Motion analysis in understanding gait pathology, AACPDM 2013

Research Using Motion Analysis: Impact in Understanding Movement Pathology

Sylvia Õunpuu, MS:
Kristan Pierz, MD
Center for Motion Analysis
Connecticut Children’s Medical Center

Introduction

• Motion analysis techniques have been used to understand typical and pathological movement since the 1800’s
• Computerized motion analysis moved this tool from the research realm into routine clinical services in the 1980’s
• The resulting documentation of movement has expanded to a wide variety of gait pathologies

Outline

• Review how motion analysis has improved our understanding of movement pathology that impacts children’s gait
  – Charcot-Marie-Tooth
  – Myelomeningocele
  – Cerebral palsy
    • Natural progression
    • Prevalence of gait deviations
    • Classification/patterns
    • Skeletal modeling

Objectives

• At the end of this section, participants will be able to:
  – Describe how motion analysis has improved our understanding of the pathomechanics in a number of gait pathologies

Charcot-Marie-Tooth
CMT

• Most commonly inherited neurological disorder = de-myelination of large peripheral nerves

• CMT is characterized by:
  • distal muscle weakness and imbalance
  • foot and ankle deformities
  • associated gait implications
  • impairment progression at varying rates

Textbook gait description:

• Foot drop (excessive equinus) in swing phase
• Steppage (hyper-flexion of knee and hip in swing)
• Circumduction and pelvic hiking in swing

(Fenton, JOPA 1984)
(Morrey, Pediatric Orthopaedics)
(Vinci, Archives of Physical Medicine & Rehab 2002)
CMT and Motion Analysis

- Adults or across all ages
  - Vinci et al., Archives of Phys Med and Rehab, 2002
- CMT patients grouped together
  - Newman et al., Gait and Posture, 2007
  - Don et al., Clinical Biomechanics, 2007
- Description of different gait patterns
  - Burns et al., Muscle and Nerve, 2009
  - Ferrarin et al., Gait and Posture, 2011
  - Öunpuu et al., Gait and Posture, 2013

Clinical Examination Findings

- The most common impairments at the ankle
  - reduced passive dorsiflexion ROM
  - plantar flexor weakness
  - dorsiflexor, forefoot inverters and evertors weakness
  - cavus

Ankle Sagittal Plane
Kinematic – Sub Groups

- less than typical (dash-dot)
- typical (large dash)
- greater than typical (solid)

Long axis of the shank vs. plantar aspect of the foot

Group 1 – Toe Walkers

(toe walkers = dashed/dot black line)

Group 2 – Cavus Foot

(cavus foot = large dashed red line)
Conclusions

- Patients with CMT present differently from typically developing and within the diagnosis
- Therefore, TREATMENT needs to be SPECIFIC to the INDIVIDUAL patient
- Weak plantar flexors were consistent with the functional findings reported by many patients – difficulty in running
- Delayed peak dorsiflexion may be the first “gait sign” of CMT

Future – What is left to do!

- Motion analysis can help establish:
  - How pathomechanics related to phenotype
  - Understanding of functional changes with disease progression
  - Define prognosis of future function using documentation of pathomechanics and phenotype
  - Treatment outcomes studies
  - More detailed foot skeletal model needed

Implications for Ambulation

- Characterized by level of lesion: sacral, low lumbar (L5 and L4), etc.
- Loss of muscle function – weakness to paralysis
- Sensory deficits
- Asymmetry in lower extremity function
- Contractures and bony torsions
- Balance issues related to CNS injury and weakness
- Functional loss over time: tethered cord
- Spasticity

Myelomenigocele

- Congenital malformation that results from failure of embryonic neural tube closure.
- 4-5 of every 10,000 births
- Damage to the spinal cord and other congenital deformities persist

Group 3 – Flail Foot

(flail foot = solid blue line)
Pathomechanics of Myelomeningocele


Energy Cost


Treatment Assessment


Sacral Level 1 – Barefoot Walking

Partial loss of: intrinsics of the foot, gastrocnemius, soleus, lateral hamstrings and gluteus maximus.

Sagittal Plane Kinetics - Right

- Hip and knee – Typical
- Ankle – Increased dorsiflexion terminal stance*
- Passive ankle ROM typical
- Plantar flexor strength 4/5
Lumbar Level 5 – Barefoot Walking

Loss of: gastrocnemius and soleus, lateral hamstrings, gluteus maximus, flexor hallucis and digitorum longus, Partial loss of: gluteus medius and minimus, medial hamstrings, posterior tibialis, long toe extensors, peroneals

Lumbar Level 5

• Sagittal plane kinematics and kinetics
  – Reduced ankle plantar flexor moment and power
  – Increased hip and knee extensor moments

• Coronal plane kinematics and kinetics
  – Increased lateral trunk lean
  – Reduced hip abductor moment
  – Knee adductor moment

• 3D – Kinematics
  • Increased ankle dorsiflexion in terminal stance
  • Increased crouch and hip flexion
  • Minimally increased trunk range of motion in coronal and transverse planes

Lumbar Level 4 – Barefoot Gait

Loss of Sacral and L5 level muscles, Additional loss of: Gluteus medius and minimus, tensor fascia latae, medial hamstrings, extensor digitorum longus, posterior tibialis, peroneals (longus and brevis)

Lumbar Level 4

• 3D – Kinematics
  • Increased lateral trunk lean and transverse plane trunk ROM
  • Increased hip and pelvis coronal and transverse plane ROM
  • Increased ankle dorsiflexion in TST
What have we learned?

- Complex relationships between trunk motion and strength and knee function
- Excessive trunk motion is a
  - compensation for hip abductor weakness
  - “motor” to assist in forward progression
  - Increased knee adductor moment (valgus thrust)

Motion analysis in understanding gait pathology, AACPDM 2013

What have we learned?

• Ankle-foot-orthosis (AFO)
  – improved ankle/knee and hip sagittal plane function
  – increased knee transverse plane motion


Conclusions

• Ambulation for persons with myelomeningocele is complex
• Appreciating pathomechanics is the best way to make treatment decisions
• Visual assessment is limited

Cerebral Palsy

• Gait Analysis and Cerebral Palsy
  – Natural progression
  – Prevalence Studies
  – Classification or gait patterns in cerebral palsy
  – Electromyography
  – Skeletal Modelling
Natural Progression and Motion Analysis

• Understanding the implications of not undergoing surgical intervention in children with cerebral palsy
• Required to interpret treatment results such as orthopaedic intervention
• Provide a justification for the importance of treatment

Johnson et al. Results

• 18 subjects with spastic diplegia, ranging in age from 4 to 14 years assessed at 32 months apart
• Deterioration of gait stability evidenced by increases in double support and decreases in single support with time and growth ($p < 0.05$).
• Kinematic analysis revealed a loss of excursion about the knee, ankle, and pelvis ($p < 0.05$).
• Passive range-of-motion analysis revealed a decrease in the popliteal angle over time ($p < 0.05$).

Published Studies

• Johnson, David C.; Damiano, Diane L; Abel, Mark F. The Evolution of Gait in Childhood and Adolescent Cerebral Palsy, J Pediatr Orthop, 17:392-396, 1997

Gough et al. Results

• Twelve patients (mean age 10 years) with no treatment (control group)
• Showed a significant increase in minimum hip and knee flexion in stance 17 months after first gait analysis

Bell et al.

• 25 children with cerebral palsy
• Two gait analyses an average of 4 years apart
• No intervening surgery
• Clinical Measures
  – Statistically significant reductions in
    • Popliteal angle
    • Passive maximum ankle dorsiflexion
  – No change in passive maximum hip internal/external ROM

Gait Changes:

• Functional Walkers (>81 cm/sec walking velocity)
• Less Functional Walkers (<80 cm/sec)
Conclusions

• Functional Walkers
  – Getting “stiffer”
  • Decreased knee flexion in swing
  • Decreased ankle, knee and hip range of motion
• Less Functional Walkers
  – Increased crouch
  • Increased knee flexion and ankle dorsiflexion in stance

Conclusions

• ambulatory ability tends to worsen over time in children with spastic cerebral palsy
• outcome studies comparing postoperative gait with preoperative gait require this understanding to interpret results

Future – What is left to do!

• Increase study numbers
• Understand natural progression by GMFCS level

Prevalence Studies

• Studies that help to define the characteristics/pathomechanics of a particular diagnostic group such as cerebral palsy
• Provides important information for counseling parents and patients with cerebral palsy
• Information about prognosis in terms of
  – possible treatment needs
  – future gait function

Prevalence of Gait Abnormalities in CP

• 492 patients with cerebral palsy
• computerized motion analysis
• prevalence of 14 specific gait abnormalities was evaluated and compared based on
  – involvement (hemiplegia, diplegia, or quadriplegia)
  – age
  – history of previous lower extremity surgery

Prevalence of Gait Abnormalities in CP

• In hemiplegic, diplegic, and quadriplegic groups, more than 50% of patients had
  – stiff knee in swing
  – equinus
  – in-toeing
• In diplegic and quadriplegic groups, more than 50% of patients also had
  – increased hip flexion
  – crouch

Wren et al. JPO, 2005
Prevalence of Gait Abnormalities in CP

- In quadriplegic group, more than 50% of patients also had
  - Increased hip adduction

Wren et al., JPO, 2005

Prevalence of Gait Abnormalities in CP

- The likelihood of having stiff knee in swing, out-toeing, calcaneus deformity, and crouch increased with prior surgery.
- The likelihood of having rotational malalignment of the leg (internal hip rotation with out-toeing), calcaneus, out-toeing, varus and valgus foot deformities, and hip internal rotation increased with age.

Wren et al., JPO, 2005

Understanding Gait Pathology

- Increased understanding of pathomechanics – causes of gait issues
- Increased understanding of appropriate treatment options

Causes of In-toeing Gait in Children with Cerebral Palsy

- 412 children with cerebral palsy (587 involved sides)
- Combination of motion analysis and clinical assessment information


Most common causes of in-toeing

- Internal hip rotation (322 of 587 sides)
- Internal tibial torsion (296 of 587 sides).
- Pes varus contributed to in-toeing of 35 of the eighty-two involved limbs of the patients with hemiplegia
- Pes varus contributed to in-toeing in 42 of the 505 limbs of the patients with diplegia or quadriplegia

1/3 rd of children with CP have multiple causes of internal rotation
- Multiple causes of in-toeing were noted in 215 of the 587 involved limbs
  - Bilateral involvement: 176 of the 505 limbs of the patients with bilateral involvement
  - Hemiplegic involvement: 39 of the 82 involved limbs
Causes of in-toeing

- Bilateral involvement:
  - internal hip rotation (288 of 505)
  - internal tibial torsion (261 of 505)
  - internal pelvic rotation (ninety-two of 505)
- Hemiplegic involvement:
  - internal tibial torsion (35 of 82)
  - pes varus (35-82)
  - internal hip rotation (34-82)
  - metatarsus adductus (20-82)

Conclusion

- 1/3 of children with CP have multiple causes of internal rotation
- Pes varus is common in hemiplegia and rare in children with bilateral involvement
- Knowledge of possible causes helps direct clinical assessment and understanding
- Is critical to treatment decision making

Gait Classifications/Patterns in Cerebral Palsy

- Effort to develop a “typology” that differs from the present diagnostic system which classifies a cerebral palsy patient as either quadriplegic, diaplegic or hemiplegic or more recently GMFCS level.
- Typology based upon function at the joint level
  - Single joint – knee
  - Multiple joints – knee and ankle
- Motion analysis data based

Benefits of Classification/Patterns

- standardization of gait management/treatment
- communication within and across professions if organized based upon visually identifiable gait characteristics: crouch, equinus etc.
- must be:
  - Clinically meaningful categories
  - Related to specific impairments
- illustrative representation of characteristics for each pattern = clinically friendly

Initial Efforts


Gait Patterns in Hemiplegia

Con’t


Classifications - Methodology

- Quality is limited:
  - Reliability
  - Validity
  - Arbitrary decisions
  - Adequate numbers
  - Sagittal plane focus

Gait Patterns: Hemiplegia

- Provided frame work for thinking about hemiplegia as a continuum of increasing involvement with associated increasing requirements for treatment
- 4 types – sagittal plane (Winter, 1987)
- Kinetics and EMG (Hullin, 1996)
- Addition of transverse plane (Ounpuu, 2000 and Rodda, 2001)
- EMG alone (Stebbins, 2004)

Type 1

- Excessive equinus in swing
- Associated drop foot in swing
- Heel cord contracture/spasticity and/or anterior tibial weakness
- TREATMENT = excessive equinus in swing

Type 2

- Excessive equinus in stance and swing
- Associated toe walking and drop foot in swing
- Heel cord contracture/spasticity and/or anterior tibial weakness
- TREATMENT = excessive equinus in stance and swing

Type 3

- Increased knee flexion at initial contact
- Hamstring spasticity and/or tightness
- TREATMENT = excessive equinus in swing and knee issues
**Type 4**

- Decreased hip extension in terminal stance on involved side (solid line)
- Increasing anterior pelvic tilt on involved side during stance (solid line)
- TREATMENT = excessive equinus in swing and knee and hip issues

**Transverse Plane**

- Increased internal hip rotation, involved side (solid line)
- Compensatory external pelvic rotation, involved side (solid line)
- Increased femoral anteversion involved side
- Visual vs. actual – inconsistencies

---

**Knee Patterns**

- Sutherland D et al., Common Gait Abnormalities of the Knee in Cerebral Palsy, Clinical Orthopaedics & Related Research, 288, 1993.
- 588 children with CP
- Each abnormality is described by its motion analysis laboratory profile (clinical exam, motion parameters, electromyography data, and force plate data).

---

**Joint Kinetic Patterns**

- Framework for the discussion of gait pathology
- Link to surgical intervention decision-making
- Establishing the link between kinematics (joint angles) and kinetics (joint loads)

---

**Background**

“Double Bump” Ankle Pattern:
- Kinematic and kinetic (moment and power)
- Toe initial contact
- Spasticity in ankle plantar flexors

EMG and Cerebral Palsy
- Continuously active
- Prolonged
- Premature
- Out of phase
- Reverse phase

EMG and Cerebral Palsy
- 10 children with CP during gait
- Co-activation of antagonistic leg muscles during the stance phase of a gait cycle and a general reduction in amplitude of EMG activity

EMG and toe walking
- Evaluated EMG data from typically developing persons during normal walking and walking in crouch and toe walking patterns and compared to children with CP walking in crouch and toe walking

EMG and Bracing
- Peak activity of the tibialis anterior muscle was reduced by 36.1% at initial contact and loading response and by 57.3% in initial swing when using a HAFO

Gastrocnemius and tibialis anterior activity was similar in both groups
Rectus femoris activity in mid-swing phase in persons with CP and not typically developing
Help to consider differences between primary and secondary deformity
EMG and Treatment Planning


Motion Analysis - Skeletal Modeling

- Peak Knee Flexion Deficit
- Role of rectus femoris vs. vastii
- Other factors:
  - Stance phase knee kinetics (increased knee extensor moment)
  - Rotational deformity
- Simulation


Biomechanical Factors that can Contribute to Stiff-knee Gait

- Decreased knee flexion velocity at toe-off
- Excessive force in: rectus femoris vastii
- Diminished force in: iliopsoas
- Decreased peak knee flexion
- Increased force in: rectus femoris vastii

Summary

- Computerized motion analysis techniques have increased our understanding of the pathomechanics of gait in a wide variety of pathologies
- Leads to more informed treatment decision-making and improved outcomes

(Reinbolt J, et al., Journal of Biomechanics 2008)