Surgical Treatment of Pediatric Upper Limb Spasticity: The Wrist and Hand

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Abstract

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The wrist and hand are essential in the placement of the upper extremity in a functional position for grasp, pinch, and release activities. This depends on the delicate balance between the extrinsic and intrinsic muscles of the wrist and hand. Spasticity alters this equilibrium, limiting the interaction of the upper limb with the environment. Classically, pediatric patients with upper limb spasticity present with a flexed wrist, thumb-in-palm, and flexed finger posture. These contractures are typically secondary to spasticity of the extrinsic flexor muscles of the wrist and hand and intrinsic muscles of the thumb and digits. Tendon release, lengthening, or transfer procedures may help correct the resultant abnormal postures. A total wrist arthrodesis with or without proximal row carpectomy may help address the severely flexed wrist deformity. With proper diagnosis, a well-executed surgical plan, and a consistent hand rehabilitation regimen, successful surgical outcomes can be achieved.

The wrist and hand are essential in the placement of the upper extremity in a functional position for grasp, pinch, and release activities. This relies on an orchestrated balance between the wrist flexor/extensors, digit flexor/extensor, thumb flexor/extensor, and thumb abductor/adductor muscles. Spasticity alters this delicate equilibrium. Classically, pediatric patients with upper limb spasticity present with a flexed wrist, thumb-in-palm, and flexed finger posture (–Fig. 1).¹

Depending on the severity, the wrist and hand contracture may produce a hygienic, cosmetic, and/or functional deformity.^{2,3} Severe flexion deformities can eventually lead to digging of the fingernails into the palm, producing wounds that require timely management. Physical appearance is also an important consideration, as the flexed wrist deformity represents one of the key stigmata of cerebral palsy (CP). The wrist and hand contracture make grasp, pinch, and release activities difficult to impossible to perform.

Here we will discuss the diagnostic approach, surgical options, postoperative management, and outcomes of pediatric patients presenting with upper limb spasticity at the wrist and hand.

Clinical Evaluation

The flexed wrist deformity may be secondary to spasticity of the extrinsic flexors of the wrist (flexor carpi radialis/ulnaris), digits (flexor digitorum superficialis and profundus), and thumb (flexor pollicis longus). The thumb-in-palm deformity may arise in the setting of spasticity of the adductor pollicis and other intrinsic/extrinsic muscles. The flexed finger posture manifests due to involvement of the flexor digitorum superficialis and profundus muscles. In the chronically flexed and adducted position, the soft tissue structures may respond with a variable degree of contraction and shortening. This can include contraction of the volar skin of the wrist, thumb, and digits, shortening of the neurovascular structures, and tightening of the capsular ligaments. Thus, though the inciting cause may be strictly muscular, the subsequent mechanisms for contracture may be multifactorial (skin deficiency, muscular spasticity, neurovascular shortening, and capsular contracture).⁴

Proper diagnosis of wrist and hand contractures relies on careful identification of each of the contributing factors. The exam begins with visual inspection of the wrist and hand

Fig. 1 Classic posture of pediatric patients with upper limb spasticity, marked by a flexed wrist, thumb-in-palm, and flexed finger posture.

region. The quality of the surrounding skin should be evaluated for color, presence of surgical/traumatic scars, evidence of skin breakdown or intertrigo, and presence of taut musculotendinous units. The wrist should be noted for its resting angle and presence of increased muscular tone versus slow repetitive movements indicative of dyskinesia. Second, the volar wrist crease should be palpated to better appreciate the degree of skin laxity (if any) and pinpoint the spastic musculotendinous units (→**Fig. 2**). The radial volar wrist is comprised of the flexor carpi radialis muscle, which originates from the medial epicondyle of the humerus and inserts onto the volar base of the second metacarpal. The ulnar volar wrist contains the flexor carpi ulnaris muscle, which originates from the medial epicondyle of the humerus and inserts onto the pisiform. The central wrist is composed of the palmaris longus (if present), flexor digitorum superficialis, and flexor digitorum profundus. Tight neurovascular structures, particularly the median nerve, are best appreciated deep within the central wrist.

To confirm the involved musculotendinous units at the wrist, the examiner should present items to initiate grasp while palpating the flexor carpi radialis and ulnaris tendons

Fig. 2 Taut musculotendinous unit evident at radial volar wrist crease, indicative of flexor carpi radialis involvement.

at the wrist. Under normal circumstances, the wrist flexors relax while the finger flexors are activated with the wrist extensors to power grasp. In the setting of spasticity, co-contraction of the flexor carpi ulnaris and sometimes the flexor carpi radialis will be observed during grasp activities.

The thumb and digits should then be noted for their resting posture. Close attention should be paid to whether the thumb interphalangeal and metacarpophalangeal joints are held in flexion or extension, and whether the thumb is in abduction or adduction. The digits are similarly evaluated for their resting posture at the proximal and distal interphalangeal joints. Particular attention should be paid for the presence of swan neck deformities and whether they are static or dynamic in nature. Dynamic deformities tend to correct once the proximal interphalangeal joint is placed into a semiflexed posture. These observations are especially important as swan neck deformities will be exacerbated or unmasked following flexor tendon lengthening procedures. The palmar thumb and digital creases should be palpated to better appreciate the degree of skin laxity, if any.

Passive and active wrist, finger, and thumb range of motion (ROM) measurements should then be obtained with a goniometer. The Volkmann's angle should also be recorded. With the wrist flexed and fingers held in complete extension, the wrist is brought into maximal extension. The wrist angle at which the digits go into a flexed posture is referred to as the Volkmann's angle. The larger the Volkmann's angle is, the higher is the severity and degree of spasticity and shortening. To differentiate between spasticity of the superficialis versus profundus tendons at each finger, the wrist should be placed into maximal extension and the proximal and distal interphalangeal joints should be passively extended. Limited passive extension of the proximal and distal interphalangeal joints is indicative of flexor digitorum superficialis and profundus tendon spasticity, respectively. Finally, the first web space's passive and active opening angle should be recorded.

Several modalities exist to analyze movement in CP patients to aid in diagnosis. Movement deviations in reaching tasks, three-dimensional analysis of motion quality, and dynamic EMG testing are specific in identifying CP in children.⁵⁻⁷ Wrist and finger deformities are typically evaluated together in most classification systems. The Zancolli Classification evaluates finger and wrist extension in combination, separating deformities into three groups based on the degree of spasticity.⁸ Patients in Group 1 can actively extend the fingers with the wrist extended < 20 degrees from neutral. In Group 2, patients can only actively extend their fingers with the wrist flexed > 20 degrees from neutral. Patients in Group 3 demonstrate no active digital extension. The House Functional Classification separates thumb-in-palm deformities into four groups, performed by the patient making a fist with the thumb in a lateral pinch position.⁹ Type 1 deformity is described as a simple first metacarpal adduction contracture, secondary to spasticity of the adductor pollicis and first dorsal interosseous muscles. Type 2 refers to a first metacarpal adduction contracture with a metacarpophalangeal joint flexion deformity, resulting from

spasticity of the adductor pollicis and first dorsal interosseous and flexor pollicis brevis muscles. Type 3 is described as a first metacarpal adduction contracture with a metacarpophalangeal joint extension deformity, resulting from spasticity of the adductor pollicis and first dorsal interosseous and extensor pollicis brevis muscles. Type 4 refers to a first metacarpal adduction contracture with an interphalangeal joint flexion deformity, resulting from spasticity of the adductor pollicis and first dorsal interosseous and flexor pollicis longus muscles.

Radiographs can also be obtained to help evaluate the extent of joint remodeling and arthropathy. Wrist plain films should be evaluated for loss of proximal carpal row height and/or narrowing of the radiocarpal joint space. With regard to swan neck deformities of the digits, the proximal and distal interphalangeal joints should be evaluated for articular head changes and/or joint space narrowing.

Surgical Indications and Timing

Proposed guidelines for the surgical release of the wrist and hand include (1) restriction in pinch, grasp, and release function of the hand; (2) impairment of custodial care, whether for hygiene or dressing; and (3) skin breakdown problems in the palm. Specific degrees of the deformity are typically not considered in the surgical indications.¹⁰ That being said, for lesser degrees of contracture, nonsurgical options include serial extension splinting and/or botulinum toxin A (BoNT-A) therapy. A relative contraindication includes the presence of athetosis, which manifests as fluctuations in tone and opens the possibility for reconstructive overcorrection.¹¹

In relation to the timing of surgery, reliance on strict age criteria should be avoided. Although the effects of CP are often recognized in the perinatal period, it is wise to defer surgery until a clear evaluation of function can be performed. Additionally, there is merit in delaying surgery until predominant patterns of upper extremity use become apparent. These two points often coincide during childhood age, between 5 and 12 years of age. That being said, some authors have advocated for earlier surgical correction around 18 months to 5 years of age. While the optimal surgical age remains up for debate, there is a clear consensus that surgery remains an option for the older patient. It is not uncommon for a patient to be referred in their teenage years—there still remains a role for surgery—albeit with a lower expectation for improvement.

Treatment

Physical/occupational therapy, BoNT therapy, and/or surgical reconstruction can help rebalance these abnormal muscular forces. Though not the topic of this article, splinting and BoNT therapy are useful as stand-alone or as adjunctive modalities for treating spasticity about the wrist and hand. Surgical strategies will be further explored.

When addressing contractures about the wrist and hand, the surgical plan must take into account the multifactorial potential etiologies: skin deficiency, muscular spasticity, neurovascular shortening, and capsular contracture. Therefore, one must be

prepared for local flap resurfacing of the volar wrist and palmar digital creases, musculotendinous lengthening of the involved units, and capsulotomy performed to the limits of neurovascular tension and within the confines of stability.

Depending on the musculotendinous units contributing to the deformity, the surgical incisions can vary. If the flexor carpi ulnaris is co-contracting and producing a flexed wrist posture, this tendon can be transferred to the extensor carpi radialis brevis as described by Green.¹² This maneuver removes the deforming wrist flexor and simultaneously transforms it into a useful wrist extensor. The procedure begins with a longitudinal incision from the mid-forearm overlying the flexor carpi ulnaris to the wrist crease (► Fig. 3). The skin and subcutaneous tissues are elevated and the flexor carpi ulnaris tendon is identified. The soft tissue is then freed off the flexor carpi ulnaris tendon in a 360-degree fashion, protecting the ulnar neurovascular bundle abutting its radial aspect. Blunt dissection is then used to free the deep aspect of its muscular belly from the ulna for the distal two-thirds of its origin. This step is critical toward creating a straight-line vector to aid in supination (if passed ulnarly) or in pronation (if passed radially), as described by Van Heest and colleagues.¹³ The flexor carpi ulnaris tendon is then released off the pisiform and prepared for transfer to the extensor carpi radialis brevis.

A longitudinal incision is placed along the distal dorsal forearm up to the wrist crease. The skin and subcutaneous tissues are elevated and the dissection then proceeds along the second compartment, located radial to the Lister's tubercle. The dorsal forearm fascia overlying the second compartment is released and the extensor carpi radialis tendons are retrieved. The extensor carpi radialis brevis is verified by its more central location. Based on whether additional supination or pronation is desired, a subcutaneous tunnel is created to pass the flexor carpi ulnaris tendon along the ulnar or radial route, respectively. Alternatively, the flexor carpi ulnaris tendon can be passed through the interosseous membrane if additional forearm rotation is not warranted. The wrist is then placed into the desired

Fig. 3 Longitudinal incision overlying the flexor carpi ulnaris to the wrist crease in preparation for a Green's tendon transfer procedure.

amount of extension, ranging from neutral to 20 degrees of extension. The flexor carpi ulnari tendon end is then woven through the extensor carpi radialis brevis as a Pulvertaft weave using a 2-0 or 3-0 permanent suture. Care is taken to ensure that the flexor carpi ulnaris is placed on maximal tension when performing the weave.

In the absence of wrist flexor tendon co-contraction, flexor musculotendinous lengthening and wrist extensor tendon re-balancing are concurrently performed to correct the deformity. The Volkmann's angle provides a rough indication as to the type of technique necessary to achieve the flexor lengthening. Fractional lengthening can be performed for small angles, Z-step lengthening for larger angles, and superficialis to profundus tendon transfers for the most severe circumstances.

Depending on the number of flexor tendons requiring lengthening and type of technique employed, either a limited longitudinal incision centered over the musculotendinous junction or an extensile curvilinear incision from the mid-forearm to wrist crease can be utilized. The skin and subcutaneous tissue is elevated, and the antebrachial fascia is divided. In radial to ulnar fashion, the flexor carpi radialis, palmaris longus, and flexor carpi ulnaris are located. Next, the flexor digitorum superficialis and profundus tendons are located deep to the palmaris longus within the central forearm. Care is taken to protect the median nerve, which lies between these two tendinous units. Finally, the flexor pollicis longus is found radial and deep to the median nerve. If performing a fractional lengthening, the musculotendinous junction is located. A tenotomy is then performed where the tendinous fibers still overlap the muscular belly.¹⁴ Depending on the circumstances, a second tenotomy can be performed in the musculotendinous junction and spaced 1 cm from the previous one. The wrist is then set into neutral with the thumb and fingers in a slightly flexed posture. This maneuver opens up the tenotomy sites, while still preserving contact between the muscle belly and tendinous ends. Care is taken not to overextend the digits as this can overly weaken the extrinsic flexors and result in swan neck deformities of the fingers. In the more common, moderate situation, a Z-step lengthening is performed. To do so, the hemitendon is divided radially at one end and ulnarly at the other end to complete the transection. The lengthening should be performed across as much length of the tendon as possible. This will ensure the ability to repair the lengthened tendon ends with maximal contact, allowing for optimal healing. The wrist and hand is then set into the desired posture and the repair is performed using a 2-0 permanent suture in a side-to-side running horizontal mattress fashion (►Fig. 4).

In the more-severe flexion deformities, a superficialis to profundus tendon transfer is performed. For this procedure, the superficialis tendons are dissected as far distal as the volar wrist crease and the profundus tendons as far proximal as the musculotendinous junction. The fingers are then set to their normal cascade. The superficialis tendons are then sutured together distally near the wrist crease with 2-0 permanent suture. The profundus tendons are then sutured together proximally at the musculotendinous junction with 2-0 permanent suture (►Fig. 5). The superficialis and profundus

Fig. 4 Side-to-side running horizontal mattress repair following Z-step lengthening of all three wrist flexor tendons (flexor carpi radialis, palmaris longus, and flexor carpi ulnaris).

Fig. 5 The superficialis tendons are then sutured together distally, and the profundus tendons are then sutured together proximally at the musculotendinous junction in preparation for the superficialis to profundus tendon transfer.

tendon groups are then cut just distal and proximal to the suture ties, respectively. The wrist is then placed in neutral and the metacarpophalangeal and proximal interphalangeal joints are set at 45 degrees. The superficialis tendon group is then held on maximal tension as it is sown to the profundus group using a 2-0 permanent suture in a side-to-side running horizontal mattress fashion (►Figs. 6 and 7).

Although musculotendinous lengthening can correct extrinsic flexor tendon tightness and/or spasticity, it does not address the extrinsic tendon laxity over the wrist. This is treated by either plication of the extensor carpi radialis tendons or by transfer of the extensor carpi ulnaris hemitendon to the extensor carpi radialis brevis. The second extensor tendon compartment is accessed as previously described. The extensor carpi radialis tendons are then plicated by the amount necessary to hold the wrist from neutral to 20 degrees of extension. The plication is secured with 2-0 permanent suture. If the plication fails to secure the

Fig. 6 The superficialis tendon group is then held on maximal tension as it is sown to the profundus group using a 2-0 permanent suture in a side-to-side running horizontal mattress fashion.

Fig. 7 The wrist is then placed in neutral and the metacarpophalangeal and proximal interphalangeal joints are set at ~45 degrees.

wrist into a desirable position, the sixth compartment can be accessed and the extensor carpi ulnaris tendon retrieved. Its radial half is released from the base of the fifth metacarpal and woven through the extensor carpi radialis brevis as a Pulvertaft weave using a 2-0 or 3-0 permanent suture. Care is taken to ensure that the extensor carpi ulnaris is placed on maximal tension when performing the weave and to reinforce the Y-shaped junction of the hemitendon with its ulnar counterpart with 2-0 permanent suture to prevent propagation of the tenotomy line (► **Fig. 8**).

With regard to the thumb-in-palm deformity, the surgical approach depends on the tendinous structures requiring correction, and whether the first web space requires length-

Fig. 8 The extensor carpi ulnaris is placed on maximal tension when performing the Pulvertaft weave into the extensor carpi radialis brevis. The Y-shaped junction of the hemitendon with its ulnar counterpart is reinforced with 2-0 permanent suture to prevent propagation of the tenotomy line.

ening. For the type I deformity with first web space contracture, a 4-flap Z-plasty or Manta Ray flap¹⁵ (► **Figs. 9 and 10**) can be designed. Through this incision, the flaps are elevated with a healthy bed of subcutaneous tissue. Along the dorsum, the first dorsal interosseous fascia is released. Care is taken to protect the princeps pollicis and radialis indicis arterial branches to the thumb and index finger, respectively. The fascia overlying the adductor pollicis is next released. For type 2 deformities with additional involvement of the flexor pollicis brevis, an extended carpal tunnel incision is made along the thenar crease (► **Fig. 11**). The skin flaps are elevated and dissection continues proximally. The volar carpal ligament and transverse carpal ligaments are released and effectively disorignates the intrinsic muscles of the thumb, including the flexor pollicis brevis. The dissection then proceeds distally, releasing the palmar fascia, while being careful of the superficial palmar arch. The lumbrical to the index finger is retracted radially and the common digital neurovascular bundle to the index and long finger is gently retracted ulnarly. The adductor pollicis muscle is next identified, with its transverse head and oblique heads originating off the third metacarpal. With the thumb maximally abducted, the taut muscular origin of the adductor pollicis is released in a distal to proximal direction. Care is taken to protect the deep palmar arch and motor branch of the ulnar nerve that separates the transverse and oblique heads.

In patients with volitional thumb extension and a thumb-in-palm deformity, an extensor pollicis longus rerouting procedure can be performed next. A longitudinal incision is made radial to Lister's tubercle and just proximal to the

Fig. 9 For the type I thumb-in-palm deformity with first web space contracture, a Manta Ray flap.

Fig. 10 First web space opening angle following Manta Ray flap procedure.

extensor retinaculum, to access the extensor pollicis longus. A counter incision is made over the dorsal aspect of the metacarpophalangeal joint to expose the extensor aponeurosis. The extensor pollicis longus is transected at this level with a strip of extensor aponeurosis dissected out from its mid-portion. The extensor aponeurosis is repaired with a 3–0 or 4–0 monofilament suture. The tendon is retrieved through the proximal incision. A curved Carroll tendon retriever is passed from the thumb incision, through the first dorsal compartment, and out the dorsal wrist incision. Sometimes an incision over the first dorsal compartment may be required to accomplish this. The extensor pollicis longus is then drawn through the first dorsal compartment, running it along the radial side of the abductor pollicis longus. It is then passed through an incision in the metacarpophalangeal joint capsule and sutured into place. The repair should be done with enough tension to hold the thumb metacarpal extended.

Digital swan neck deformities can be corrected by several procedures, ranging from a central slip tenotomy, superficialis proximal interphalangeal tenodesis, or lateral band rerouting. The senior author prefers using a dynamic flexor

Fig. 11 For type 2 thumb-in-palm deformity with additional involvement of the flexor pollicis brevis, an extended carpal tunnel incision is made along the thenar crease.

Fig. 12 More-severe wrist flexion deformity requiring proximal row carpectomy and total wrist arthrodesis to achieve neutral positioning.

digitorum superficialis sling, which combines the benefits of the tenodesis and rerouting procedures. An ulnar midlateral incision is placed along the affected digit. The neurovascular bundle is maintained with the volar flap and the ulnar lateral band is dissected free from the dorsal flap and the extensor apparatus. The A3 pulley is incised and the ulnar slip of the

flexor digitorum superficialis is isolated. The ulnar slip is dissected as far proximally as possible and then cut. The ulnar slip cut end is then placed on enough traction to produce ~20 degrees of “springy” flexion at the proximal interphalangeal joint. The distal aspect of the ulnar slip is then tenodesed to the proximal phalangeal neck region with 4–0 permanent suture. The remaining length of the ulnar slip of the flexor digitorum superficialis is then looped from dorsal to volar around the ulnar lateral band and then tenodesed back onto itself with 4–0 permanent suture.

In the more severe wrist deformity (►Fig. 12), an arthrodesis procedure may offer a more definitive means for correction. For significant wrist flexion deformities with concomitant wrist extensor tendon laxity, tendon lengthening and/or transfer procedures will not be sufficient to keep the wrist at neutral. In the patient approaching skeletal maturity, a total wrist arthrodesis will provide for a more stable and neutral wrist position. If there is loss of proximal carpal row height and/or narrowing of the radiocarpal joint space, a proximal row carpectomy can be performed simultaneously. A dorsal incision is placed along the third metacarpal, dorsal wrist, and distal forearm. The skin flaps are elevated and the extensor retinaculum is identified. Extensor retinaculum flaps are raised in a sigmoidal shaped fashion, basing one flap radially and the other ulnarly (►Fig. 13). As these flaps are raised, the extensor compartments are serially opened while protecting their encased tendons in the process. The third compartment with its extensor pollicis longus is retracted radially; the fourth compartment is retracted ulnarly. The posterior interosseous nerve is visualized deep to the fourth compartment and neurectomized to lessen surgical site wrist pain. The dorsal capsule is next encountered, and can be either opened longitudinally or in a ligament

splitting fashion as described by Berger and colleagues. In patients with loss of proximal row height or narrowing of the radiocarpal joint space, a proximal row carpectomy is next performed. For this process, a towel clip is placed on the scaphoid and a No. 15 blade is used to sharply release its surrounding ligaments (►Fig. 14). A towel clip is successively placed on the lunate and triquetrum and ligament release continued. Care is taken to preserve the surrounding structures, including the carpal row distally and the triangular fibrocartilage complex proximally. The cartilage surrounding the proximal pole of the capitate and scaphoid and lunate facets of the radius are then denuded down to bleeding subchondral bone. The proximal pole of the capitate is then recessed into the lunate facet of the radius, as the wrist is corrected into either a neutral or slightly extended and ulnarly deviated position. Whether or not a proximal row carpectomy is performed, the dorsal cortex of the third metacarpal, capitate, and Lister’s tubercle of the radius are burred down to ensure no step-off with the wrist arthrodesis plate. Autologous bone graft, whether derived from the proximal row carpectomy or distal radius, is placed around the fusion site. A 1.8- to 2.6-mm total wrist arthrodesis plate is then positioned onto the third metacarpal and provisionally held in place with Kirschner wires. Proper plate positioning is confirmed with minifluoroscopy; the distal holes are drilled and measured for proper 2.0 mm bicortical screw placement. The hand is then maintained in its corrected wrist position, and the proximal plate is positioned onto the radius

Fig. 13 Extensor retinaculum flaps are raised in a sigmoidal shaped fashion, basing one flap radially and the other ulnarly.

Fig. 14 A towel clip is placed on the scaphoid and a No. 15-blade is used to sharply release the surrounding ligaments as part of the proximal row carpectomy.

and provisionally held with either Kirschner wires or a bone clamp. The proximal holes are then drilled and measured for proper bicortical 2.3-mm screw placement. Minifluoroscopy is used to confirm proper plate positioning and screw length. One leaflet of the extensor retinaculum is then draped above the wrist arthrodesis plate and secured to the surrounding tissue with 3–0 monofilament (►Fig. 15). The extensor digitorum communis is then returned to the area and then draped with the second leaflet of the extensor retinaculum, thereby preserving tendon gliding and limiting adhesions to the plate or surrounding tissue (►Fig. 16).

Metacarpophalangeal joint hypermobility is a concern when considering tendon transfers to augment abduction and extension. If the metacarpophalangeal joint can be passively extended beyond neutral, these transfers may produce undesirable hyperextension at this joint instead of abduction and extension of the thumb ray. Arthrodesis of the metacarpophalangeal joint prevents hyperextension and is more reliable than joint capsulodesis. The metacarpophalangeal joint is approached through a dorsal incision. The interval between the extensor pollicis longus and brevis is split, and subperiosteal dissection of the articular surface of the proximal phalanx and metacarpal head is performed. Care should be taken not to extend the dissection proximally on the metacarpal or distally on the proximal phalanx to expose the physes. The articular surface is removed first with a knife to expose the ossification center; then the subchondral bone can be removed with an oscillating saw. The osteotomies should be performed to position the joint in 10 degrees of flexion. The metacarpophalangeal joint is fixed with two 0.035-inch Kirschner wires.

Fig. 15 One leaflet of the extensor retinaculum is then draped above the wrist arthrodesis plate and secured to the surrounding tissue with 3–0 monofilament.

The skin defects at the wrist, thumb, first web space, and digits are next assessed. Depending on the degree of release, the skin can either be closed in a straight-line fashion or with the help of local flaps. This may include advancement or rotational flap coverage at the volar wrist crease, Z-plasty reconstruction of the tight first web space, and homodigital or heterodigital flap coverage of the volar digital creases.

Postoperative Care

Following surgical reconstruction of the wrist and hand, a custom made four-piece splint is fabricated. This begins with a volar piece across the digits, placing them into a semiflexed position at the metacarpophalangeal and interphalangeal joints. A c-shaped piece is then added to place the thumb into maximal abduction, neutral position at the metacarpophalangeal joint, and a slightly flexed posture at the interphalangeal joint. Next, a volar splint is placed across the wrist to hold it into a neutral position. An above-elbow sugar tong splint is next fabricated to hold the forearm in the desired amount of pronation or supination. These combined splints (►Fig. 17) stay in place continuously to promote healing of the lengthened and transferred musculotendinous units and union across the fusion mass, thereby lessening the degree of relapse. Four weeks following a soft tissue procedure and 6 weeks following bone and joint surgery, the patient is transitioned to a thermoplastic splint. This is worn continuously for 4 weeks, except when engaging in gentle ROM and therapy exercises. Eight to 10 weeks postoperatively, the patient is transitioned to nocturnal use of thermoplastic splints for up to 12 months postoperatively.

Fig. 16 The extensor digitorum communis is then returned to the area and then draped with the second leaflet of the extensor retinaculum, thereby preserving tendon gliding and limiting adhesions to the plate or surrounding tissue.

Fig. 17 Following surgical reconstruction of the wrist and hand, a custom-made four-piece splint is fabricated and kept in place for 4 to 6 weeks to promote healing of the lengthened and transferred musculotendinous units and union across the fusion mass.

Outcomes

Following transfer of the flexor carpi ulnaris to the extensor carpi radialis brevis, pronator teres release, and extensor pollicis longus rerouting with adductor pollicis release, Van Heest and colleagues observed significantly greater improvement in the Shriners Hospital Upper Extremity Evaluation (SHUEE) dynamic positional analysis (DPA) as compared with those undergoing BoNT-A or ROM therapy.¹⁶ Improvements in SHUEE DPA reflected improved supination and wrist extension and surgical patients showed more improvement in the Pediatric Quality of Life Inventory Cerebral Palsy Module domain of movement and in the Canadian Occupational Performance Measure score for satisfaction than the other two groups. Both the surgical and ROM therapy groups showed more improvement in pinch strength than did those undergoing BoNT-A.

The surgical correction of thumb-in-palm deformity has a high clinical success rate and patient satisfaction in the long term. However, it should be taken into account that the clinical result around 1-year postoperative cannot be considered final. As reported by Alewijnse and colleagues,¹⁷ the success rate was 87% at short-term follow-up, which in the long term decreased to 80%. Interestingly, thumb position deteriorated in 29% of the patients between short-term and long-term follow-up. In the long term, 74% of the patients were satisfied with the position of their thumb; 87% would undergo the surgery again.

Results following swan neck correction have varied with the type of technique employed. Following lateral band translocation (rerouting), de Bruin and colleagues reported that correction was successful for 84% of the operated fingers at 1-year follow-up and 60% after 5 years.¹⁸ Carlson and colleagues reported improvement in dynamic swan-neck deformity averaging 32 degrees for the central slip tenotomy method.¹⁹ No swan-neck deformity was worse than its preoperative state, and no patient developed boutonniere deformity. All patients would repeat the procedure.

The union rate following total wrist arthrodesis has been reported as high as 98% by Van Heest and colleagues.²⁰ Eighteen of forty-one patients (43.9%) developed plate irritation requiring hardware removal after union and five patients (12.1%) experienced a major complication, including four fractures and one nonunion. Patient outcome assessment showed that Disability Assessment Scale scores improved significantly from a preoperative mean of 9.6 to a postoperative mean of 5.5; visual analog scale scores demonstrated substantial improvements in appearance, function, ease of daily care, and hygiene. Ninety-four percent of patients were satisfied, with an average satisfaction visual analog scale score of 8.3.

Future Directions

In 2011, Xu and colleagues reported on a 4-year-old girl with hemiplegic CP and subsequent spasticity in the left upper extremity, who underwent a C7 nerve root rhizotomy and a contralateral C7 nerve root transfer to the ipsilateral middle trunk of brachial plexus through an interpositional sural nerve graft.²¹ In a 2-year follow-up, the results showed a reduction in spasticity and an improvement in extension power of the elbow, the wrist, and the second to fifth fingers. Scores from both Quality of Upper Extremity Skills Test and Modified Ashworth Scale had significantly improved during follow-up. This case outcome provides evidence that combining C7 nerve root rhizotomy with contralateral healthy C7 nerve root transfer can not only release flexional spasticity but also strengthen upper extremity extensor power in children with CP.

In the future, management of pediatric upper limb spasticity will focus on re-establishing a normal impulse pathway to the dysfunctional musculotendinous unit. By severing the faulty neuronal input responsible for spasticity and replacing it with a more physiologic pattern of input, one may be able to prevent or reduce spasticity. In turn, this could stem the downstream effects of myocontracture and/or joint contracture. One potential pathway could be through the use of nerve transfers, from expendable muscle groups outside the affected extremity. Time will tell whether so-called peripheral rewiring can overcome the untoward effects of a central nervous system injury.

References

- 1 Van Heest AE, House JH, Cariello C. Upper extremity surgical treatment of cerebral palsy. *J Hand Surg Am* 1999;24(2): 323–330
- 2 Carroll RE. The surgical treatment of cerebral palsy. I. The upper extremity. *Surg Clin North Am* 1950;31(2):385–390
- 3 Hoffer MM. The use of the pathokinesiology laboratory to select muscles for tendon transfers in the cerebral palsy hand. *Clin Orthop Relat Res* 1993;(288):135–138
- 4 Chin TY, Duncan JA, Johnstone BR, Graham HK. Management of the upper limb in cerebral palsy. *J Pediatr Orthop B* 2005;14(6): 389–404
- 5 Jaspers E, Desloovere K, Bruyninckx H, et al. Three-dimensional upper limb movement characteristics in children with hemiplegic

- cerebral palsy and typically developing children. *Res Dev Disabil* 2011;32(6):2283–2294
- 6 Jaspers E, Feys H, Bruyninckx H, et al. The reliability of upper limb kinematics in children with hemiplegic cerebral palsy. *Gait Posture* 2011;33(4):568–575
 - 7 Klotz MC, van Drongelen S, Rettig O, et al. Motion analysis of the upper extremity in children with unilateral cerebral palsy—an assessment of six daily tasks. *Res Dev Disabil* 2014;35(11):2950–2957
 - 8 Zancolli EA, Zancolli ER Jr. Surgical management of the hemiplegic spastic hand in cerebral palsy. *Surg Clin North Am* 1981;61(2):395–406
 - 9 House JH, Gwathmey FW, Fidler MO. A dynamic approach to the thumb-in palm deformity in cerebral palsy. *J Bone Joint Surg Am* 1981;63(2):216–225
 - 10 Domzalski M, Inan M, Littleton AG, Miller F. Pectoralis major release to improve shoulder abduction in children with cerebral palsy. *J Pediatr Orthop* 2007;27(4):457–461
 - 11 Carlson MG. Cerebral palsy. In: Wolfe SW, Hotchkiss RN, Pederson WC, Kozin SH, eds. *Green's Operative Hand Surgery*. 6th ed. Philadelphia, PA: Elsevier; 2010:1139–1172
 - 12 Green WT, Banks HH. Flexor carpi ulnaris transplant and its use in cerebral palsy. *J Bone Joint Surg Am* 1962;44-A:1343–1430
 - 13 Van Heest AE, Murthy NS, Sathy MR, Wentorf FA. The supination effect of tendon transfer of the flexor carpi ulnaris to the extensor carpi radialis brevis or longus: a cadaveric study. *J Hand Surg Am* 1999;24(5):1091–1096
 - 14 Namdari S, Alosch H, Baldwin K, Mehta S, Keenan MA. Outcomes of tendon fractional lengthenings to improve shoulder function in patients with spastic hemiparesis. *J Shoulder Elbow Surg* 2012;21(5):691–698
 - 15 Coombs CJ, Thomas DJ. The Manta Ray flap: a technique for first web space release. *Tech Hand Up Extrem Surg* 2010;14(1):41–45
 - 16 Van Heest AE, Bagley A, Molitor F, James MA. Tendon transfer surgery in upper-extremity cerebral palsy is more effective than botulinum toxin injections or regular, ongoing therapy. *J Bone Joint Surg Am* 2015;97(7):529–536
 - 17 Alewijnse JV, Smeulders MJ, Kreulen M. Short-term and long-term clinical results of the surgical correction of thumb-in-palm deformity in patients with cerebral palsy. *J Pediatr Orthop* 2015;35(8):825–830
 - 18 de Bruin M, van Vliet DC, Smeulders MJ, Kreulen M. Long-term results of lateral band translocation for the correction of swan neck deformity in cerebral palsy. *J Pediatr Orthop* 2010;30(1):67–70
 - 19 Carlson MG, Gallagher K, Spirtos M. Surgical treatment of swan-neck deformity in hemiplegic cerebral palsy. *J Hand Surg Am* 2007;32(9):1418–1422
 - 20 Van Heest AE, Strothman D. Wrist arthrodesis in cerebral palsy. *J Hand Surg Am* 2009;34(7):1216–1224
 - 21 Xu WD, Hua XY, Zheng MX, Xu JG, Gu YD. Contralateral C7 nerve root transfer in treatment of cerebral palsy in a child: case report. *Microsurgery* 2011;31(5):404–408