allows bimanual hand function and also allows direct line of sight to the thumb and radial side of the hand, improving overall hand function and development.³⁶

Lower Extremities

The treatment of children with lower extremity contractures has evolved over the past two decades to become more interventionistic. It is no longer acceptable for a child with moderate to severe contractures to be relegated to a lifetime of wheelchair use without carefully assessing their potential for ambulation. Most patients have the potential to ambulate, and even those adults who give up community ambulation appreciate standing for transfers or ambulating short distances within the home.^{23,25}

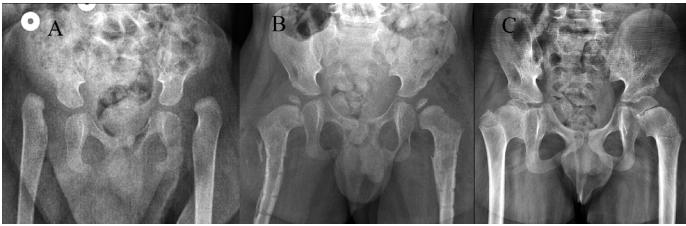


Figure 2. A 21-month-old boy with AMC secondary to agenesis of the corpus callosum with bilaterally dislocated hips. A) AP pelvis radiograph prior to open reduction and femoral shortening procedures bilaterally. B) AP pelvis radiograph at 3 years of age. C) AP pelvis radiograph at 6 1/2 years old. Patient is a community ambulator but prefers his wheelchair for longer distances.

Hips

Hips in arthrogryposis can present as congenital dislocations and/or contractures. The dislocations are teratologic, occurring earlier in pregnancy, and are therefore stiffer with higher displacement. Nonsurgical methods of relocation are not effective.^{37,38} Concerns that a surgical relocation of such hips would lead to stiffness have been offset by follow-up studies that show only an average loss of 4 degrees along the flexion-extension arc following an open reduction.³⁹ One study noted that two-thirds of open reductions required a femoral

shortening.⁴⁰ The anterolateral and medial approaches have both been described, and stability of the reduction can be enhanced by tethering the ligamentum teres to the acetabulum or provisionally pinning the femoral-acetabular joint³⁹⁻⁴² (Figure 2). Avascular necrosis occurs frequently (24%) but is usually minor and does not seem to affect hip motion.³⁹

Hip contractures can vary from mild/moderate flexion contractures to severe multiplanar contractures. In cases of isolated hip flexion or mild flexion/abduction contractures, the contracted conjoint tendon of the sartorius and tensor fascia lata can be released percutaneously just inferior to the anterior superior iliac spine (ASIS).^{39,40,43} The more severe, multiplanar contractures position the hip in flexion, abduction, and external rotation. A proximal femoral reorientational osteotomy will reposition the lower limb in line with the body, leaving the femoral head in its original position within the acetabulum (Figure 3). In this way, the hip's total arc of motion is unchanged but oriented so that the limb itself is more functional. In one study, ambulation increased from 9% pre-treatment to 55% at follow-up with another 31% still walker dependent.⁴³

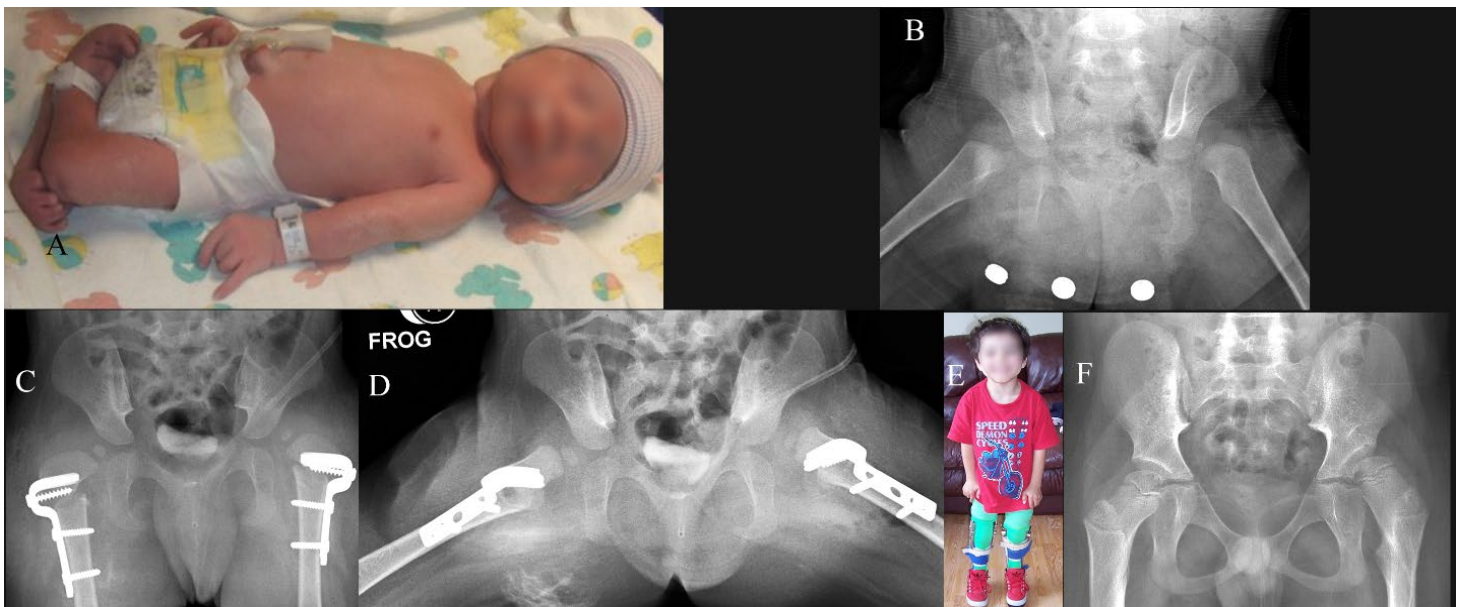


Figure 3. A boy with Amyoplasia and bilateral severe hip contractures. A) Newborn hip position. B) AP pelvis radiograph in resting position at 14 months of age just prior to reorientational osteotomy. C) and D) AP and frog leg pelvis radiograph immediately after procedure. E) Walking in bilateral KAFOs 5 years of age after straightening of 90 degrees knee flexion contractures by joint distraction with external fixators. F) AP pelvis radiograph at 9 years of age. He is a community ambulator.

Knee

Knee flexion contractures are more common than extension contractures. Flexion contractures can be grouped as mild (< 30 degrees), moderate (30–50 degrees) and severe (> 50 degrees). Growth guidance with femoral anterior distal hemiepiphyseodesis (FADHE) plates has been effective for the mild contractures and when supplemented with a posterior knee release, also effectual for the moderate contractures⁴⁴ (Figure 4). The implants have been relatively well tolerated so long as range of motion exercises are started after a brief period of postsurgical rest. The rigidity of the posterior soft tissue limits the success of the FADHE procedure in severe contractures. Instead, gradual joint extension distraction with a knee spanning external fixator, along with posterior knee release, allows for contracture resolution. To prevent posterior tibial subluxation, the fixator hinges must be positioned along the knee rotational axis; initial distraction of the joint prevents joint impingement at extension.⁴⁵

Recurrence of knee flexion contractures is common, regardless of treatment modality. To limit recurrence, patients are encouraged to wear a Knee Ankle Foot Orthosis (KAFO) at nighttime for many years posttreatment. Due to the high rate of relapse from physal remodeling, distal femoral extension osteotomies are best indicated for patients nearing skeletal maturity.⁴⁶

Extension contractures are initially less problematic since they do not hinder ambulation, but eventually, sitting in small spaces becomes difficult. Serial casting can be attempted in infants and young children, followed by a percutaneous or mini-open rectus femoris tenotomy if indicated.⁴⁷ Older children with more rigid contractures likely require a Judet quadricepsplasty, possibly with a femoral shortening osteotomy.³⁹ The important distinction between arthrogryptic knee extension contractures and most idiopathic congenital knee dislocations is the quality of the knee extensor musculature, which seems stiffer and less able to stretch in the former. Maintaining knee flexion range in the months after surgery is difficult,

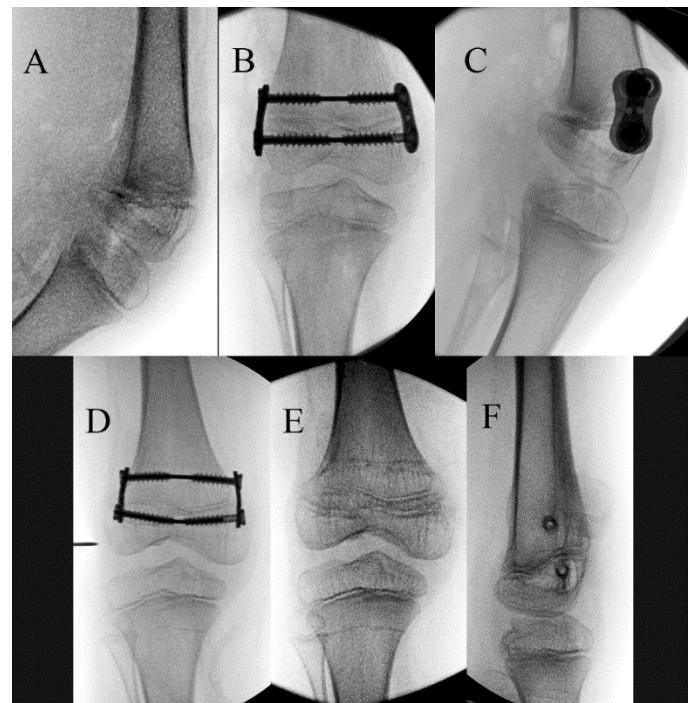


Figure 4. A 6-1/2-year-old girl with Amyoplasia and bilateral knee flexion contractures. A) Fluoroscopic lateral view of right knee immediately preoperatively, 40 degrees flexion contracture. B) and C) AP and lateral fluoroscopic views after placement of femoral anterior-distal hemiepiphyseodesis (FADHE) plates using the physal bridge technique. D) Sixteen months after FADHE procedure with knee in full extension, AP fluoroscopic view, just prior to hardware removal. Note the divergence of the screws and bridging wires. E) and F) AP and lateral fluoroscopic views after hardware removal. Note the obliquity of the distal femoral physis, and the remodeling of the anterior distal metaphysis.

requiring an emotionally mature patient and diligent physical therapy.

Foot

Foot deformities in arthrogryposis are either clubfeet or congenital vertical tali. Arthrogryptic clubfeet have a high rate of relapse, regardless of the corrective treatment. Since relapses after surgically treated feet are stiffer, more painful, and more difficult to correct treatment has shifted to the Ponseti method of serial casting for arthrogryptic clubfeet.^{12,48} Repeated casting series becomes part of the treatment plan during the early growing years. The casting technique is largely the standard



Figure 5. A 9-1/2-year-old girl with Amyoplasia, s/p previous extensive clubfoot soft tissue releases with severe recurrence. A) View of the right foot prior to casting. B) and C) Views of both feet prior to casting. Note the deep cavus, severe heel varus, forefoot adductus, and supination. D) After eight casts she underwent a percutaneous Achilles tenotomy bilaterally, followed by another six casts and then was transitioned to braces. E) F) G) Views of the right foot as well as posterior bilateral ankles at 16 years old. She underwent another three series of castings in the intervening 6 years.

Ponseti technique, although in cases of severe equinus (> 40 degrees), an Achilles tenotomy is done early to unlock the calcaneus from the posterior tibia. A second tenotomy may be needed for residual equinus at the end of casting (Figure 5). Since the arthrogryptic patient lacks active ankle motion and does not spontaneously kick, the standard foot-abduction brace used for idiopathic clubfoot is not effective. Rather, a custom-molded leaf spring ankle-foot orthosis (AFO) with correction of the hindfoot varus and forefoot adduction is used. The ankle strap originates inside laterally to help roll the heel into valgus. Removable dorsiflexion straps stretch the ankle at nighttime. A surprising finding was the high prevalence of external tibial torsion associated with arthrogryptic clubfeet which can make treatment of the clubfoot confusing.¹² Tibial derotational osteotomies in mid childhood is now common practice.

Approximately 10% of the arthrogryptic clubfeet have a characteristic shape with less heel varus and forefoot adductus but a pronounced midfoot cavus and a transverse plantar crease closely resembling the atypical clubfoot

described by Ponseti et al. We have named this the equinovarus clubfoot variant⁴⁸ (Figure 6). Similar to the atypical clubfoot, the equinovarus clubfoot does poorly with standard Ponseti casting, developing into an irrecoverable valgus/abductus foot. Instead, the same casting method that Ponseti described for the atypical clubfoot is used—dorsiflexing the forefoot relative to the midfoot, with minimal to no abduction.⁴⁹ Bracing is similar to the classic clubfoot.

The congenital vertical talus is the less common arthrogryptic foot deformity.¹³ The “reverse clubfoot” casting technique described by Dobbs et al. has revolutionized its treatment, stretching the contracted ankle structure with a combination of plantarflexion, forefoot supination, and adduction.⁵⁰ Just prior to the last cast, the talonavicular joint is reduced (either open or closed) and pinned, possibly with an Achilles tenotomy. The foot position is maintained by an AFO molded to correct hindfoot valgus and forefoot adductus, the ankle strap originating inside medially.

Spine

Spine deformities have a prevalence of about 23% in arthrogyriposis, with some conditions having a much higher risk (Escobar syndrome, Freeman-Sheldon syndrome) than others.⁵¹ A number of deformities are present at birth, including fetal cervical hyperextension and a form of scoliosis that mirrors the fetus's intrauterine position.⁵² These are not "congenital scoliosis" as there are no vertebral malformations. Instead, we refer to them as "prenatal" deformities.⁵³ If cervical hyperextension is identified on the prenatal ultrasound, the baby should be carefully delivered by Caesarian section to prevent cervical spine injury. In the younger child, Mehta casting can decrease the size of curves and/or slow progression but seldom corrects the scoliosis⁵¹ (Figure 7). In the older child, non-fusion spinal instrumentation with expandable implants is effective but limited to about 5 years of treatment time due to spine stiffness and autofusion limits.^{51,54,55} Therefore, delaying surgery to after 6 years of age can allow for more overall growth.

Both severe scoliosis and hypokyphosis can lead to pulmonary dysfunction which is worsened by an increased BMI.⁵⁶ Spinal fusion for arthrogryptic scoliosis is common and effective. The fusions on average are two levels longer than for idiopathic curves and there is a lower expected percentage correction rate (44% versus 71%). The 1-year reoperation risk is 7% mostly for infections and 29% at 4 years primarily for pseudoarthrosis.^{57,58}

Summary

Arthrogyriposis multiplex congenita is a very heterogeneous entity in presentation, in underlying causes, and prognosis for independent living. As we learn more about the different conditions that cause arthrogyriposis, we can develop more condition-specific orthopaedic treatments and protocols. Yet, there are many overarching treatment principles that are related to arthrogryptic limb deformity treatment, regardless of the underlying condition. Protocols and algorithms need to be explored and refined based on newer procedures and outcome studies. Internationally, a community of practitioners is developing, devoted to treating adults and children with



Figure 6. A 2-year-old boy with presumed Amyoplasia and bilateral equinovarus clubfoot variants previously untreated. A) B) C) Views of the right foot prior to casting. Note the deep transverse midfoot crease and midfoot cavus/equinus. There is only minimal hindfoot varus and forefoot adductus. D) Right foot after four casts using the "4-finger" technique described by Ponseti.⁴⁹ E) Right foot after percutaneous Achilles tenotomy. The feet remained in their last cast for 4 weeks prior to implementing brace treatment.

arthrogryposis.⁵⁹⁻⁶¹ Projects currently underway should better describe outcomes, allowing the next generation of those born with arthrogyriposis to be treated more specifically for their individual needs and to be able to participate more fully in society.

Additional Links

- Arthrogyriposis Multiplex Congenita Support, Inc. <https://www.AMCSupport.org>
- AMC Adult Registry, Bonnie Sawatzky, PhD, Project Lead www.amcresearch.org
- "Understanding Arthrogyriposis Multiplex Congenita" Margaret Chaidez, ADAC, interviews Harold van Bosse, MD <https://vimeo.com/24626314>

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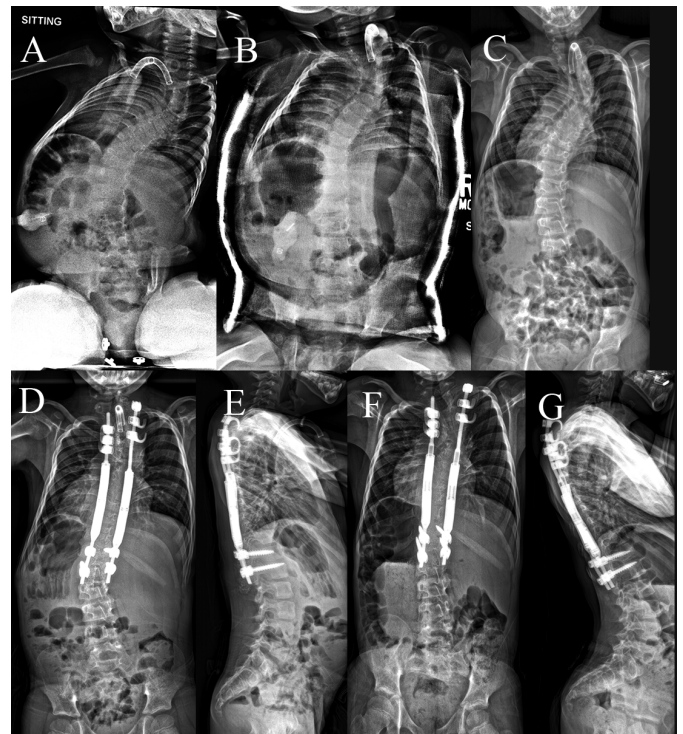


Figure 7. A boy with Escobar syndrome and severe scoliosis. A) Sitting AP spine radiograph at 19 months old with 60 degrees right thoracic and 70 degrees left thoracolumbar curves immediately prior to initiating serial spinal casting. B) Sitting AP radiograph in first cast. C) AP standing spine radiograph at 7 1/2 years of age after 16 casts with 45 degrees right upper thoracic and 40 degrees left lower thoracic curves just prior to placement of expandable implants. Patient required release of an asymptomatic tethered cord prior to surgery. D) and E) AP and lateral standing spine radiographs immediately after implantation of magnetically actuated expandable spinal instrumentation. F) and G) AP and lateral standing spine radiographs at 10 years of age. Expansion of the devices was limited, but chest symmetry was maintained. The patient was able to have his tracheostomy decannulated.

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