Evaluation of Orthosis Function in Children with Neuromuscular Disorders Using Motion Analysis Outcomes

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Outline
• Terminology
• Methods
• Typically developing
• Case examples – variety of pathologies

Case Studies
• Examine the role of joint kinematics and kinetics in orthosis prescription and evaluation of orthosis function
• Variety of pathologies
  – Myelomeningocele
  – Cerebral palsy
  – Charcot-Marie-Tooth
  – Down’s Syndrome
• Focus on the joint(s) of interest
• Examples of both “good” and “poor” orthosis prescriptions

Pre-requisites of Typical Gait
• 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)

Case 1 – L5 Myelomeningocele
• Impairments:
  – Ankle plantar flexors/dorsiflexors: 0/5
  – Forefoot invertors/evertors: 0/5

Case 1 – L5 Myelomeningocele
• Stance phase stability?
• Swing phase clearance?
• Appropriate pre positioning of the foot at initial contact
• Adequate step length?
• Energy conservation?

video
Orthosis Evaluation Using Motion Analysis - Part 2

Sagittal Ankle Kinematics/Kinetics
- Increased peak dorsiflexion in terminal stance
- Excessive equinus in mid swing
- Minimal peak plantar flexor moment in terminal stance
- Minimal peak power generation in terminal stance

Solid Ankle-foot-orthosis (AFO)
- Goal: limit ankle sagittal plane motion stance and swing and provide medial/lateral stability in stance
- Anterior entry
- Support strapping at proximal end and sometimes at ankle and forefoot

Bilateral Solid AFO’s
- Stance phase stability?
- Swing phase clearance?
- Appropriate pre positioning of the? foot at initial contact
- Adequate step length?
- Energy conservation?

Mechanical Basis Behind AFO’s
- AFO’s provide the force required to produce an ankle plantar flexor moment
- Therefore, weight bearing on the distal aspect of the foot is possible

BF vs. AFO Ankle Kinematics/Kinetics
- Normal peak dorsiflexion in terminal stance
- Normal dorsiflexion in mid swing
- Normal peak plantar flexor moment in terminal stance
- Minimal peak power generation in terminal stance

Case 1 - Summary
- The AFO allows for weight bearing on the distal aspect of the foot and associated improved stability by providing a net internal plantar flexor moment
- There are also associated benefits at the knee and increased walking velocity due to increased step lengths
- Conclusion: the solid AFO is a good solution for this patient
Impact of Joint Kinetic Data

The joint kinetic data (GRF and C of P) provided an understanding of the extent of weight bearing during barefoot walking and how that changes with the addition of an AFO. This information provides a mechanical basis for understanding the increased stability experienced by the patient with the AFO and the associated impact of being able to provide an internal plantar flexor moment at the ankle.

Case 2 – L4 Myelomeningocele

- Impairments:
  - Ankle plantar flexors, dorsiflexors (0/5)
  - Forefoot invertors, evertors (0/5)
  - Knee flexors (2/5)
  - Hip extensors (1/5), abductors (0/5), hip flexors (4/5)
- Substantial compensations at the trunk and pelvis

Case 2 - L4 Myelomeningocele

video

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

Barefoot Ankle/Knee Kinematics/Kinetics

- Excessive knee flexion in stance
- Knee extensor moment pattern and increased power absorption
- Excessive and delayed dorsiflexion in terminal stance
- Excessive equinus in swing
- Minimal peak plantar flexor moment and power generation in terminal stance

Hinged ankle-foot-orthosis (H-AFO)

- Goal: articulated ankle joint that allows for sagittal plane dorsiflexion in stance and eliminates plantar flexion in swing
- Support strapping at proximal tibia and sometimes at ankle and forefoot
- May have posterior strap to limit dorsiflexion range

Bilateral Hinged AFO’s

video

- Stance phase stability?
- Swing phase clearance?
- Appropriate pre positioning of the? foot at initial contact
- Adequate step length?
- Energy conservation?
Orthosis Evaluation Using Motion Analysis - Part 2

**BF vs. HAFO Ankle Kinematics/Kinetics**

- Reduced excessive equinus in swing
- Increased plantar flexor moment in stance

**BF vs. HAFO Knee Kinematics/Kinetics**

- No change - Ongoing excessive knee flexion/knee extensor moment and power absorption

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**Case 2 - Summary**

- Improved medial/lateral ankle stability and equinus in swing
- Excessive ankle dorsiflexion and knee flexion in stance not addressed with H-AFO’s
- Continued inability to weight bear over distal foot because of lack of plantar flexor moment
- Conclusion: solid AFO’s recommended to provide internal ankle plantar flexor moment to reduce excessive ankle dorsiflexion and associated knee flexion

**Case 3 – L4 Myelomeningocele**

- Impairments: (strength – MMT)
  - Ankles plantar flexion/dorsiflexion: 0/5
  - Ankles inversion/eversion: 0/5
  - Knee flexion: 4/5
  - Knee extension: right 5/5
  - Hip flexion: 4/5
  - Hip extension: right 2/5, left 4/5
  - Hip abduction: 2/5
- Impairments: (passive range of motion)
  - Right knee extension: -5 deg

**Case 3 – L4 Myelomeningocele**

- The knee valgus thrust has been associated with the cause of knee pain and reduction in ambulation in persons with myelomeningocele
- The KAFO has been used to minimize this moment
- Coronal plane knee kinetics can allow us to document this problem

**Is there a knee valgus thrust?**

“Visual” vs. “Actual”? KAFO? Knee coronal plane moment?
Knee Coronal Kinematics and Kinetics

- Net internal knee coronal plane moment is abductor
- Visual valgus thrust not substantiated by an abnormal knee moment
- Does this person need a KAFO to protect the knee in the coronal plane?

(Ounpuu et al, JPO 2000)

Associated Complex Kinematics

- Simultaneous motion of
  - Internal pelvis
  - Internal hip
  - Knee flexion

Impact of Joint Kinetics

The knee coronal plane moment indicates that there was not an "actual" knee valgus thrust occurring during ambulation. Since there are no abnormal coronal plane knee moments, there is no mechanical basis for recommending the KAFO to protect the medial aspect of the knee.

There may, however, be another basis for recommending a KAFO, for example, reduce transverse plane motion at the knee.

(Thomson et al, JPO, 1999)

Knee-ankle-foot Orthosis: KAFO

- Solid ankle
- Free knee flexion-extension
- Medial and lateral uprights at knee
- Thigh cuff

Case 3 - Summary

- Motion analysis allows for documentation of the presence of a kinetic knee valgus thrust – evidence for the need of supporting the medial knee with a KAFO
- Conclusion: For this patient a solid AFO would be adequate to provide sagittal plane improvements for gait function at this point in time
- May be negative implications for transverse plane knee

(Thomson et al, JPO, 1999)

Case 4 – Cerebral Palsy GMFCS II

- Impairments: (strength – MMT)
  - Ankles plantar flexion: 3/5
  - Ankles dorsiflexion: 5/5
  - Knee flexion: 4/5
  - Knee extension: 5/5
  - Hip flexion: 5/5
  - Hip extension: 4/5
- Impairments: (passive range of motion)
  - Ankle dorsiflexion: -10 deg (knee flexed and extended)
  - Knee extension: 0 deg

(Thomson et al, JPO, 1999)
Case 4 - Cerebral Palsy GMFCS II

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

Barefoot Kinetics - Ankle

- Premature plantar flexion in mid-stance
- Excessive equinus in terminal swing and resultant toe initial contact
- Associated “double bump” ankle moment pattern, excessive power absorption and generation MST

Barefoot Kinetics – Knee

- Increased knee flexion at IC
- Abnormal knee flexor moment and power absorption

Posterior Leaf Spring (PLS)

- Goal: limit excessive equinus in swing
- Trim line posterior to medial and lateral malleolus
- Thinner ankle coverage that allows sagittal plane motion in dorsiflexion during weight bearing
- Support strapping at proximal tibia

Bilateral PLS Walk Cerebral Palsy

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

Barefoot vs. PLS – Ankle Kinematics/Kinetics

- Elimination of excessive equinus in swing and initial contact
- Elimination of quick stretch on ankle plantar flexors and premature plantar flexion
- Continued power generation capabilities at the ankle

(Aungpau et al., JPO, 1996)
Orthosis Evaluation Using Motion Analysis - Part 2

Barefoot vs. PLS – Knee Kinematics/Kinetics

**Barefoot**

- Increased knee extension at IC
- Reduced knee flexor moment pattern
- Normal power absorption in MST

**PLS**

- Elimination of drop foot in swing allowing for a heel initial contact and elimination of early heel rise in stance
- Elimination of knee flexion moment, excessive and premature ankle plantar flexor moment
- Elimination of abnormal knee and ankle power absorption and ankle power generation
- Confirms ankle power generation capabilities
- Confirms appropriate prescription of PLS brace versus SAFO

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Impact of Joint Kinetic Data

- PLS brace results in subtle changes in visual gait pattern
  - Elimination of drop foot in swing allowing for a heel initial contact and elimination of early heel rise in stance
- PLS brace results in significant kinetic changes
  - Elimination of knee flexion moment, excessive and premature ankle plantar flexor moment
  - Elimination of abnormal knee and ankle power absorption and ankle power generation
  - Confirms ankle power generation capabilities
  - Confirms appropriate prescription of PLS brace versus SAFO

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Case 4 - Summary

- Excessive equinus in swing has been eliminated with associated changes at the ankle in stance and knee in stance
- Conclusion: PLS AFO is a good bracing option for this patient

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Case 5 – Cerebral Palsy GMFCS III

- Impairments: (strength – MMT)
  - Ankles: bilateral unable to isolate, 4/5 dorsiflexion in synergy (confusion testing)
  - Knee flexion: 3/5
  - Knee extension: right 4/5, left 5/5
  - Hip flexion: right 5/5, left 4/5
  - Hip extension: unable to isolate
- Impairments: (passive range of motion)
  - Bilateral knee flexion contractures: right 40 deg, left 30 deg
  - Dorsiflexion knee 90 deg: right -5 deg, left 5 deg

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Case 5 – Cerebral Palsy GMFCS III

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

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Barefoot Knee & Ankle Kinetics

- Abnormal ankle modulation and ankle plantar flexor moment pattern
- Minimal power generation at the ankle in TST
- Excessive knee flexion and knee extensor moment pattern

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Floor Reaction Orthosis (FRO)

- **Goal:** provide ankle support to reduce ankle dorsiflexion and excessive knee flexion in stance – via plantar flexion knee extension couple
- **Entry:** rear or anterior
- **Strapping:** large proximal tibial strapping to support greater forces on anterior tibia

**Bilateral FRO - CP (video)**

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

Bilateral FRO Knee & Ankle Kinetics

- Minimal ankle range of motion\(^1\)
- Ankle plantar flexor moment\(^2\)
- No power generation at the ankle in terminal stance\(^3\)
- Severe knee flexion\(^4\)
- Severe knee extensor moment pattern\(^5\)

**Barefoot vs. FRO – Ankle Kinematics/Kinetics**

- Reduced ankle sagittal plane range of motion
- No change in ankle kinetics – on going toe walking

**Case 5 - Summary**

- FRO minimizes ankle sagittal plane motion
- No impact on knee flexion and knee extensor moment pattern
- Knee angle at initial contact due to knee flexion contracture is excessive for appropriate function of the FRO
- Conclusion: increased knee extension at initial contact is **required** for optimal orthosis function

**Barefoot vs. FRO – Knee Kinematics/Kinetics**

- No change in knee kinematic or kinetics
Case 6 – Cerebral Palsy GMFCS II

- Impairments: (strength – MMT)
  - Right ankle: normal - 5/5
  - Left ankle: unable to isolate, 5/5 dorsiflexion in synergy (confusion testing)
- Impairments: (passive range of motion)
  - Left ankle: 5 deg (knee flexed), 0 deg (knee extended)

Ankle Kinetics – Right Barefoot

Ankle Kinetics - Left (hemi) Barefoot

Posterior Leaf Spring (PLS)

- Goal: limit excessive equinus in swing
- Trim line posterior to medial and lateral malleolus
- Thinner ankle coverage that allows sagittal plane motion in dorsiflexion during weight bearing
- Support strapping at proximal tibia

Bilateral PLS

- Stance phase stability?
- Swing phase clearance?
- Appropriate pre positioning of the? foot at initial contact
- Adequate step length?
- Energy conservation?
Orthosis Evaluation Using Motion Analysis - Part 2

Case 6 - Summary

- **Benefits:**
  - Eliminates excessive equinus in swing left side
- **Problems:**
  - Ongoing left toe walking due to continued excessive knee flexion initial contact
  - Ongoing left clearance problems related to continued decreased peak knee flexion in swing
  - Eliminates compensatory vault on right side
- **Conclusion:** surgical intervention


Case 7 - CMT

- **Impairments – strength (MMT)**
  - Ankle dorsiflexion/plantar flexion: bilateral 0/5
  - Ankle inversion/eversion: right 0/5 and left 1/5
  - Knee flexion: bilateral 3/5
  - Knee extension: bilateral 3/5
  - Hip flexion: bilateral 3/5
  - Hip abduction: bilateral 3/5
- **Impairments – passive ROM**
  - Bilateral knee flexion contractures: -5 deg
  - Bilateral limited dorsiflexion: right -10/left -5 deg

Case 7: CMT

- Stance phase stability?
- Swing phase clearance?
- Appropriate pre positioning of the foot at initial contact
- Adequate step length?
- Energy conservation?
Orthosis Evaluation Using Motion Analysis - Part 2

Sagittal Knee and Ankle/Foot Progression

- Increased knee flexion in stance
- Increased ankle equinus in swing
- Increased external foot progression
- Walking velocity reduced: 0.41 to 0.49 m/sec (TD 1.20 m/sec)

Solid ankle-foot-orthosis (AFO)

- Goal: limit ankle sagittal plane motion stance and swing and provide medial/lateral stability in stance
- Anterior entry
- Support strapping at proximal end and sometimes at ankle and forefoot

Barefoot vs. Solid AFO’s

- Independent ambulation
- Reduced base of support
- Improved walking velocity: 0.62 to 0.75 m/sec
- Reduced equinus in swing
- Internal foot progression

Changes in Pelvic Motion

- Improved balance results in reduced pelvic coronal and transverse plane ROM

Case 7 - Summary

- Solid AFO’s provide excellent support and stability for the ankles
- More proximal benefits in terms of balance and associated trunk compensations are reduced
- AFO’s unmask internal tibial torsion
- Conclusion: maintain bilateral solid AFO’s

Case 8 - CMT

- Impairments – strength (MMT)
  - Unable to assess accurately
  - Global assessment suggests weakness issues
- Impairments – passive range of motion
  - Unable to assess accurately
  - No major contractures evident

(Surnpaa et al., Dev Med Child Neurol, Suppl No 98, Vol 46, 2004)
Case 8 - CMT

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

Foot Pressures

- Patient shows weight bearing under the heel only bilaterally even though forefoot is in contact with the ground
- Implies plantar flexor strength that is less than antigravity

Case 8 - Summary

- Foot pressure data provides valuable insight into functioning of ankle plantar flexor strength
- Conclusion: solid AFOs are recommended to provide support for the weak ankle plantar flexors, improve stance phase balance and increase walking velocity

Case 9 - CMT

- Impairments – strength (MMT)
  - Ankle dorsiflexion: bilateral 5/5
  - Ankle flexion: bilateral 2/5
  - Ankle inversion/eversion: right 4+/5
  - Knee flexion/extension: bilateral 5/5
  - Hip flexion: bilateral 5/5
  - Hip abduction: bilateral 4-5/5
- Impairments – passive ROM
  - Bilateral limited dorsiflexion: right 0/left 5 deg

Case 9: CMT

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

Sagittal Knee and Ankle

- Increased peak ankle dorsiflexion in terminal stance
- Reduced ankle power generation in terminal stance
- Increased knee flexion and associated knee extensor moment in stance
Hinged ankle-foot-orthosis (H-AFO)

- Goal: articulated ankle joint that allows for sagittal plane dorsiflexion in stance and eliminates plantar flexion in swing
- Support strapping at proximal tibia and sometimes at ankle and forefoot
- May have posterior strap to limit dorsiflexion range

Sagittal Knee and Ankle H-AFO

- Ongoing ability to generate ankle power in terminal stance
- Hinge allows ongoing increased knee flexion in stance and associated knee extensor moment

Case 9 - Summary

- H-AFO allows ankle to continue to function, however, does not provide adequate support with ongoing increased knee flexion
- Increased knee extensor moment results in increased patellar femoral forces – implications on long-term knee health
- Conclusion: consider PLS AFO that could provide more support in stance but allow ankle plantar flexion power

Case 10 – Down’s Syndrome

- Impairments – strength (MMT)
  - Normal strength 5/5
  - Except ankle plantar flexors: 3/5
- Impairments – passive range of motion
  - Bilateral limited dorsiflexion: 0 deg (knee extended), 15 deg (knees flexed)

Case 10 – Down’s Syndrome

- Stance phase stability?
- Swing phase clearance?
- Appropriate pre positioning of the? foot at initial contact
- Adequate step length?
- Energy conservation?
Orthosis Evaluation Using Motion Analysis - Part 2

Sagittal Knee & Ankle/Foot Progression

- Decreased peak ankle plantar flexor moment and power generation
- Increased knee extensor moment

University California at Berkley (UCBL)

- Trim line falls distal to medial and lateral malleolus
- Medial and hind foot support correct for supple bony alignment issues
- Wedge provides further support to minimize atypical hind foot positions

Case 10 – Shoes and UCBL’s

video

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

Barefoot vs. UCBL Foot Progression

Case 10 - Summary

- UCBL re-aligns the foot by supporting the medial arch and hind foot which results in improved foot progression
- Allows weight bearing over distal aspect of the foot and associated improved kinematics/kinetics at the ankle and knee and improved function with increased walking velocity
- Conclusion: the UCBL (in combination with a shoe) provides excellent foot support and improved gait function
Orthosis Evaluation Using Motion Analysis - Part 2

Important

- Joint contractures/foot deformity may need to be treated prior to optimal bracing outcomes

Final Conclusions

- Motion analysis provides additional understanding about orthosis function not possible upon visual assessment of gait that allows optimization of orthosis design choices for the individual patient
- Through motion analysis, we have documented that AFO’s do not always “match” the design goal

Final Conclusions

- Understanding the following is critical for understanding appropriate orthosis prescription
  - Patient impairment – weakness, passive ROM, spasticity
  - Phase(s) of the gait cycle when the impairment(s) are problematic (brace design needs to match biomechanical demand)
    - A brace to address equinus in swing is a different brace than needs to address excessive dorsiflexion in stance

Final Conclusions

- Better is great, but improved function can be possible in many patients
- With a better understanding of the pathomechanics a clinician can provide better care

Thank You!