Lower Limb Orthoses to Enhance Ambulation

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OBJECTIVES
• Discuss the principles used in designing orthotic interventions for the lower extremity to restore mobility and function
• Identify orthotic components and relate their function and use to patient criteria
• Analyze the effect of orthoses on joint motion based on biomechanical needs during ambulation

Role of Orthoses in the Rehabilitation Process
• Provide safe and efficient ambulation to access surroundings
• Maximize function
• Reduce long term effects of skeletal malalignment

OBJECTIVES
• Identify indications for use of specific orthosis designs based on goals related to
  – functional ambulation,
  – protection,
  – and contractures
Patient Assessment

The assessment aids in determining the biomechanical forces necessary to provide:

- Stable skeletal alignment
- Stable base of support to facilitate safe ambulation
- Substitute for impaired muscle strength
- Control unwanted motion from spasticity

Biomechanical Principles

- Three-point force systems
- Ground reaction force vectors
- Alignment
  - Tibial angle to floor
  - AFO/Footwear Combination (AFO-FC)

3-Point Force System
Subtalar Eversion Control

- Corrective Forces
  - Proximal to medial malleolus
  - Sustentaculum tali

- Counteractive Forces
  - Proximal lateral calf
  - Distal lateral calcaneus

3-Point Force Systems

Sustentaculum tali modification

Courtesy of Martin Carlson, CPO
3-Point Force System
Subtalar Eversion Control

- Corrective Force
  - Proximal to medial malleolus
  - Sustentaculum tali
- Counteractive Forces
  - Proximal lateral calf
  - Distal lateral calcaneus

Describe the 3-point force system used to control excessive plantarflexion in a thermoplastic AFO?

a. posterior calf, plantar surface of the foot at the MT head region, ankle strap
b. posterior calf, dorsum of the foot, anterior calf
c. anterior calf, posterior calcaneus, dorsum of the foot
d. proximal lateral calf, medial malleolus, lateral calcaneus

Ground Reaction Force Vectors

Tibial Angle to Floor

- Distal 1/3 of tibia/fibula to floor
- Considerations
  - Ankle joint ROM
  - Heel height of shoe
Tibial Angle to Floor

While wearing shoes
• Heel height
  – Differential from the ball of the foot to the heel
• Heel wedges may be used in the shoe to accommodate a plantarflexion contracture

AFO-Footwear Combination

• Shank vertical angle
  – Line of shank is along anterior tibial crest in relationship to vertical
  – Measurement taken with shoe
  – Evaluate overall postural alignment

Anatomy of an AFO

• Stirrup
• Soleplate
• Sidebar/Upright
• Calf band
• Pretibial shell

Anatomy of a Thermoplastic AFO

• Foot plate
  – Length
• Trim lines
  – Rigidity through position of trim lines at ankle region
Ankle Joint Controls

- Double Adjustable / Dual Channel ankle joint
  - Plantarflexion stop: Pin placed in the posterior channel
  - Dorsiflexion stop: Pin placed in the anterior channel

Plantarflexion Stop

- Tilts the tibia anterior and positions the ankle joint in dorsiflexion
- Function:
  - Provide clearance during swing phase
  - Produce a knee flexion moment at loading response

Dorsiflexion Weakness

- AFO with a Plantarflexion (PF) Stop
  - Provides stability in the sagittal plane by controlling ankle PF during swing phase
  - Relationship between:
    - adequate clearance during swing phase
    - knee flexion stability during loading response

Dorsiflexion Stop

- Limits dorsiflexion or tibial advancement
- Function:
  - Create a knee extension moment midstance through terminal stance
Plantarflexion Weakness

AFO with a Dorsiflexion Stop

- Provides stability in the sagittal plane by controlling tibial advancement during midstance and terminal stance
- Relationship between
  - adequate clearance during swing phase
  - knee stability during stance phase

An ankle-foot orthosis with a plantarflexion stop positioned in dorsiflexion will induce a/an

a. decreased knee flexion moment.
b. increased knee extension moment.
c. increased knee flexion moment.
d. increased hip extension moment.

Ankle Joint Controls

Double Adjustable / Dual Channel

- Spring placed in the posterior channel to allow controlled PF at loading response
- Pin placed in the anterior channel for a DF stop

Ankle joint with a spring in the posterior channel

- allows PF ROM at loading response
- provides increased knee stability at loading response by decreasing the knee flexion moment
Ankle Joint Controls

Dorsiflexion Assist

Posterior Leaf Spring AFO

Functions:
• allow controlled plantarflexion at loading response and
• dorsiflexion ROM during late midstance and terminal stance

Indications:
• Dorsiflexion weakness
• Minimal need for stability of subtalar and midtarsal joints
Biomechanical goal:
• Limit unwanted plantarflexion ROM during swing phase

Carbon AFO Designs

• Varied designs
  – Similar to Posterior Leaf spring
  – Rigid limiting dorsiflexion and plantarflexion
  – Prefabricated
Ankle Foot Orthoses

Custom fabricated
- Polypropylene
- Laminated
- Carbon
- Hybrid

Case Scenario-Hx of Polio

Biomechanical goals:
- DF during swing phase
- Stance phase stability

Clinical Considerations:
- Knee strength
- Activity level, function
- Leg length discrepancy
- PF contracture

Case Scenario-Polio

Custom fabricated carbon AFO
- Rigidity/flexibility
- Ankle
- Metatarsal heads
Lower Limb Orthoses
Categories based on Purpose

- Ambulation
  - To improve mobility and independence
- Protection
  - Protect or prevent further deformity
- Contractures
  - Reduce or prevent limitation of range of motion

Lower Limb Orthoses
For Ambulation

- Accommodative Foot Orthoses
  - Accommodate alignment and deformities
  - Lower durometer materials

Lower Limb Orthoses
For Ambulation

- Biomechanical Foot Orthoses
  - Coronal plane alignment control
  - Subtalar and midtarsal joint control

UCBL FO
- (UC Biomechanics Lab Foot Orthosis)
- Indications:
  - Midtarsal pronation/supination, forefoot abduction/adduction
- Biomechanical goals:
  - Control of midtarsal and transtarsal joints
AFO Function
Clearance during Swing Phase

• Indications
  – Inadequate DF strength

• Design Options
  – DF assist
  – PF stop

Dorsiflexion Weakness

• Clinical Observations
  – Absent heel strike if weakness <3/5
  – Adequate clearance during swing, foot slap at LR with 3/5
  – Clearance of the foot reduced during swing phase
  – Compensation with a steppage gait pattern
  – Instability of the subtalar joint

Case Scenario-CMT

MMT:
• Weak DF, PF
• Good knee and hip
Biomechanical goals:
• Clearance during swing phase
• Subtalar joint control

Dorsiflexion Assist AFO

• Clinical Considerations:
  – DF ROM of the ankle joint since the design allows DF ROM midstance to terminal stance
  – Allows PF ROM at loading response
  – Stability of the subtalar, midtarsal, and transtarsal joints
Articulated Plastic AFO
Plantarflexion Stop

- **Indications:**
  - Dorsiflexion weakness
  - Sagittal, coronal and transverse plane control

- **Biomechanical goals:**
  - Clearance of the foot during swing phase
  - Stability of the subtalar, midtarsal joints
  - Allow DF/tibial advancement

Clinical Considerations

- Produces a knee flexion moment at loading response dependent on tibial angle to floor or shank vertical angle
- Trade off between clearance of the foot during swing and knee stability during stance phase

Case Scenario-CMT

Solid Ankle AFO

- **Biomechanical goals:**
  - Clearance of the foot during swing phase
  - Control of dorsiflexion/tibial advancement
  - Provide stability of the subtalar and midtarsal joints
Solid Ankle AFO

• Indications:
  – Combined dorsiflexion and plantarflexion weakness
  – Sagittal, coronal and transverse plane control

• Clinical Considerations
  – Fair quadriceps strength to control destabilizing knee flexion moment at loading response (LR)
  – Shoe modifications to reduce knee flexion moment at LR
    • Bevel heel
    • Cushion heel
    • Rocker sole

Carbon AFOs

• Custom Fabricated
  – Determine PF/DF resistance
  – Footplate length/flexibility

Case Scenario
Spinal Muscular Atrophy

MMT:
• No DF or PF strength

Biomechanical goals:
• Clearance of foot during swing phase
• Substitute for PF during stance phase
• Tri-planar control
Plastic Ground Reaction AFO

- **Design Characteristics**
  - Solid ankle with pretibial shell
  - Tibial angle 90 degrees to floor with shoes
  - Shank vertical angle with shoes
  - Extended footplate

- **Indications:**
  - Quadriceps weakness (3/5)
  - Plantarflexion weakness

Plastic Ground Reaction AFO

- **Biomechanical goals:**
  - Provide knee extension moment midstance through terminal stance

- **Considerations:**
  - Creates a knee flexion moment at loading response

Articulated Ground Reaction AFO

- **Spring in the posterior channel**
- **Stop in the anterior channel**
- **Reduces knee flexion moment at loading response**

Articulated Ground Reaction AFO

- **Indications:**
  - Weak plantarflexors
  - Weak quadriceps
  - Weak hip extensors

- **Biomechanical goals:**
  - Provide a knee extension moment midstance through terminal stance
  - With a spring in the posterior channel, decrease the knee flexion moment at LR
Case Scenario Stroke

Biomechanical goals:
- Prevent mal-alignment and deformities
- Substitute for muscle weakness/motor control
  - Ankle joint
  - Subtalar joint
  - Forefoot
  - Knee
  - Hip

Case Scenario-Stroke

- Affect sagittal plane control at the knee by ankle position and control
  - Hyperextension
  - Flexion

Knee Ankle Foot Orthosis

- Indicated for control at the knee
  - Valgum
  - Varum
  - Recurvatum
  - Quadriceps weakness

Knee Ankle Foot Orthosis

Genu valgum 3-point force system

- Corrective force
  - Medial femoral condyle

- Counteractive forces
  - Lateral proximal thigh
  - Lateral distal calf
Knee Ankle Foot Orthosis

Recurvatum control
- 3-point force system
- Plantarflexion stop

Knee Ankle Foot Orthosis

- Indicated for use with less than 3-/5 Quadriceps strength OR bilateral weakness

Bilateral KAFO’s

- Locked knee joints
- Ankles locked in dorsiflexion
- Weight line maintained posterior to hip joint to provide stability at the hips

Knee Ankle Foot Orthoses Components

- Ankle joints
- AFO section
- Thigh section
- Infrapatellar and suprapatellar straps
- Knee Joints
Knee Joints

- Bail Lock
- Drop Lock
- Offset Free Knee

Knee Joint Components

Bail Lock
- Easier to unlock when moving from standing to sitting
- Consider use with
  - bilateral KAFOs
  - decreased hand function

Knee Joint Components

- Drop Lock/Ring Lock
  - Good hand function required to operate
  - Freely falls into locked position when fully extended

Knee Joint Components

Offset Knee Joint
- Provides increased knee stability during stance phase
- Mechanical knee axis aligned posterior to anatomical knee joint axis
Knee Joint Components

• Offset knee joint optimal function
  – Approximately 10 degrees plantarflexion ROM at loading response
  – Incorporate a dorsiflexion stop at the ankle joint

Quadriceps Weakness

• Clinical Observation
  – Mild to moderate weakness
    • Eliminate knee flexion by maintaining knee extension at initial contact
  – More severe weakness
    • Forward trunk leaning
    • Genu recurvatum

Quadriceps Weakness

• Cauda Equina Injury
• No intervention for many years

Quadriceps Weakness Offset Free Knee KAFO

• Dorsiflexion stop
• Plantarflexion stop
  – Posterior spring
• Degree of recurvatum determined for stability
• 3-pt. Force system
**Offset Knee Joint KAFO Indications**

- Unilateral involvement
- Vertical hip-trunk alignment
- Absence of contractures
  - Knee and hip
- Plantigrade foot
- Quadriceps weakness
- Hip strength 2/5 or >
- Joint proprioception

**Quadriceps Weakness Offset Knee Joint KAFO Option**

- Center of mass in relationship to mechanical knee joint axis
  - Hip extensor strength most effective

**Quadriceps Weakness**

- Quadriceps strength
  - at least 3-/5 or 3/5
- Center of mass must be maintained anterior to knee joint axis
  - ground reaction force vector for knee stability

**Offset Knee Joint KAFO Stability**

- Center of mass maintained anterior to the mechanical knee joint axis
  - mechanical knee joint moves into extension
  - hip extensor strength necessary
Offset Knee Joint KAFO Instability

- If the Center of mass passes posterior to mechanical knee joint axis, the mechanical knee joint flexes

Lister, MJ, Principles LE Bracing, 1967

Offset Knee Joint KAFO Instability on Inclines

- Weak hip extensors or trunk extension
  - Center of mass falls posterior to mechanical knee joint axis
  - Knee flexion instability

Lister, MJ, Principles LE Bracing, 1967

Offset Knee Joint KAFO Instability

- Uneven ground
  - Elevation under heel of shoe

Lister, MJ, Principles LE Bracing, 1967

KAFO with Offset Knee Joints

- Advantages
  - Ease in rising from a chair
  - Ease in walking due to lack of knee locked in extension

- Disadvantages
  - Uneven ground instability
  - Difficulty in going down inclines
  - Cognitive demand
What muscle group is assessed to determine if an individual with quadriiceps weakness would be able to successfully utilize a unilateral KAFO with an offset knee joint?

a. ankle dorsiflexors  
b. hip flexors  
c. abdominals  
d. hip extensors

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**Quadriceps Weakness**  
**AFO Option**

- Hip extensor strength 3/5  
  - Pre-tibial shell, DF stop  
- Knee extensor strength 3/5  
  - Pre-tibial shell, DF stop  
  - Spring in posterior channel DAAJ

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**Quadriceps Weakness**  
**AFO with DF stop**

- DF stop limits ankle dorsiflexion  
  - Midstance to terminal stance

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**AFO with DF stop**  
**PF stop/spring**

- Controlled PF ROM  
  - Spring in posterior channel  
  - Decreases knee flexion moment at loading response
A patient with fair minus quadriceps strength wearing a ground reaction ankle-foot orthosis will have knee extension facilitated from midstance to terminal stance by utilization of a

a. plantarflexion stop
b. dorsiflexion assist
c. dorsiflexion stop
d. plantarflexion resist

Stance Control KAFOS

- Method of activation
  - Ankle, gait
- Many recommend use with 3/5 hip extensors
- <10-15 degrees genu valgum
- Knee flexion contractures <10 degrees
- Achieve knee extension at terminal stance
- Unilateral
- Varied weight limits

Stance Controlled Knee Joints

- Ability to flex knee during swing phase
- Stabilization with a locked knee during stance phase
- Limited designs have stabilization of knee with flexion

Stance Controlled Knee Joints

- Tubular upright houses cables
  - Full extension locks the joint
  - Unlocks at terminal stance with
    - 5-10 degrees DF ROM
    - Knee extension
- Recommendations
  - 3/5 hip extensors
  - <5 degrees knee flexion contracture
Stance Controlled Knee Joints

- Ankle joint with dorsiflexion ROM to unlock knee joint
- Full extension locks knee at terminal stance

Stance Controlled Knee Joints

- Create knee extension moment during terminal stance with
  - active muscle control of hip extensors, plantarflexors
  - passive orthotic control
    - DF stop
    - Longer footplate length
    - Rocker fulcrum moved distally on the shoe

Stance Controlled Knee Joints

- Trial orthoses are available from most companies
HKAFO
- Sagittal, coronal, and transverse plane control

Reciprocating Gait Orthosis
- Pelvic band and connected hip joints
- Hip flexion or trunk extension on one side facilitates hip flexion on the contralateral side
- Used in conjunction with KAFOs or AFOs

RGO

Orthoses for Protection
- Goal:
  - Protect or prevent further deformity
  - Fracture bracing
  - Knee orthoses
  - Hip orthoses
  - CROW
  - PRAFO
Fracture Bracing

• General Principles
  – Protection/immobilization of the injured area through soft tissue compression
  – Mobilization of the patient once acute symptoms subside
    • ROM of adjacent joints
    • Muscle function
  – Graduated weight bearing

Fracture Bracing

• Tibial diaphysis fractures
• Used post cast application (7-10 days)
• Orthosis will not address shortening
• Considerations
  – Apex anterior or posterior angulation
  – Tibial fx without fibular fx
  – Above tibial tubercle, distal tibial fx

Orthosis Design

• Prefabricated
• Thin, well conforming anterior section
  – 1/4” foam padding
• Foot section
  – Maintain heel in correct AP position
  – Maintain suspension
• Posterior calf flattened

Ankle Foot Fracture Orthoses

• Immobilization of the affected area
• Rocker bottom to aid in smooth roll-over
• Circumferential Compression
• Post-operative rehabilitative orthosis
• Available in various styles with fixed and adjustable ankle ROM

Courtesy Wheaton Brace Co.
Femoral Fracture Orthoses

- Distal 1/3, tibial plateau fx
- Provides for variable ROM at the hip and knee
- Free Motion at the ankle
- Circumferential compression
- Does not limit internal or external rotation at the hip

Hip, Knee, Ankle, Foot, Ankle Orthosis (HKAFO)

- Proximal Femoral Fractures
- Available prefabricated or custom to measurements
- Various joint selection available for hip and knee
- Limits internal and external rotation at the hip
- Circumferential compression

Three Categories of Knee Orthoses

Prophylactic
- Attempt to prevent or reduce severity of knee ligament injuries

Rehabilitative
- Protect motion of injured knee or post-op

Functional
- Provide stability during activities

Knee Orthoses for OA

- Pre-fabricated and custom fabricated designs
- Uni-compartmental involvement
Hip Orthoses

- Pre-fabricated designs
- Adjustable
- Use of heel cup extension if rotational control desired

CROW

- Charcot Restraint Orthotic Walker
- Goal:
  - Reduce pressure on specific areas of the plantarsurface of the foot
  - Rocker sole facilitates normal gait pattern

PRAFO

- Pressure Relief AFO
- Pre-fabricated
- Reimbursement guidelines
  - Not covered for addressing heel ulcers
  - Covered for plantarfascitis, and contractures up to 45 degrees with 10 degrees PROM, active stretching program, interfering with functional abilities

Objectives

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Objectives

- Identify indications for use of specific orthoses designs based on the categories of ambulation, protection, and contractures