Pediatric Disorders and Their Orthotic Management

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Outline
• Overview – CP/Orthotic Mgt.
• Orthotic Design
• Management of the Hip, Knee, Foot and Ankle
• Case

Overview - Cerebral Palsy
“The only action that a human can bring about is muscle contraction. This muscular contraction will cause movement that may in turn produce actions such as locomotion or speech. However any action must start as a thought.”

Warwick J. Peacock MD
Overview - Cerebral Palsy

- Injury to different brain control centers generate different types of functional loss but all contribute in different ways to three primary abnormalities of gait:
  - Loss of selective motor control
  - Impaired balance
  - Abnormal tone

Gage JR, Schwartz M

Overview - Cerebral Palsy

- Muscle Imbalance and Impaired Balance
  - May respond to orthotic management
- Abnormal Tone
  - Generally not amenable to management orthotically

Overview – Cerebral Palsy

- From an orthotic perspective, as we look at pathological gait we must remember that we are looking at a combination of cause and effect

Gage JR, Schwartz M
Overview – Cerebral Palsy
• Brain injury can interfere with gait in several ways causing:
  • Primary effects
  • Secondary effects
  • Tertiary effects

Pathological gait is a mixture of primary, secondary and tertiary abnormalities

Overview
• Primary Effect:
  • Occurs as a direct result of a brain injury Examples in PVM might be:
    • Loss of selective muscle control
    • Balance difficulties
    • Abnormal muscle tone

Overview
• Secondary Effect
  • Because the primary effects of brain injury imposes abnormal forces on the skeleton, neither bone nor muscle grow normally
  • These changes are not immediate
  • Muscles and bones grow slowly over time and these skeletal deformities emerge slowly and in direct proportion to the rate of skeletal growth
Overview

- **Tertiary Effects**
  - The *primary* and *secondary* effects of the brain injury burden the child with structural and dynamic abnormalities that make walking difficult
  - The child will develop "coping or compensatory mechanisms" to walk and increase energy consumption
  - These coping mechanisms represent the *tertiary* effects of brain injury

Gage JR, Schwartz M

Goal

- Identify *tertiary* abnormalities and define optimal orthosis for each patient

Characteristics of Pathological Gait in Cerebral Palsy

- In Cerebral Palsy
  - The muscle forces are neither appropriate or adequate as the result of
    - Muscle contracture
    - Poor body segment balance/or position
    - Poor selective motor control
    - Abnormal bone lever arms
Characteristics of Pathological Gait in Cerebral Palsy: Lever Arm Dysfunction

- Abnormal Bone Lever Arms:
  - Short Lever Arms
  - Flexible Lever Arms
  - Malrotated Lever Arms
  - Abnormal Pivot or Action Point
  - Positional Lever-Arm Dysfunction

Characteristics of Pathological Gait in Cerebral Palsy: Lever Arm Dysfunction

- Short Lever Arm:
  - Coxa Valga
    - Hip joint with excessive valgus reduces the length of the moment-arm from the center of rotation (hip-joint center) to the line of action of the muscle

- Hip lever arm is reduced by 25% as Glut. Med. insertion moves medially
  - Even though the m. force has remained the same the magnitude of the moment is reduced by 25%
  - Resultant gait comp. is upper body shift and pelvic drop to reduce demand on hip abductor

- Orthotic Goal – Block Hip Adduction, Stabilize Hip
- Orthosis - ??? Swash
Characteristics of Pathological Gait in Cerebral Palsy - Lever Arm Dysfunction

- **Flexible Lever Arm:**
  - Lever arm is not rigid enough to transmit force and therefore bends as the force increases.
  - Like trying to pry up a rock with a rubber cross bar.
  - Classic example: Child with spastic diplegia and a flexible pes valgus (mid-foot break).
- **Orthotic Goal –** Reestablish PF/KE Couple.
- **Orthosis –** AFO with DF Stop, PF Resist/Stop, AFO G/R F/A.

- **Malrotated Lever Arm:**
  - Most commonly torsional deformities of the long bones of the lower extremity.
  - In CP due to failure to remodel fetal anteversion, with resultant femoral torsion.
  - In spastic diplegia may lead to femoral anteversion and external tibia torsion (malignant malalignment syndrome).

- **Orthotic Goal –** Re-establish effective lever arm, block DF and reduce toe out.
- **Orthosis –** AFO S/A, G/R, G/R F/A.
Characteristics of Pathological Gait in Cerebral Palsy - Lever Arm Dysfunction

- Malrotated Lever Arm
- Femoral Antversion
- Orthotic Goal - Accommodate deformity, possibly reduce rate of progression
- Orthosis - Single Lateral upright HKAFO attached to AFO G/R

Characteristics of Pathological Gait in Cerebral Palsy - Lever Arm Dysfunction

- Unstable Fulcrum:
  - Hip subluxation or dislocation.
  - Even in the presence of adequate force and lever an effective moment cannot be generated.
  - Because of the subluxation or dislocation there is no stable fulcrum.
- Orthotic Goal – Post Op hip stabilization, ROM control
- Orthosis – Maple Leaf

Characteristics of Pathological Gait in Cerebral Palsy

- Positional Abnormalities:
  - Crouched gait in CP can be the result of a variety of causes and it is often complex and challenging to differentiate primary, secondary and tertiary effects as causes
  - This illustrates the biomechanical disadvantage the child is placed in by a knee flexion contracture
- AFO alone can’t overcome this disadvantage NOTE:CG
- Orthotic Goal - Stance Stability
- Orthosis – AFO G/R, Heel Wedge
Cerebral Palsy

Orthotic Treatment Goals

- To Correct or Prevent Deformity
- To Provide a Base of Support
- To Facilitate Training in Skills
- To Improve Efficiency in Gait

Condie and Meadows 1995

Cerebral Palsy - Treatment Goals

Correct or Prevent Deformity

- Flexible Deformities
  - Due to unbalanced muscle forces
  - Can be corrected passively
  - Orthoses can maintain corrected position

- Fixed Deformities
  - Due to shortened soft tissue and muscles cannot be passively corrected
  - Orthosis must accommodate deformity

Cerebral Palsy - Treatment Goals

- Provide a Base of Support
  - Stability in standing or sitting requires the center of mass be well positioned over the supporting area
  - AFO’s can be used to provide a stable base for standing and walking
  - Hip abduction orthoses may improve sitting stability by increasing the size of the base of support
Cerebral Palsy - Treatment Goals

- Facilitate Training in Skills
  - AFO’s directly influence the alignment of the body segments supported within the device
  - AFO’s influence hip, knee and ankle moments by manipulating the GRF
  - Stabilizing the ankle and foot allows therapy to focus training on strengthening and improved control over more proximal joints

Cerebral Palsy - Treatment Goals

- Improve Efficiency in Gait
  - Lower Limb Orthoses may improve gait efficiency by restoring the prerequisites of gait
    - Improved stance stability
    - Improved swing phase clearance
    - Improved limb positioning at terminal swing
    - Improved step length
    - Conservation of energy
  - Lower Limb Orthoses may also ↓ energy expenditure by ↓ the need for compensatory gait deviations

Cerebral Palsy - Treatment Goals

- Review - Efficacy of AFO Management of the Spastic Lower Limb
  - Van Gestel et al 2008 - Orthoses tested successfully improved gait pattern
  - Morris et al 2002 - Review of 450 children w/ CP in 28 studies concluded blocking PF improved gait efficiency
  - Maltais et al. 2000 - Blocking plantarflexion improves energy expenditure based upon O2 consumption
  - Romskes, Brunner 2000 - AFO’s improve pre-positioning for stance
  - Miller, Chambers 1999 - AFO’s improve stance stability
  - Ounpuu et al. 1996 - AFO’s improve clearance in swing phase
  - Abel et al. 1998 - AFO’s increase step length and walking speed
**Cerebral Palsy - Spastic Hemiplegia**

- **Type I**
  - Equinus only in swing phase (open kinetic chain)
  - Orthotic Goal
    - Improve swing phase clearance and pre-position ankle for IC
  - Orthotic Treatment
    - AFO PLS or SAFO PE (Long) Possibly SAFO PE (Short)

- **Type II**
  - Equinus persists in swing and stance and knee tends toward hyperextension during stance
  - Orthotic Goal
    - Stabilize ankle in stance and block knee hyperextension
    - Improve swing phase clearance and pre-position ankle for IC
  - Orthotic Treatment
    - Appropriately tuned SA AFO

- **Type III and IV**
  - Hip and knee involvement, may be associated w/ femoral antversion causing an internal rotational foot deformity
  - Orthotic Goal
    - Stabilize ankle at mid stance and create extension moment at knee
    - Improve swing phase clearance and pre-position ankle for IC
  - Orthotic Treatment
    - Requires pharmacological or surgical intervention and then GR AFO or SA AFO
Cerebral Palsy - Spastic Diplegia

- Spastic Foot and Ankle Equinus
  - Initial contact with forefoot causes GRFs to pass in front of the knee and hip joint causing
    - Excessive external knee extension moment
    - Hyperextension
    - Flexion moment at the hip
  - Orthotic Goal
    - Realign GRF with hip, knee and ankle joints
  - Orthotic Treatment
    - AFO SA (most effective with good ROM at hip, knee and ankle) or AFO with heel wedge

- Spastic Proximal Lower Limb Musculature
  - Knee and hip joints remain flexed during stance
  - GRF passes behind the knee
  - Increased external flexion moment causes excessive knee flexion and buckling
  - Orthotic Goal
    - Reestablish PF/KE couple
  - Orthotic Treatment
    - AFO GR or AFO SA (most effective with good ROM at hip, knee and ankle) or AFO with heel wedge

- Knee Ext/PF couple
  - Crouch gait/single bump
  - Dorsiflexion stop/double bump

Barefoot AFO

Hullin et al
Cerebral Palsy—Spastic Diplegia

- Foot and Ankle
  - Premature and prolonged external DF moments can cause the foot and ankle to buckle
  - This may cause hindfoot inversion or eversion and midfoot collapse and may lead to permanent deformity
- Orthotic Treatment
  - AFO SA or AFO GR
  - Goal
    - Stabilize ankle and support and realign boney segments of the foot

Cerebral Palsy—Spastic Diplegia

- Knee, Hip and Pelvis
  - Hip abduction
    - Apparent hip abduction — occurs when internal rotation occurs simultaneously with hip flexion
    - Femoral Antversion
  - Orthotic Treatment
    - Hip orthosis (swash)
    - Twister Straps (mild rotational problems)
  - Goal
    - Improve knee clearance

Cerebral Palsy—Spastic Diplegia

Ground Reaction AFO:

- df angle is critical
  - Optimize forward progression
  - Consider hamstring tightness
- Adjustability
  - anterior df stop
Cerebral Palsy
Spastic Diplegia

- Foot
  - In children with very mild symptoms or in the hypotonic child the foot may not be capable of maintaining normal alignment
  - The arches of the foot may collapse and permanent boney deformity may develop
- Orthotic Treatment
  - UCBL
  - Goal
    - Reestablish arches of the foot

Cerebral Palsy
Spastic Diplegia

- Tuning considerations
  - Knee Moments
    - Flexion
    - Extension
  - Shoe Modifications
    - Rockers etc.
    - Assist initiation of swing

Spina Bifida
Spina Bifida
- Myelomeningocele
  - Developmental defect of the spinal cord and vertebral arches
  - Most common in the lumbosacral region
  - Neurological deficit at and distal to the level of injury
  - Prevalence is 1/1000 live births
  - Slightly more common in females 1.3:1
  - $\frac{1}{2}$ w/ a child born w/ mm have a – 5% increased chance of 2nd child w/ a NTD
  - Hydrocephalus present 85%–90% of kids w/ MM
  - 80% of infants w/ MM have ventricular shunt

Spina Bifida
- Categorized by functional level of involvement
  - Thoracic/High Lumbar
  - Low Lumbar
  - High Sacral
  - Low Sacral

Spina Bifida Early Management
- Early Management
  - Determine level of any orthopedic deformities at birth
  - Assess - hip integrity, lower extremity contracture and foot deformities

Driscoll, Novak, Dias
Spina Bifida
Early Management
- Early Management
- Goal
  - Maintain joint alignment
  - Prevent deformity
  - Correct flexible deformities
  - Accommodate fixed deformities
  - Facilitate independent mobility and function
  - Protect the insensate limb

Spina Bifida
Thoracic/High Lumbar
- Typical Presentation
  - Hip Flex/Add – often (+) [L₁ - L₃]
  - Hip Ext - typically (-) [L₂–₅ - S₁]
  - Knee Ext - typically (-) [L₂–₅]
- Goal
  - Position trunk over pelvis and lower limbs

Spina Bifida
Thoracic/High Lumbar
- Ambulatory Potential
  - Although some form of ambulation is possible during early childhood and adolescence, only a small percentage of these patients will ambulate as an adult
  - Due in part to
    - Hip and knee flexion contractures
    - High energy cost of upright mobility

Dias, 2001
**Spina Bifida**

**Short Term Ambulation**

Why do they stop???
- ↑ energy expenditure
- obesity
- height
- contracture
- motivation

When do they stop?
- Second decade of life

-Sillwell and Menelaus

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**Spina Bifida**

**Thoracic/High Lumbar**

- Standing Frame
  - First standing orthosis
  - Consider at about 12 months of age
  - Use w/ AFO S/A to avoid development of varus or valgus deformities of foot and ankle
  - Assists with:
    - Postural Control
    - Trunk Strength
    - Balance and righting reactions (how to fall)
    - Hip joint formation
    - Improved motor skills

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**Spina Bifida**

**Short Term Ambulation**

Benefits of standing and walking for patients above L4
- ↓ joint contracture
- ↑ bowel and bladder function
- ↑ bone density
- ↑ upper ext. strength
- ↑ independence
- ↑ social development

-CAPO
Spina Bifida
Thoracic/High Lumbar

- Parapodium
  - Patient with poor sitting balance
  - Aprox 2 years of age
  - Use with forearm crutches or walker and swing to gait

Spina Bifida
Thoracic/High Lumbar

- Rochester Parapodium
  Short Term Ambulation

Spina Bifida
Thoracic/High Lumbar

- Swivel Walker
  Short Term Ambulation
Spina Bifida
Thoracic/High Lumbar

- RGO
  - Patient with good hands free sitting balance and minimal spinal deformities
  - Permits Reciprocal gait without Gluts or good Hip Flex
  - Hip flexion contracture up to 35°
  - Knee flexion contracture up to 45°
  - Hip flexion contracture ≥ 30° → ↓ stride length → ↑ energy consumption
  - Katz et al (1997) demonstrated that RGO reduced energy consumption as compared to HKAFO

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Spina Bifida
Short Term Ambulation

RGO
- hip flexion = contra. hip ext
- hip ext = contra. hip flex
- trunk extension
- weight shift
Spina Bifida
Thoracic/High Lumbar

- HKAFO
  - Appropriate when a reciprocal gait is not a goal
  - Pelvic band with inferior and superior extensions → ↑ lever arm → improved end point control → ↑ forward flexion of thorax and hips and ↓ lumbar lordosis
  - Controls LE Rotation, Joint motion in sagittal plane, lateral trunk lean
  - Utilize a reverse walker or loftstrand crutch for swing to or swing through gait

Spina Bifida
Low Lumbar

- Usually Active
  - Iliopsoas (L₁₋₂)
  - Quads (L₂₋₄)
  - Hamstrings (L₁₋₂)

- Usually Absent
  - Glut's (L₄₋₅ – S₂)
  - Gastox/Soleus (S₁ – S₂)
  - Ant Tib (L₁₋₁₃)

Spina Bifida - Low Lumbar

- 79% remain community ambulators as adults
- Typical Gait
  - Weak Glut max → anterior pelvic tilt, hip flexion and pelvic obliquity
  - Weak Glut med → lateral trunk lean
  - Weak ankle PF’s → ↑ed hip and knee flexion, ↓ velocity and step length
  - Swing through gait is more efficient in this group than reciprocation (Moore et al, 2001)
Spina Bifida - Low Lumbar

- KAFO
  - Improved control of knee varus and valgus angulations
  - Various knee joints provide different motion control at the knee joint
    - Quads at least ≥ 3+/5 = free knee
    - Quads ≥ 3+/5 = locking knee
    - Dial Locks – used to accommodate knee flexion contractures

Spina Bifida - Low Lumbar

- Single Lateral upright HKAFO
  - Can be used to either internally or externally rotate the limb to improve foot progression angle
  - May provide proprioceptive sensory input to stabilize lower limb

Spina Bifida Low Lumbar

- Ground Reaction AFO
  - Appropriate
    - With good LE alignment
    - Can correct < 5° knee flexion contracture
    - Must accommodate > 5° contracture at the knee
  - Creates a knee extension moment
Spina Bifida - Low Lumbar

• AFO S/A
  • Most common orthotic device for children w/ MM
  • Blocks ankle DF and PF, corrects flexible foot deformities
  • Good swing phase clearance, good stability at mid stance
  • Indication
    • Quads ≥ 3/5
    • HS ≥ 2+/5

Spina Bifida - Low Lumbar

• In children w/ Low Lumbar MM and tibial torsion > 20°, AFO effectiveness was compromised (Vankowski et al, 2000)
• Presence of 30° of external tibial torsion → a 25% reduction in knee axis lever arm
• We would add single lateral upright to the AFO to rotate foot inward and re-establish the PF/KE Couple

Spina Bifida - High Sacral Level

• Typically have active
  • Hip Ext
  • Hip Flex
  • Hip Abd
  • Hip Add
  • Knee Flex
  • Knee Ext

• Typically Absent
  • Dorsiflexors (+/-)
  • Plantarflexors (-)
Spina Bifida - High Sacral Level

- 94% of these children remain community ambulators as adults
- Typically ambulate w/ S/A AFO’s s/ mobility aids
  - AFO F/A is only indicated w/ DF control strap, to block excessive DF and prevent crouched gait

Spina Bifida - Low Sacral Level

- Complete innervation of hip and knee musculature
- Ankle PF and DF are present but they may be weak
- Relatively normal movement around the hip
- Orthosis choice can be difficult
  - S/A AFO - PF’s < 3/5
  - F/A AFO w/ DF Ctrl strap may be OK
  - SAFO – PF’s > 3/5 (no crouch)
  - UCBL – Pronated mid-foot

Spina Bifida

Short Term Ambulation
- Thoracic and upper lumbar levels
- Childhood ambulation

Long Term Ambulation
= L4 and below
- Full quad innervation
Spina Bifida

Long Term Ambulation

- Knee Ext/PF couple
  - crouch gait/single bump
  - dorsiflexion stop/double bump

Barefoot

AFO

-Hullin et al

Spina Bifida

Long Term Ambulation

- Knee Ext/PF couple
  - Tuning considerations
    - Knee Moments
      - Flexion
      - Extension
    - Shoe Modifications
      - Rockers etc
      - Assist initiation of swing

Shoe Modifications

Spina Bifida

Long Term Ambulation

- Insensate Feet
  - Pt and family diligence
  - Always check skin integrity
  - Orthosis occasionally taken away
Muscular Dystrophy

Duschenne Muscular Dystrophy
Progressive
1) Independent ambulation
2) Orthotic assisted ambulation
3) Wheelchair mobility/contracture management

Muscular Dystrophies
- Duchenne Muscular Dystrophy
  - Rapidly progressive
- Becker Muscular Dystrophy
  - More mildly progressive
Duchenne Muscular Dystrophy

- Slightly delayed at 3 to 5 years
- Proximal m. weakness causing limitations in running, jumping and climbing stairs
- Proximal to distal progression of m. weakness leads to
  - Hyperlordosis
  - Equinus
  - M. contractures

Duchenne Muscular Dystrophy

- Early Ambulatory Stage
  - Contractures
    - Develop due to m. imbalance and gradual fibrosis within the muscle
  - Gait
    - Large knee and hip extensor weakness associated with early functional decline
    - Equinus develops due to m imbalance (wk ant tib and peroneals) and need to keep GRF ahead of the knee to create knee extension and stability

Sutherland et al. 1980; Khodadadeh et al. 1986

Duchenne Muscular Dystrophy

Early Ambulatory Phase

- Delayed, clumsy, falls
- Gower’s sign
  - prox muscle weakness
- Pseudohypertrophy
  - calves
- Active stance plantarflexion 2° to quad weakness
- Anterior pelvic tilt and hyperlordosis 2° to hip ext weakness
**Duchenne Muscular Dystrophy**

- Early Ambulatory Stage
  - Providing AFO to correct toe walking is detrimental to the child's mobility and ability to utilize the GRF for stability
  - Combination of passive stretching and AFO's is more effective than passive stretching alone in delaying contracture and prolonging independent ambulation
  - Night AFO's should be offered when the child shows signs of toe walking and/or knee extended ankle range is reduced

- Late Ambulatory Stage
  - As soon as independent ambulation ceases
  - Coupled with surgical releases
  - Light weight KAFOS
  - Prolong ambulation ≈ 2 years
    - ↓ severity of scoliosis
    - ↑ cardiopulmonary function
    - ↓ obesity
    - Slows disease progression

**Typical Gait Pattern**

- Wide base shuffle
- IC - flat foot
- LR - ext knee
- TS & e a r l y heel rise
- Sw - clearance?
Duschenne Muscular Dystrophy

Wheelchair mobility/contracture management
- TLSO/scoliosis concerns
  - Cardiopulmonary concerns
- Hip, knee and ankle contractures progress
  - Continue solid AFO's/night splints
  - Comfort ↑ tolerance
  - Extreme equinovarus hurts

Questions

Thank You