Musculoskeletal Development and Orthopedic Practice

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Goals of Presentation

1. Review musculoskeletal growth and development
2. Review developmental biomechanics related to specific pediatric conditions
3. Present select examination procedures for pediatric musculoskeletal orthopedic conditions
4. Discuss common pediatric musculoskeletal pathology
5. Provide evidence based approach to current concepts of intervention of pediatric musculoskeletal conditions

Musculoskeletal Development

- Maternal Health & Nutrition
- Genetics
- Intrauterine Position & Mechanics
- Mus-Skel Development
- Terminology
- Growth & Health of Fetus
- Gestational Age
Genetics

- General anthropometrics
- Syndromes
  - Down Syndrome - www.ndss.org
  - Achondroplasia - www.marchofdimes.com/professionals/681_1204.asp
  - Osteogenesis Imperfecta - www.oif.org/site/PageServer?pagename=BoneStrut
  - Muscular Dystrophy - www.mdausa.org

Teratogens

- Select Medications
  - Thalidomide, Dilantin, Accutane
- Environmental toxins
  - Mercury, Lead or Arsenic
  - Tobacco & alcohol
- Infection exposure
  - CMV, HIV, Rubella, Toxoplasmosis, STDs

Maternal Health & Nutrition

- Maternal fever > 100 degrees – 1st trimester
  - Arthrogryposis multiplex congenita
- Folic Acid Deficiencies
  - Neural tube defects
  - 3-4 weeks gestational age
  - Sources: orange juice, milk, chicken, green leafy vegetables, whole grains, salmon, tuna, root vegetables, vitamins

http://www.neighborhoodlink.com/article/Homeowner/Teratogens
Interuterine Position & Mechanics

- Fetus size / Uterine Incompatibly
- Breech positioning
- Amniotic Band
- Torticollis
- Plagiocephaly
- Metatarsus adductus

Interuterine Position & Mechanics

Lack of fetal movement:

- Delays Ossification
- Fragile bones
- Malformed Bones
- Joint may not form

Gestational Age

Premature delivery & lack of physiologic flexion & fetal movement

General information on prematurity:
http://www.marchofdimes.com/peristats/Peristats.aspx
Growth & Health of Fetus

- Need appropriate bone and muscle growth for development
- Physiologic flexion is related to normal growth and gestational age at delivery
- Poor fetal health leads to lack of movement and mechanical changes to the musculoskeletal system

Embryology Review

- Zygote (0-2 wks) — Implantation
  - Ectoderm — skin, brain & spinal cord
  - Mesoderm — blood vessels, bone & muscles
  - Endoderm — digestive system, lungs & urinary system

Events of Prenatal Development

- Zygote
- Embryo (2-7 wks) — Major System Development
  - Differentiation of ectoderm, mesoderm, & endoderm
Events of Prenatal Development

- Zygote
- Embryo
- Fetus (8-40 wks)
  - Maturation of systems

Morphologic Abnormalities

- Malformation = abnormal development

Morphologic Abnormalities

- Malformation
- Disruption - breakdown of normal development

www.tanner.hope.twinstuff.com/custom2.html
Morphologic Abnormalities

- Malformation
- Disruption
- Deformation = normal response to abnormal forces

Bone Growth & Development

Mesoderm

Endochondral (Intracartilaginous)  Membranous (Appositional)

Ossification begins around 7-8 wks GA
Premies have less ossification
2nd centers develop in epiphysis postnatally

Endochondral Ossification (Intracartilaginous)

- Formation of cartilaginous model
- Deposition of bone mineral
- Requires supply of O₂ for osteoblasts to form bone
- Osteomyelitis
- Most bones
- Postnatal Length
Intramembranous Ossification (Appositional)

- Deposition of osteoid tissue
- Hardened with calcium phosphate
- Pelvis, sternum, skull
- Post-natal bone thickness / density

Principles of Bone Growth & Remodeling

- Wolff's Law
  - Response to stresses
- Heuter-Volkmann Principle
  - Type of loading matters
- Cantilever Flexure Drift

Spinal Anomalies During Embryogenesis

- Disorders of somatogenesis
- Disorders of vertebral shape:
  - hemivertebrae
  - wedged vertebrae
  - spina bifida occulta
  - missing or fused vertebrae
- Neural tube defects
  - Meningocele
  - Myelomeningocele
  - Myeloschisis
Bone Health Determinants

- Growth
  - Adequate growth & thyroid hormone
- Nutrition & exercise (Raffing et al, 2006)
  - Calcium intake (Greer & Krebs 2006)
- Exercise
  - Preterm babies (Moyer-Miles et al, 2003)
  - Weight bearing (French, et al, 2000)

Who is at Risk for Osteopenia?

- Acute lymphoblastic anemia
- Cancer survivors (Wasilewski-Masker et al, 2008)
- Children with CP (GMFCS levels III – V) (Henderson et al, 2002)
- Crohn’s Disease & Ulcerative Colitis (Boost et al, 1998)
- Juvenile Idiopathic Arthritis (Kotaniemi et al, 1999)

Recommended Calcium Intake

<table>
<thead>
<tr>
<th>Age</th>
<th>Calcium Intake (Mg/day)</th>
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<tbody>
<tr>
<td>0-6 mo</td>
<td>210</td>
</tr>
<tr>
<td>7-12 mo</td>
<td>270</td>
</tr>
<tr>
<td>1.3 y</td>
<td>500</td>
</tr>
<tr>
<td>4-8 y</td>
<td>800</td>
</tr>
<tr>
<td>9-18</td>
<td>1,300</td>
</tr>
<tr>
<td>19-50 y</td>
<td>1,000</td>
</tr>
<tr>
<td>50 – 70 y</td>
<td>1,200</td>
</tr>
</tbody>
</table>

Greer & Krebs, 2006
How do we keep bones healthy?

- Weight bearing
  - Load in Compression, Tension & Torsion
- Greatest modeling with growth
- Stimulus for modeling is strain
- Concept of Minimum Effective Stimulus for modeling and growth
- Dynamic loading / movement is key for modeling & growth

Standing Programs

- Joint modeling
  - Early Static WB may help deepen acetabulum
- Better
  - Early Intermittent WB / with Movement may help more normally shaped joints

- Mineral Density
  - 60 minutes of standing, 4 – 5 times/wk
  - 30 minutes was insufficient

Standing is not a Panacea

- Pin (Ped PT, 2007) & Paleg et al (Ped PT, 2013)
  - Positive for increasing bone mineralization & contractures
  - Generally positive for short term reduction in hand and ankle spasticity
  - Limited to no difference in hand skills
  - Mildly positive for short term changes in gait
  - No conclusive evidence regarding ability to reduce / prevent hip dysplasia, improve bowel / bladder function, improve self-esteem or improve communication
  - Have a plan to DC standing in older individuals if appropriate & needed

Muscle development

- Exercise
- Disease
- Nutrition
- Genetics
- Gender

Disease Determinants

Musculotendinous Growth in Spastic Muscles

- Muscle growth at “Muscle Growth Plate (MGP)”.
- MGP at muscle-tendon junction.
- Growth in spastic muscles only 45% (animal model).

EM Scan of Normal Musculotendinous Junction

Dix & Eisenberg, 1990

EM Scan of MTJ Following Stretch

Myofibrillogenesis

Musculotendinous Growth in Spastic Muscles

- Muscle growth at “Muscle Growth Plate (MGP)”. 18%
- MGP at muscle-tendon junction. 45%
- Growth in spastic muscles only 45% (animal model). 34%

Ziv, 1984
Reliability of Strength Measures

Hand-held Dynamometry:
- CP – Taylor et al, 2004
- MD – Escolar et al, 2001
- SB – Mahoney et al, 2009
- Metcalf, 1988
- McDonald et al, 1986

Isokinetic Testing:
- CP – Ayalon et al, 2000

Manual Muscle Testing

Developmental Biomechanics Refresher

Pelvis / Spine Mobility
Torsion vs Anteversion

**Torsion**
- Twisting of a bone through the long axis
- Femoral head changes position in relation to condyles

**Anteversion**
- Active position of femur relative to frontal plane
- Changes with hip rotation

http://www.gaitways.com/resources/terms.html
**Torsion**


Normal neonate femoral torsion (30 deg)
Normal adult femoral torsion (12 deg)

**Hip Anteversion**

Anteversion occurs with external rotation

Normal neonate = 60 degrees
Normal Adult = 12 degrees


**Newborn Angles**

60 deg anteversion – 30 antetorsion =
net 30 degrees external rotation
(Externally rotated hip position at rest)
**Ryder or Craig Test for Femoral torsion**

- Child is prone with knee at 90
- IR/ER hip until greater trochanter is most prominent
- Measure rotation
- May underestimate femoral torsion by 9-12°
  - Stuberg, 1989

If you measure 25 degrees of hip internal rotation, true femoral torsion may be up to 34-37°

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**Excessive Femoral Antetorsion**

Clinically seen as excessive hip internal rotation and medial facing patellas

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**Tibiofemoral Angle**

- Alignment change
  - Newborn: 10-15 degrees varus
  - 5-7 years: increased valgus 7-10 degrees
  - Adult alignment: 5-7 degrees of valgus

3 years old 5 years old Adult
Foot Angle Progression

- Bisect foot from middle of heel to between 2nd and 3rd toes
- In toeing
  - Mild 1-10 degrees
  - Mod 10-15 degrees
  - Severe > 15 degrees

Cusick & Stuberg, 1992

Thigh-foot angle

- Prone
- Line through long axis of femur
- Line heel through 2nd toe

Cusick & Stuberg, 1992

Transmalleolar Axis

- Line bisecting femur
- Line connecting malleoli
- Line perpendicular to transmalleolar line that bisects heel

Cusick & Stuberg, 1992
Tibio-fibular Torsion (TMA)

- Tibiofibular torsion
  - Newborn: 0-5 deg. Internal
  - 1 year: 6-10 deg. External
  - 2 year: 10-15 deg. External
  - 3-7 year: 15-20 deg. External
  - Adult: 15-25 deg. External

Engel & Staheli 1974 & LeVea7 & Bernhardt 1984

Feet & the Longitudinal Arch

- Newborn foot
  - Hindfoot varus, non-weight bearing
  - Mild, flexible forefoot adductus
  - Hindfoot valgus in weight-bearing with no longitudinal arch

What about that arch?

- Normative data on longitudinal arch development
  - Hindfoot valgus up to 7 deg at birth in weight bearing and decrease 1 deg per year (Valmassey, 1982)
  - Hindfoot valgus below 5 +/- 2 degrees in childhood (Kanati et al, 2006)
  - Arch Index (Looper et al, 2012)
Overview of Select Orthopedic Measures & Conditions

Torticollis

- Unilateral shortening of the SCM muscle
  - Head tilt toward involved side and face rotated away
- Osseous
  - Congenital malformation of vertebrae
- Neurogenic
  - CNS tumor, Arnold-Chiari malformation, syringomyelia or dystonia

Torticollis

- Management principles / options
  - Positioning & active movement away from deformity pattern
    - eg. Head rotation to opposite side of rotation & tilt for bottle feeding & positioning in crib. Tummy time
  - Gentle manual therapy
  - Orthotic support
  - Biofeedback
  - Medical
    - Surgical or injections
Positional Deformity of Head

- Management principles / options
  - 80% of brain's growth in first 13 months
  - Decision tree on management (van Vlimmeren et al, 2006)
  - Positioning away from deformity pattern
  - Orthotic support (4-13 months)
  - FDA Approved devices
  - Surgical

Scoliosis

Forward Bend Test – scoliometer result of 7° correlates to 20° curve = referral (Glancy, 2007)

Scoliosis – Curve Progression

- Progression related to residual growth of spine
- Risser Sign to determine stage
  - Curve <25 deg; observe
  - Orthotic between 25 - 50 degrees
  - Surgical intervention if curve progresses > 50 degrees

Risser Sign = calcification of iliac apophysis. 1 = 25% to 5 = complete and fused to ilium.
### Scoliosis

- Bracing 23 hrs/day stops progression of 90% of 20-35 degree curve
- Compliance can be major issue ranging from 8 to 90% (Nicholson, 2003)
- Over 50% of untreated spines progress (Rowe et al, 1997)

### Leg Length Discrepancy

**General Intervention Guidelines**
- 0-2 cm: No treatment
- 2-4 cm: Shoe lift
- 2-6 cm: Epiphysiodesis on long side
- 6-20 cm: Lengthening procedure (Ilizarov) that may / may not be combined with other procedures
- >20 cm: Prosthetic fitting
Patella Alta

Over-lengthening of the patellar ligament common in crouch gait with CP

Developmental Hip Displasia (DHD)

- Radiographic Presentation
  - Shallow Acetabulum
  - Flat femoral head
  - Antetorsion (30 deg)
  - Anteversion (60 deg)
  - High neck shaft angle

- Clinical Presentation
  - Asymmetrical hip abduction & skin folds
  - Positive Ortolani test

Galeazzi Test
Ortolani Test

1. Begin in hip flexion and adduction with child relaxed.
2. Slowly adduct hip & feel for “click” as femoral head moves back into the acetabulum.

DHD Intervention

- Pavlik harness
  - Best under 6 months of age
  - Wear 24 hours/day
- Surgery
  - After 6 months closed reduction
  - After 2 years open reduction

Legg-Calve Perthes

- Avascular necrosis of the femoral head
- Pressure and asymmetric growth
  - Short, thickened femoral neck (coxa vara)
  - Enlarged femoral head (coxa magna)
- Normal growth of greater trochanters
- Possible leg length discrepancy

www.medmedia.com/orthoo/2221.htm
LCP – Clinical Presentation

- Limping
- Limitation of hip IR, Ext & Abduction
- + Trendelenburg with gait
- Pain complaint
  - Anterior thigh or referred to knee

LCP - Management

- Pain Management
- Maintain / Restore ROM
  - Traction
  - Gait training & stretching
- Bracing (controversial (Nelitz et al, 2009))
  - Femoral head containment
  - ABD brace with hip IR
- Operative
  - Femoral varus osteotomy or pelvic osteotomy

Slipped Capital Femoral Epiphysis

www.xray2000.f9.co.uk/index.htm
SCFE Severity

Grade 1 (mild) – up to 1/3 of femoral head slips off of the thigh bone (A)

Grade 2 (moderate) – 1/3 to 1/2 of head slips off (B)

Grade 3 (severe) - ½ slips off (C)

SCFE

- Presentation
  - Boy who is obese between age of 10 & 15 years
  - Limping & complaint of thigh or knee pain
  - Limb held externally rotated
  - Limitation of hip flex, IR & Abduction

- PT Management
  - Reduce weight bearing with crutches
  - Pain management
  - Restore ROM

SCFE – Medical Management

- Deformity is the displacement of the femoral head posteriorly and inferiorly
- Antalgic gait with excessive hip external rotation
- Surgical management if acute
**Osgood – Schlatter Disease**

- Stress related inflammation of tibial tuberosity
- Pain with palpation / contraction
- Adolescence growth spurts
- Intensifies with exercise
- Male > Female
- Athletes

**Intervention**

- Rest, Ice, Quad strengthening, time

[www.familydoctor.org/handouts/135.html](http://www.familydoctor.org/handouts/135.html)

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**Blount Disease (Tibia Vara)**

- Idiopathic bowing of the tibia
  - Metaphysial-diaphyseal angle > 11°
  - Femoral-tibial angle with excessive varus

- **Management**
  - Orthotic (KAFO)
  - Tibial osteotomy

[www.radiology.vcu.edu/02-19-03.htm](http://www.radiology.vcu.edu/02-19-03.htm)

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**Osteogenesis Imperfecta**

- Genetic disorder of collagen structure or amount
- Also know as “brittle bone” disease
- Significant variability in clinical presentation leading to multiple classification systems

[www.brittlebone.org](http://www.brittlebone.org)
Osteogenesis Imperfecta (OI)
Classifications

**Congenita**
- Severe form
- Blue sclera
- Dentinogenesis imperfecta
- Long bone deformities

**Tarda**
- Type 1
  - Dentinogenesis imperfecta
  - Short stature
  - LE bowing
- Type 2
  - Normal teeth
  - Few fractures

Osteogenesis Imperfecta (OI) - Non-Operative Management

- **Goal** - prevent/ minimize deformities, and maximize functionality at home & community
- **Non-Operative Management**
  - Bisphosphonates
  - PT
  - Orthotics
- **Operative Management**
  - Scoliosis & rod placement surgical intervention

Arthrogryposis multiplex congenital

- Multiple contractures & occasionally amyoplasia
- Treatment including;
  - PT Management
  - ROM & splinting
  - Exercise
  - Orthotics
  - Surgical intervention

www.geocities.com/SouthBeach/Surf/7325/jamielee.html
Juvenile Idiopathic Arthritis

- Arthritis causing joint inflammation & stiffness >6 wks. in child < 16 years
- Lab tests helpful, but may be inconclusive
  - Antinuclear Antibody (ANA), Rheumatoid Factor (RF) & Erythrocyte Sedimentation Rate (ESR)
  - X-ray
- Treatment with Medication, PT, exercise & splinting
- Exercise to include stretching, positioning, strengthening & aerobics

www.arthritis.org

Juvenile Idiopathic Arthritis

- Diagnostic Categories:
  - Pauciarticular
    - Four or fewer joints affected
    - Usually affects large joints
    - Girls under age 8 most commonly affected
  - Polyarticular
    - Five or more joints affected
    - Usually affects small joints
  - Systemic
    - Fever, rash and internal organs usually affected
    - May persist into adulthood

Juvenile Idiopathic Arthritis

- Regular exercise recommended (Feldman 2007; Klepper 2003; Gennoni, 2007 & Takken 2003):
  - Decrease pain & improved functional skills
  - Improved parent perceptions of child’s well being & improved child’s quality of life
  - Improved aerobic capacity
  - Improved bone mineralization

Takken 2003
Spina Bifida

- Spina Bifida Cystica
  - L 3-4 common lesion level
  - High incidence of hip flexion contracture, hip dislocation & calcaneovalgus foot deformity
  - Children typically do not maintain walking for mobility into adolescents if antigravity quads are lacking

Lesion Level & Ambulation Prognosis

<table>
<thead>
<tr>
<th>Level</th>
<th>Orthosis</th>
<th>Device</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 &amp; Above</td>
<td>PampeoRtum Standing Frame HKAFOs</td>
<td>Parallel Bars Walker Forearm Crutches</td>
<td>Household or Non walker</td>
</tr>
<tr>
<td>L2-3</td>
<td>As Above</td>
<td>As Above</td>
<td>Household</td>
</tr>
<tr>
<td>L3-4</td>
<td>RGO KAFO</td>
<td>Forearm Crutches</td>
<td>Household or Community</td>
</tr>
<tr>
<td>L5 &amp; Below</td>
<td>AFO None</td>
<td>None</td>
<td>Community</td>
</tr>
</tbody>
</table>

Deformity and Ambulation

- Lesser support is not desirable
- Goal to minimize progressive deformity & arthritic changes.
Duchene’s Muscular Dystrophy

- X-linked recessive disorder with absent protein dystrophin
- Diagnosis between 3 to 5 years
- Gower's sign & pseudohypertrophy of the posterior calf musculature
- Difficulty keeping up with peers, stair climbing & running
- Toe walking & progressive weakness leading to contracture formation

Medical Management

- Corticosteroids (prednisone or deflazacort)
- Adverse problem with obesity
- Surgical management of scoliosis

PT Management

- Night splints
- Exercise tolerance & prescription
- Power mobility
- Pulmonary exercise
- Assist school & family with ADL modifications

Spinal Muscular Atrophy

- Autosomal recessive disorder with absent or damaged protein SMN
Spinal Muscular Atrophy

<table>
<thead>
<tr>
<th>Type</th>
<th>Onset</th>
<th>Death</th>
<th>Motor Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 - Werdnig-Hoffman</td>
<td>0-6 month</td>
<td>&lt;2 years</td>
<td>Usually doesn’t sit</td>
</tr>
<tr>
<td>Type 2 - Werdnig-Hoffman</td>
<td>7-18 months</td>
<td>&gt;2 years</td>
<td>Usually doesn’t stand</td>
</tr>
<tr>
<td>Type 3 - Kugelberg-Welander</td>
<td>&gt;18 months (5-10 years)</td>
<td>Adult</td>
<td>Generally walks &amp; stands alone</td>
</tr>
</tbody>
</table>

**Spinal Muscular Atrophy**

- **PT Intervention**
  - **Type 1**
    - Positioning, postural drainage, adaptive equipment & developmental activities
  - **Type 2**
    - Developmental activities, strengthening (swimming), contracture prevention, adaptive equipment & power mobility with custom seating
  - **Type 3**
    - Activity precautions for PE at school, strengthening, mobility equipment & orthotics as indicated

**Suggested References for PCS**

- **Text**
  - Campbell’s *Physical Therapy for Children*
  - Techlin’s *Pediatric Physical Therapy*
  - Ratliffe’s *Clinical Pediatric Physical Therapy*
  - Cusick’s *Progressive Casting & Splinting for Lower Extremity Deformities in Children with Neuromotor Dysfunction*
  - Magee’s *Orthopedic Physical Assessment*
  - ABPTS’s *Pediatric Advanced Clinical Competencies & Description of Specialty Practice in Pediatrics*
  - APTA’s *Topics in Physical Therapy: Pediatrics*
Acknowledgment
This presentation includes a collaborative effort of materials prepared by Carrie Gajdosik, Linda Pax Lowes, Margo Orlin and Wayne Stuberg