Purpose

To describe gait pathology in CP in terms of primary, secondary and compensatory deviations.

Pathological Gait

video

Objectives:

- Define primary and secondary deviations and compensations seen in gait
- Differentiate between primary deviations that need to be treated and other gait deviations that will resolve if the primary problem is addressed
- Understand common multi-level gait patterns in CP
- Describe how motion analysis can help us understand primary vs. secondary gait deviations
Primary, Secondary and Compensatory Gait Deviations in CP

Outline

• Review of fundamentals for joint kinematics including angle definitions and plotting conventions.
• Review of typical joint kinematic patterns.
• Define, primary, secondary and compensatory gait deviations.
• Case Examples

Angle definition

• The specific body segments that make up the angle
• With consideration for the orientation of the “viewer” when looking at the angle

Joint Angle Definitions

Which one?

Joint Angle Definitions

• Kinematics for the trunk, pelvis, hip, knee and ankle/foot progression
• Coronal, sagittal, transverse planes
• Stance and swing phases of gait

Trunk Motion

Knee Flexion/Extension

What is this angle definition?
Primary, Secondary and Compensatory Gait Deviations in CP

Trunk Coronal Plane

- **Angle Definition**
  - the lateral (side to side) inclination of the long axis of the torso relative to the lab coordinate system
  - as viewed from the front and perpendicular to the plane formed by the long axis of the torso and the bi-clavicular line

Trunk Sagittal Plane

- **Angle Definition**
  - the forward inclination of the long axis of the torso relative to the lab coordinate system
  - as viewed by an observer looking along a line connecting the clavicles

Trunk Transverse Plane

- **Angle Definition**
  - the motion of the bi-clavicular line relative to the lab coordinate system
  - as seen by an observer looking down the long axis of the torso looking from above

Pelvic Motion

Pelvis Coronal Plane

- **Angle Definition**
  - Angle of inclination of the right and left anterior superior iliac spine (ASIS) in relation to the horizontal
  - As viewed from the front of and in the pelvic plane
Primary, Secondary and Compensatory Gait Deviations in CP

Pelvis Sagittal Plane
- Angle Definition
  - inclination (typically anterior) of the pelvic plane with respect to the horizontal
  - as viewed by an observer looking along a line connecting the ASIS's

Pelvis Transverse Plane
- Angle Definition
  - motion of the ASIS to ASIS line relative to the lab coordinate system (direction of progression)
  - as viewed by an observer whose site line is perpendicular to the pelvic plane

Pelvis
- Coronal (range of motion 8 degrees)
- Sagittal (range of motion 4 degrees)
- Transverse (range of motion 8 degrees)

Hip Motion
- Stance
  - LR = adduction
  - MST/TST/PS = abduction
- Swing
  - ISW = abduction
  - MSW/TSW = adduction
- ROM = 13°

Hip Coronal Plane
- Angle Definition
  - relative angle between long axis of the thigh and a perpendicular to the pelvic plane
  - as viewed from the front of and in the pelvic plane

Hip Coronal Plane Kinematic
- Stance
  - LR = adduction
  - MST/TST/PS = abduction
- Swing
  - ISW = abduction
  - MSW/TSW = adduction
- ROM = 13°
Primary, Secondary and Compensatory Gait Deviations in CP

Hip Sagittal Plane

- **Angle Definition**
  - relative angle between the long axis of the thigh and a perpendicular to the pelvic plane
  - as viewed by an observer looking along a line connecting the ASIS's

Hip Sagittal Plane Kinematic

- **Stance**
  - LR/MST/TST = extension
  - PS = flexion
- **Swing**
  - ISW/MSW = flexion
  - TSW = minimal extension
- **ROM = 43°**

Hip Transverse Plane

- **Angle Definition**
  - motion of the thigh (as defined by the knee flexion extension axis) relative to the ASIS - ASIS line
  - as viewed by an observer in the pelvic plane

Hip Transverse Plane Kinematic

- **Stance**
  - LR = internally rotates
  - MST/TST = internally rotated
  - PS = externally rotates
- **Swing**
  - ISW = internally rotates
  - MSW/TSW = externally rotates
- **ROM = 8°**

Knee Motion

- **Angle Definition**
  - relative angle between long axis of the shank and the long axis of the thigh
  - as viewed from the front of in the thigh plane

Knee Coronal Plane
Knee Coronal Plane Kinematic

- Motion
  - negligible
- Position
  - neutral

Knee Sagittal Plane

- Angle Definition
  - relative angle between the long axis of the thigh and shank segments
  - as viewed by an observer looking along the knee flexion/extension axis

Knee Sagittal Plane Kinematic

- Stance
  - LR = flexion
  - MST/TST = extension
  - PS = flexion
- Swing
  - ISW = flexion
  - MSW = extension
  - TSW = extension
- ROM = 60°

Knee Transverse Plane

- Angle Definition
  - motion of the shank (as defined by the ankle dorsi/plantar flexion axis) relative to the knee flexion extension axis line
  - as viewed by an observer above the thigh plane

Ankle Motion/Foot Progression

Knee Transverse Plane Kinematic

- Stance
  - LR/MST/TST = progressive internal rotation
- Swing
  - ISW/MSW/TSW = progressive external rotation
- ROM = 11(5)°
Primary, Secondary and Compensatory Gait Deviations in CP

Ankle Sagittal Plane

- **Angle Definition**
  - the relative angle between a perpendicular to the long axis of the shank and the plantar aspect of the foot
  - as viewed by looking along an axis perpendicular to the shank-foot plane

Ankle Sagittal Plane Kinematic

- **Stance**
  - LR = plantar flexion
  - MST/TST = dorsiflexion
  - PS = plantar flexion
- **Swing**
  - ISW = continued plantar flexion then dorsiflexion
  - MSW = dorsiflexion to neutral
  - TSW = minimal plantar flexion
- **ROM = 30°**

Foot Progression

- **Angle Definition**
  - angle between the long axis of the foot (ankle center along to space between 2nd and 3rd metatarsals) and the direction of progression

Foot Progression Kinematics

- **Stance**
  - LR/MST/TST = progressive external rotation
  - PS = internally rotates
- **Swing**
  - ISW/MSW = externally rotates
  - TSW = internally rotates
- **ROM = 6°**

- Trunk, pelvis, hip, knee and ankle/foot progression
- Coronal, sagittal, transverse planes

Pathological Gait

Can be very complicated!
Primary, Secondary and Compensatory Gait Deviations in CP

Definitions

• Primary Deviation – kinematic abnormality related to the impairment at the joint
• Secondary Deviation – kinematic abnormality at another joint that is a direct result of a primary deviation
• Compensation – kinematic abnormality that is voluntary that helps reduce impact of primary deviation

Primary Deviation

• Kinematic abnormality related to the impairment at the joint
• For example:
  – Impairment: Internal femoral torsion/femoral anteversion (65 internal)
  – Associated kinematic abnormality – Primary Deviation: excessive internal hip rotation

Secondary Deviation

• Kinematic abnormality related to the impairment at the joint
• For example:
  – Impairment: Internal femoral torsion/femoral anteversion (65 internal)
  – Associated kinematic abnormality – Primary Deviation: excessive internal hip rotation
  – Secondary Deviation: excessive internal foot progression

Voluntary Compensation

• Kinematic abnormality that is voluntary that helps reduce impact of primary deviation
• For example:
  – Vault – early plantar flexion in mid stance to aid in clearance of the contralateral (swing) limb
  – Circumduction – hip abduction in swing to aid in clearance of the ipsilateral limb
  – Increased pelvic transverse plane range of motion over the full gait cycle to increase step length
  – Increased hip flexion in swing to aid in clearance of the ipsilateral limb

Case Examples
Primary, Secondary and Compensatory Gait Deviations in CP

Pre-requisites of Typical Gait Which are compromised?

- Stance phase stability
- Swing phase clearance
- Appropriate pre positioning of the foot at initial contact
- Adequate step length
- Energy conservation

(Perry, Gait Analysis:Normal and Pathological Function, 1992)

Primary Deviation - Increased Equinus in Swing

Sagittal Plane Ankle Kinematic

- Primary deviation: increased equinus in swing

(Gray band = reference data)

Impairment

- Ankle dorsiflexor weakness
  - Weakness of the ankle dorsiflexors during isolated voluntary dorsiflexion
  - No flexor synergy (negative confusion test) possible
  - More common in hemiplegia than diplegia

Primary Deviation – Increased Equinus in Stance & Swing

Sagittal Plane Ankle Kinematic

- Primary deviations: increased equinus in stance and swing

(Gray band = reference data)
Primary, Secondary and Compensatory Gait Deviations in CP

Impairment

- Ankle plantar flexor contracture
  - Limited passive ankle dorsiflexion range of motion on clinical assessment
  - Example:
    - -10 degrees with knee flexed
    - -20 degrees with knee extended
  - Typical value = 20 degrees (Hoppenfeld, 1976)

Primary Deviation

- Increased Equinus and Knee Hyperextension in Stance

Knee & Ankle Sagittal Plane Kinematics

- Primary deviations: increased equinus in stance & swing, knee hyperextension (increased plantar flexion knee extension couple)

Impairment

- “Dynamic” ankle plantar flexor “contracture”
  - Typical passive ankle dorsiflexion range of motion on clinical assessment
  - Example: 20 degrees with knee flexed and extended
  - Increased spasticity of the ankle plantar flexors
  - Sustained clonus
  - Positive confusion response (flexor synergy)

Primary Deviation: Increased Plantar Flexion-Knee Extension Couple

- Sagittal Plane Pelvis, Hip, Knee and Ankle
  - Primary Deviation: increased equinus and knee extension in mid stance
  - Secondary Deviation: increased anterior pelvic tilt
Primary, Secondary and Compensatory Gait Deviations in CP

**Impairment**
- Increased ankle plantar flexor spasticity and tightness

**Primary Deviation: Increased Plantar Flexion/Knee Extension Couple**

**Sagittal Pelvis, Hip, Knee and Ankle**
- Primary Deviation: increased equinus and knee hyperextension in stance (solid)
- Secondary Deviations: ipsilateral increased anterior pelvic tilt in stance (solid), increased contralateral pelvic anterior tilt and increased contralateral hip flexion in swing (dashed)

**Impairment**
- Increased ankle plantar flexor tightness and spasticity

**video**

**Primary Deviation: Increased Plantar Flexion-Knee Extension Couple**
- Video 387121 – asked Jess

**Sagittal and Transverse Kinematics**
- Primary Deviation: increased plantar flexion knee extension couple
- Secondary Deviation: external pelvic rotation (retraction) in stance

**video**
Primary, Secondary and Compensatory Gait Deviations in CP

**Impairment**

- Increased plantar flexion knee extension couple – ankle plantar flexor tightness/spasticity

**Primary Deviation - Increased Knee Flexion/Ankle Dorsiflexion Stance**

**Impairments**

- Impairment – issues related to crouch gait
  - tight/spastic hamstrings
  - knee flexion contracture
  - ankle plantar flexor weakness

**Sagittal Plane Hip, Knee & Ankle**

- Primary Deviation: Increased ankle dorsiflexion and knee flexion
- Secondary Deviation: Increased hip flexion

Right side – multiple gait cycles

**Primary Deviation: Increased Peak Dorsiflexion Stance**

**Sagittal Knee and Ankle**

- Primary deviation: increased ankle dorsiflexion in stance
- Secondary deviation: increased knee flexion in stance
Impairments

- Impairment –
  - Increased ankle passive dorsiflexion ROM: 20 degrees
  - Ankle plantar flexor weakness: 1/5
  - No knee flexion contractures
  - Popliteal angles: right -30 deg, left -40 deg

Primary Deviation – Reduced Hip Range of Motion

video

Sagittal Plane Pelvis and Hip

- Primary Deviation: decreased hip sagittal plane ROM (solid)
- Secondary Deviations: increased ipsilateral anterior pelvic tilt and overall pelvic range of motion (solid) and increased contralateral hip range of motion (dashed)

Impairment

- Reduced dissociation between pelvis and femur

Primary Deviation: Internal Right Hip Rotation

video

Transverse Plane Pelvis, Hip, Knee and Ankle

- Primary Deviation: increased internal hip rotation
- Secondary Deviation: internal foot progression

(3 gait cycles right side)
Primary, Secondary and Compensatory Gait Deviations in CP

**Impairment**
- Internal femoral torsion

**Primary Deviation:**
- Internal Right Hip Rotation
- [video]

**Transverse Plane Pelvis & Hip**
- Primary Deviation: increased internal hip rotation (solid - right)
- Compensation: increased ipsilateral external pelvis rotation (solid) and increased contralateral internal pelvic rotation (dashed)

**Impairment**
- Increased femoral anteversion in hemiplegia
- Example: 55 degrees of femoral anteversion on right side

**Primary Deviation:**
- Transverse Plane Multiple Level Deformity

**Transverse Plane Pelvis, Hip, Knee and Ankle**
- Primary Deviation: internal hip rotation
- Combination of internal femoral torsion and external tibial torsion mask multilevel rotational deformity

(AACPDMA 2017 - IC #3)
Impairment

- Increased femoral anteversion and increased external tibial torsion/forefoot abduction
- Example: 55 degrees of femoral anteversion and 30 degrees of external tibial torsion on left side

Primary Deviation:
Internal Hip Rotation/Crouch

video

Coronal/Sagittal/Transverse Plane Kinematics

- Primary deviations: internal hip rotation and increased knee flexion 100% gait cycle
- Secondary deviations: increased hip adduction 100% gait cycle

Impairment

- Increased femoral anteversion
- Increased hamstring tightness/spasticity
- Hip extensor/plantar flexor weakness
- Example: 55 degrees of femoral anteversion, knee flexion contracture 15 degrees

Primary Deviation - Increased Coronal Pelvic ROM

video

Coronal Plane Pelvis and Hip

- Primary Deviation: Increased hip adduction in loading response, bilaterally and increased pelvic range of motion
- Secondary deviation: increased hip abduction in swing
Primary, Secondary and Compensatory Gait Deviations in CP

Impairment

- Hip abductor weakness
- Example: 3/5 on MMT

Compensation

Compensation: Increased Hip Flexion in Swing

video

Compensation: Toe Walking Typically Developing Side

video

Sagittal Pelvis, Hip, Knee and Ankle

- Primary Deviation: increased equinus in swing (solid)
- Compensation: increased hip flexion in swing (solid)

Impairment

- Anterior tibialis weakness and plantar flexor tightness
Primary, Secondary and Compensatory Gait Deviations in CP

**Sagittal Plane**

- Compensation: voluntary equinus through out stance on the non-involved right side (solid line)
- Goal: provide symmetry in gait and reduced vertical displacement of the COM from one gait cycle to the next

**Impairment**

- Plantar flexor contracture on the involved (left) side
- Confirmation of compensation:
  - Normal isolated voluntary control
  - Normal strength
  - Ability to dorsiflex the ankle in swing
  - Can “Dr. Walk” – heel contact gait possible

**Compensation: Vault Typically Developing Side**

- Voluntary equinus in stance on the non-involved right side (solid line)
- Goal: to allow clearance of the contralateral swing limb which has a) reduced/delayed peak knee flexion and b) increased equinus in swing

**Sagittal Plane**

- Gait issues on the involved (hemi side) that benefit from a vault on the typically developing side

**Impairments**

- Plantar flexor contracture on the involved (left) side
- Reduced peak knee flexion in swing on the involved (left) side
- Confirmation of compensation: (on typically developing side)
  - Normal isolated voluntary control at ankle
  - Normal strength at ankle
  - Ability to easily heel rise in single limb standing
  - Normal ankle dorsiflexion at initial contact and ability to dorsiflex in swing
Primary, Secondary and Compensatory Gait Deviations in CP

Compensation: Increased Hip Abduction Swing

video

Coronal and Sagittal Kinematics

• Compensation: increased hip abduction in swing (circumduction)
• Goal: to aid in clearance of the ipsilateral limb during swing phase which shows limited and delayed peak knee flexion

Impairment

• Delayed and reduced peak knee flexion in swing on the ipsilateral side due to rectus femoris activity in mid-swing

Compensation: Increased Transverse Pelvic ROM

video

Sagittal & Transverse Kinematics

• Compensation: increased transverse plane pelvic range of motion
• Goal: to increase step length and associated walking velocity that is limited due to decreased knee extension at initial contact

Impairment

• Reduced knee extension at initial contact bilaterally due to spasticity of the hamstrings and reduced passive range of knee extension
How does one “differentiate” between primary and secondary deviations and compensations?

- Knowledge of typically developing function and gait
  - Clinical exam (strength, ROM, etc.)
  - Gait function (kinematics, kinetics, EMG, etc.)
  - In the context of the phases of the gait cycle
- Detailed understanding of the patient’s impairments and gait
  - Using measures as above

Con’t

- Development of a systematic approach to understanding this information
- Also include
  - Pre versus post surgical data comparisons
  - Barefoot versus orthosis data comparisons
  - Lift versus no lift data comparisons
  - Etc…

Pathological Gait

video

Thank You