Surgical management of the wrist in children with cerebral palsy and traumatic brain injury

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Introduction

The majority of children with hemiplegia/quadriplegia resulting from cerebral palsy or traumatic brain injury demonstrate upper extremity disability related to spasticity, weakness, movement disorders, abnormal sensibility, and poor motor-sensory coordination. Within this patient group, wrist function is frequently problematic. The most common wrist deformity is flexion, which interferes with grasp; hyperextension interferes with release and is less frequent. Excessive spasticity of the extensor carpi ulnaris may compound ulnar deviation and, in the pronated forearm, contributes to flexion deformity (Fig. 1) [1–12].

Many patients with refractory wrist deformities are not surgical candidates because of concomitant movement disorders, absence of voluntary control, or impaired sensibility. It is estimated that less than 20 % of children with cerebral palsy and less than 30 % of children with traumatic brain injury are candidates for surgical procedures of the wrist [3, 7].

The purpose of this manuscript is to discuss the indications and contraindications of the treatment options for wrist spasticity associated with cerebral palsy and traumatic brain injury. In addition, the following will be detailed: (1) management goals, (2) patterns of deformity and their impact on prognosis and management, (3) the importance of dystonia and

movement disorders, (4) static evaluation and functional requirements, (5) nonoperative treatment options, (6) possible operative procedures, (7) the role of dynamic evaluation of motor activation and power in surgical decision making, and (8) postoperative care.

Management Goals

Treatments are designed to improve function, to eliminate or to decrease pain and/or discomfort, to normalize appearance, to optimize self-esteem, and/or to enhance caregiver activities. Initial management is designed to maintain range of motion, to balance muscle forces across joints, to improve strength, and/or to facilitate caregiving. Nonoperative options are implemented proactively and, if effective, can delay surgery, eliminate the need for surgery, or expand the number of patients eligible for surgery. The optimal timing for surgical intervention is poorly defined. Surgery performed too early may be compromised by motor imbalance secondary to growth, while surgery performed too late may be difficult because of the presence of irreversible joint deformity or contracture. Learned behaviors and functional adaptations are also reasons to avoid late surgery. In younger patients, growth may precipitate the recurrence of deformity, and arthrodesis can result in undesirable limb shortening. After traumatic brain injury, central nervous system reorganization can occur for up to 2 years; therefore, irreversible surgical procedures are relatively contraindicated during this time. Procedures are relatively contraindicated during growth spurts and, if possible, should be performed as close as possible to skeletal maturity.

Splinting, strengthening, neurostimulation, and chemodenervation with botulinum toxin are the most efficacious nonoperative modalities. These modalities (e.g., botulinum toxins) can delay excessive musculotendinous

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shortening of the wrist and finger motors, delay or prevent intrinsic joint contracture, and minimize adaptive osseous deformity [13–17]. However, none of these modalities provide optimal results in isolation, and only 50 % of patients respond sufficiently to botulinum toxin injections to objectively justify continual treatment.

Patterns of Deformity

The *typical patterns of deformity* in the upper extremity are internal rotation of the shoulder, flexion of the elbow, pronation of the forearm, flexion and ulnar deviation of the wrist and fingers, and the thumb is in the palm (Fig. 1). In this article, the primary focus is to describe interventions that modulate the impact of wrist deformity on gross motor function (especially grasp and release) and fine motor coordination. The article also discusses the impact of wrist position on the thumb and fingers. In an *atypical deformity*, the wrist has an extension deformity. In addition, there is frequently an associated ulnar deformity. Deformities may be dynamic (passively correctable) or static (fixed and not passively correctable).

Palmar flexion of the wrist is common among patients with cerebral palsy and traumatic brain injury. Palmar wrist deformity hinders function, produces pain, decreases sensibility (if extreme), interferes with optimal caregiver activities, and/or elicits emotional distress. This deformity can occur secondary to weak wrist and finger extensors, hypertonic or overactive wrist flexors, or a combination of both. Over time, a dynamic

Fig. 1 Typical hemiplegic posturing pattern; the arm is internally rotated at the shoulder, the elbow is flexed, the forearm is pronated, the wrist is flexed and ulnarly deviated, and the thumb is in the palm. (From Koman [40].)

deformity may become “fixed” with the development of flexor muscle contracture or shortening, abnormal elongation of extensor muscle units, contracture of the palmar capsule, wrist and carpal bone deformity or subluxation, and/or damage to the cartilage.

Wrist joint deformities can be either fixed or dynamic and can exist with or without osseous and cartilage deformities. Over time, muscle imbalance can result in muscle and joint contractures. Abnormal wrist postures frequently are interrelated with elbow and hand/finger deformities.

Importance of Movement Disorders

Hypertonic movement disorders include spasticity, dystonia (athetosis and chorea), and rigidity. Rigidity is rare in children with cerebral palsy and traumatic brain injury; however, dystonia can occur and is important to identify. Hypertonic muscles are weak, and sensibility may be impacted by central nervous system injury or chronic wrist malposition. For example, extremes of wrist position impair median and ulnar nerve function. The presence of movement disorders is a relative contraindication to tendon transfers; therefore, establishing a diagnosis of dystonia is critical before surgery. Soft tissue procedures performed in patients with athetosis portend suboptimal results [1, 7]. Therefore, arthrodesis is the most predictable option for patients with movement disorders. Even in patients with subtle movement disorders, a paradoxical and unanticipated postoperative response can occur. For example, transfer of the flexor carpi ulnaris to the extensor carpi radialis longus can produce a fixed extension deformity. This phenomenon is known as a “athetoid shift” in patients with cerebral palsy and is also seen in patients with traumatic brain injury [18].

Evaluation

In order to achieve optimal nonoperative and surgical management, patients require a careful history and physical examination. The history should focus on the following: the time course of deformity and ensuing disability, previous treatment interventions and their effectiveness, pain, spasticity, the impact of disability on health-related quality of life and function, desired goals of treatment, and a determination of treatment feasibility. A precise assessment of active, gross, and fine motor control is crucial. Measurement of active and passive wrist range of motion provides an estimate of muscle tendon contracture. It is also important to evaluate sensibility and proprioception and to determine the absence or extent of movement disorders. A determination of the effect of wrist position on function and health-related quality of life is

critical. Decision making can be enhanced by standardized assessments, which can include an evaluation of sensibility, stereognosis, proprioception, agility, and skills necessary for activities of daily living.

The use of standardized assessment tools, classification systems, and validated instruments is often advantageous. These tools include the House Functional Classification [19], the International Classification of Functioning and Disability [20], the Melbourne Assessment of Unilateral Upper Limb Function [21, 22], the Spasticity Scales [23–25], the modified House Functional Classification and the Upper Extremity Rating Scale [26], and the Gross Motor Performance Measure [27].

An evaluation of the degree of spasticity is essential and can be measured by the Ashworth scale [23, 24] or the Tardieu spasticity scale [25]. The Tardieu scale is helpful because it allows the physician to determine the degree that spasticity affects active versus passive range of motion. In our practice, the use of the Modified House Classification and Tardieu scale provides prognostic value and improves our ability to predict outcomes. To operate on these patients without using validated measures is unwise.

Treatment decisions are guided by working with the patient to identify realistic treatment goals and by each individual patient's pattern of deformity, functional deficits, and functional requirements. Identification of the optimal treatment requires a dynamic evaluation of the upper extremity in conjunction with active and passive range of motion, an assessment of motor control, a determination of sensibility, and the presence of cognitive awareness of the involved extremity.

The wrist cannot be treated in isolation as wrist position can have a profound impact upon hand function. Excessive wrist flexion can impair median and ulnar nerve function; fixed flexion contractures negate the beneficial effect of finger flexor tenodesis on grasp; fixed dorsiflexion impairs release; and loss of voluntary extension impairs effective grasp and release in many patients. In addition, long-standing deformity can damage the distal radioulnar joint blocking supination and pronation. Once the deficits are delineated, nonoperative and operative options can be outlined, planned, and prioritized.

Nonoperative Treatment Options

Treatment options include therapy, splinting, oral pharmacologies, and parenteral neuromuscular blocking agents (botulinum toxins). Currently, there are no drugs that are labelled by the FDA for managing spasticity in children. The most commonly used drugs are baclofen and tizanidine [28, 29]. Because of systemic side effects, oral medications are rarely beneficial except for severely involved patients with cerebral palsy or in patients with traumatic brain injury, especially in

the early hypertonic phase before a steady state of recovery is reached. Side effects of these drugs include lethargy, weakness, hypotonia, confusion, withdrawal symptoms, dry mouth, liver dysfunction, asthenia, and dizziness [28, 29].

Therapy and splinting are valuable adjuncts and can prevent or delay the development of fixed contractures or improve function. Modifications of neurodevelopmental therapy are commonly used. However, multimodal interventions including active and passive range of motion, home programs, neuromuscular stimulation, strengthening, and/or modified constraint-induced movement therapy (for hemiplegia) also are employed.

Botulinum toxins produce selective and partial flaccid muscle paralysis and balance muscle forces across the wrist [13–17, 30]. In many patients, 100–200 units of botulinum A toxin diluted in 4–6 cm³ can be intramuscularly injected into hypertonic flexor muscles to improve active and passive motion. Injections can also enhance function and delay the need for surgery [17]. In addition, botulinum toxin injections can be used to predict and/or plan hand surgery [15, 31]. Preoperative injections of botulinum A toxin combined with upper extremity functional assessments can be used to identify children with spastic hemiplegia who would not benefit from surgery [31]. Botulinum A toxin injections can be used to evaluate the balance between upper extremity spastic muscles and weak antagonist muscles [31]. The injections can be used to simulate the effect of surgery to lengthen muscles and tendons [31].

Surgical options for wrist palmar flexion include both soft tissue and osseous procedures, depending on the severity of the deformity [10–12]. The goal of soft tissue procedures is to balance muscle forces across joints using tendon transfers, tendon lengthening, and/or tendon shortening. Passively correctible deformities can benefit from tendon lengthenings, releases, or transfers. Fixed flexion contractures with greater than 60° of deformity may require a combination of tendon transfers, bony procedures, and/or gradual correction of joint and soft tissue contractures. Gradual correction of contractures can be achieved by serial casting or by employing a multiplanar, geared external fixator (i.e., Ilizarov or spatial frame devices).

A number of osseous procedures can be used to correct wrist palmar flexion deformity interfering with function including distal radius osteotomy, hemiepiphysiodesis, proximal row carpectomy, radial shortening (with or without angular correction), and wrist fusion (with or without carpal resection) [32].

Wrist Fusion

Patients considered as candidates for a wrist fusion should demonstrate good to excellent thumb and finger control while

the wrist is immobilized close to a neutral position. Fusion procedures can be considered for pain relief or to improve hygiene in a cortically “blind” or functionless hand. Before considering a wrist fusion procedure, a careful functional evaluation of the extremity should be performed in order to appreciate the effect of tenodesis on finger flexion and grasp and release [1].

Technique

Effective wrist fusion places the wrist in a functional position of either neutral or slight extension and aids balance of extrinsic finger flexors and extensors. This may be combined with lengthening of the long finger flexors and plication (shortening) of the extrinsic finger flexors. The procedure is performed through a longitudinal dorsal incision; fixation is provided by pins or a plate and screws. The third dorsal compartment is opened, and the fourth extensor compartment is left intact and the radius is exposed. The wrist is opened and the distal radius is exposed subperiosteally. Cartilage from the joint surface is removed, and a wedge of carpal bone is resected if necessary (Fig. 2). If the palmar structures are too tight, the proximal carpal row and half the capitate can be removed as well. In skeletally immature patients, fusion of the carpals to the epiphysis sparing the physis using smooth pin fixation is possible (Fig. 3). Fixation can be provided with longitudinal or crossed pins or with a dorsal plate that extends from the radius to the second or third metacarpal (Fig. 4).

The wrist flexors and extensors can be transferred or left in situ. When a plate is used, the authors place a wrist extensor between the plate and thumb/finger extensors to avoid tendon irritation, tenosynovitis, and potential rupture.

Fig. 2 Wedge resection of the distal radius and proximal carpal row. (From Koman [40].)

Fig. 3 Carpal-radial epiphysis fusion with a smooth pin sparing the physis indicated by the arrow. (From Koman [40].)

Osteotomy and Hemiepiphysiodesis

Osteotomy of the distal radius is rarely indicated but can be used to correct a bowed radius. A closing wedge is used to decrease forces across the wrist, and fixation is provided with pins or a plate. In skeletally immature patients with 3 to 5 years of growth potential, hemiepiphysiodesis of the distal radius permits angular correction through the immature physis. Either staples or a unicortical plate is utilized. However, the child must have the potential for sufficient bony growth to allow for correction. The use of this procedure has not been systematically evaluated in the literature.

Tendon Transfers and Evaluation of Dynamic Motor Activation

Dynamic wrist flexion deformities can be managed with tendon transfers [5, 6, 33, 34]. Assessments of tendon function are used to determine the appropriate tendon transfers; assessments include both clinical and electromyographic muscle testings of the wrist during motion [4, 7, 35, 36]. Muscles are noted as having phasic, nonphasic, or continuous activity. Transfers

Fig. 4 Carpal-radial fusion using a plate and screw construct. (From Koman [40].)

include the following: (1) the transfer of the flexor carpi ulnaris (FCU) to the extensor carpi radialis longus (ECRL), (2) transfer of the FCU to the extensor carpi radialis brevis (ECRB) [Fig. 5], (3) transfer of the FCU to the extensor digitorum communis (EDC) (Fig. 6), and (4) transfer of the extensor carpal ulnaris to the fourth metacarpal or ECRB [Fig. 7].

In patients with continuous FCU activation throughout the flexion/extension arc, a transfer of the FCU to the EDC is preferable to transfer to the ECRB or ECRL, which can produce a paradoxical fixed wrist extension deformity. Transfer of the FCU to the EDC improves wrist and finger extension, permits finger flexion, decreases excessive palmar wrist flexion, and prevents wrist extension deformity by avoiding FCU overpull. The addition of motor power from the FCU to EDC minimizes the negative impact of a continuously firing FCU. Motor balance across the wrist is maintained by the FCR and extrinsic finger flexors, countering the FCU through the EDC.

Fig. 5 Transfer of flexor carpi ulnaris (FCU) to the extensor carpi radialis brevis (ECRB). By routing the FCS ulnarly (rather than through the interosseous membrane), a supination moment is produced counteracting preexisting pronation deformity. (From Koman [40].)

Fig. 6 Transfer of flexor carpi ulnaris (FCU) to the extensor digitorum communis (EDC). By routing the FCS ulnarly (rather than through the interosseous membrane), a supination moment is produced counteracting preexisting pronation deformity.. (From Koman [40].)

If the FCU is found to contract phasically, it can be successfully transferred to the ECRB in order to improve voluntary wrist extension without creating an extension deformity. For wrists that exhibit functional ulnar deviation, the classic Green transfer of the FCU to the ECRL corrects the ulnar deviation deformity and provides wrist extension. In selected patients, transfer of the extensor carpi ulnaris (ECU) radially to the fourth metacarpal or to the ECRB improves wrist extension and decreases ulnar deviation. Concomitant contractures of the flexor carpi radialis (FCR) can also require Z-lengthening or fractional lengthening to facilitate motor balance across the wrist. Lengthening of the FCR should be done cautiously because imbalance of wrist power may occur with excessive dorsiflexion, replacing excessive palmar flexion.

Flexor Pronator Slide

In patients with severe contracture of the wrist and finger flexors, mobilization of the origin of the flexor pronator mass

Fig. 7 Transfer of the carpi ulnaris to the fourth metacarpal. (From Koman [40].)

including the origin of the flexor pollicis longus can improve the range of motion of the wrist and fingers. Achieving optimal tensioning after release is difficult, and extensive weakness is a concern prompting the judicious selection of patients appropriate for this procedure [37].

Postoperative care

Casting or splinting is required following wrist surgical procedures. The wrist is positioned to protect tendon transfers and/or plications as well as to maintain joint position after carpectomy or arthrodesis. Protection provided by a cast for 4–5 weeks followed by splinting is recommended. Therapy is initiated to prevent finger stiffness and to maintain function. After 4 weeks of full-time immobilization, active and passive range of motion and strengthening exercises are initiated. The wrist is splinted in the optimally corrected position for a minimum of 8 h a day. In addition, some patients benefit from electrical stimulation. The intraoperative use of botulinum toxin decreases postoperative pain, protects the repair site, and facilitates rehabilitation [38, 39].

Summary

In selected patients, operations to balance the wrist improve function and health-related quality of life. Wrist arthrodesis can improve wrist position and facilitate hygiene. Surgery can optimize function for patients with grasp/release with their wrist in neutral prior to surgery. However, wrist procedures often require additional surgery to extrinsic finger flexors and extensors to optimize postoperative outcomes.

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