# Clinical Gait Analysis

## *Biomechanics & Etiology of Common Walking Disorders*

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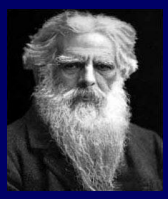
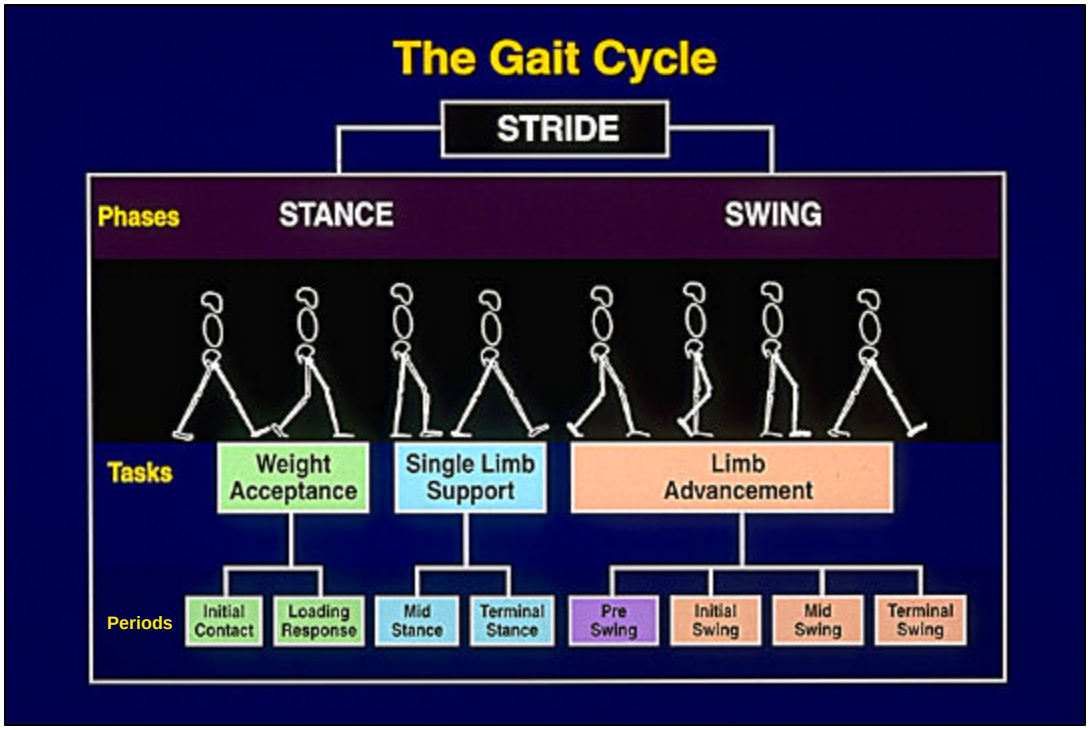
## Teaching Points

- Phases of the Gait Cycle
- Primary Muscle Actions during Gait
- Common Gait Disorders

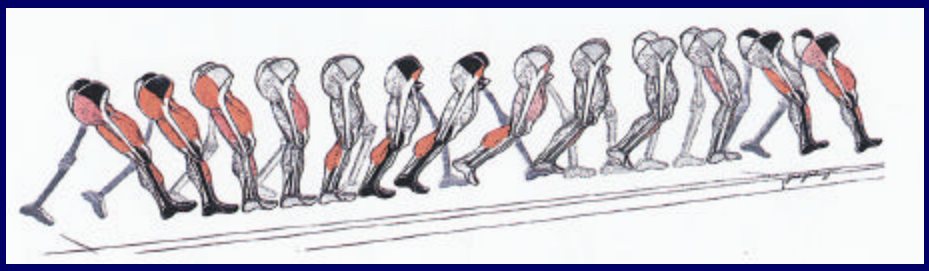
# Motion Analysis at Stanford

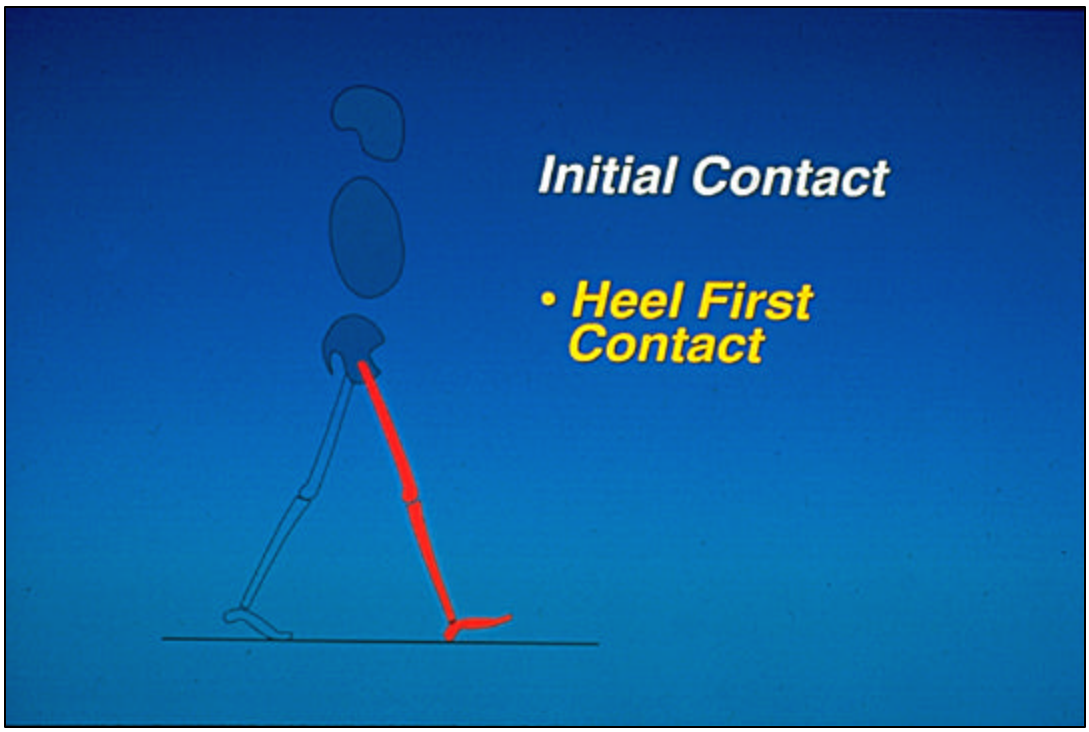
Edweard Muybridge & Leland Stanford 1878





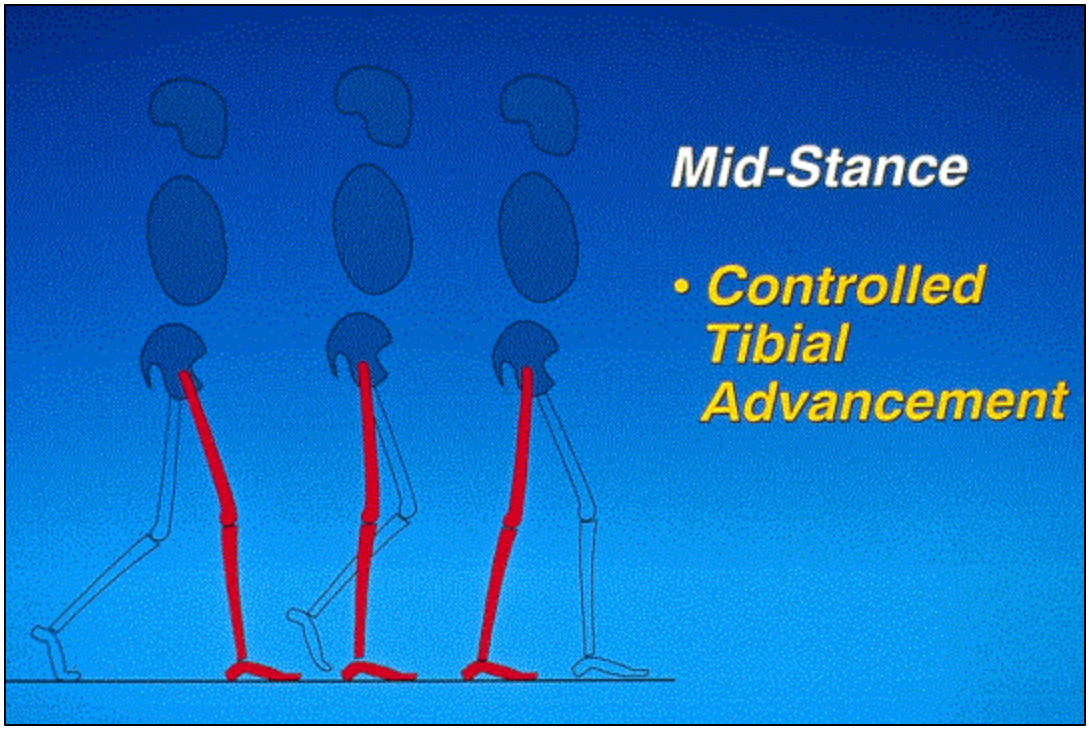
# Muscle Activity During Gait



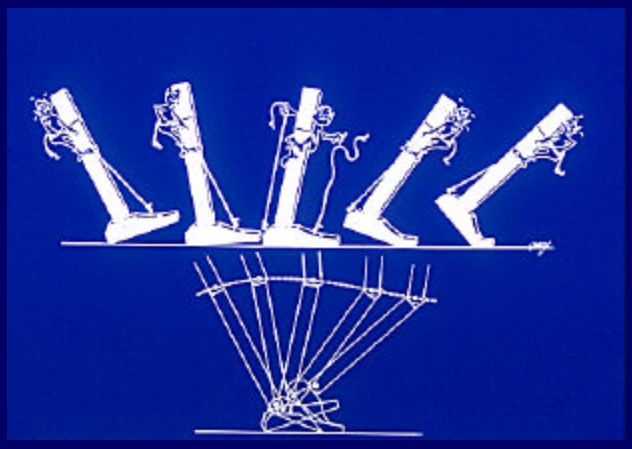


# Toe Walking

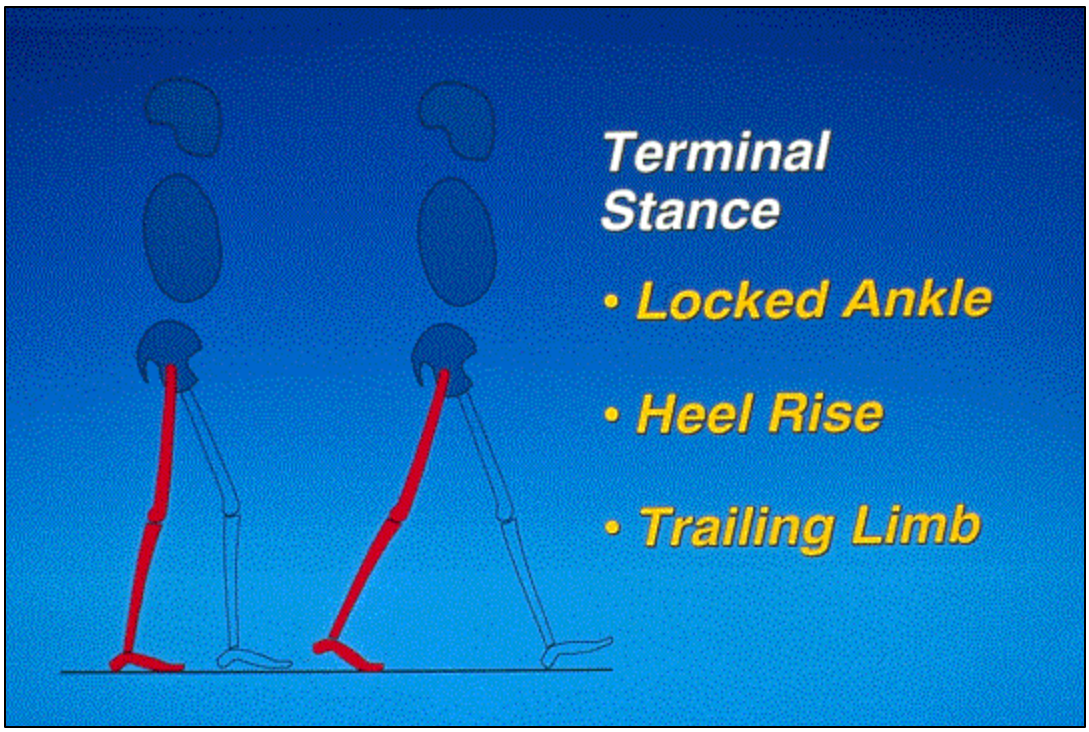
Diplegic Cerebral Palsy



# 3 Foot & Ankle Rockers



Rose J & Gamble JG, Editors. Human Walking 3rd Ed, 2006



# Calf Muscle Weakness

No Fixed Ankle or Heel Rise
Spastic Cerebral Palsy

# Swing Phase

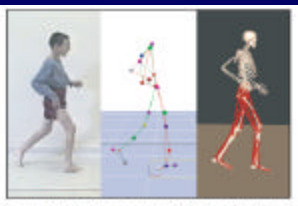
Peak knee flexion in initial swing

Ankle dorsiflexion to achieve foot clearance

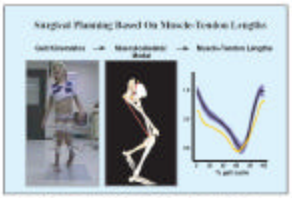
## Gait Analysis

- Video
- Kinematics and Kinetics
- Dynamic EMG
- Postural Balance
- Energy Expenditure

## Musculoskeletal Computer Models of Gait



Computer models are generated from gait kinematics (joint motion) and kinetics (joint forces) and reveal the biomechanical features that influence gait.



The changing muscle lengths during gait are calculated using the computer model. Muscles that are too short and limit gait can be identified and selected for treatment.

## Diplegic Cerebral Palsy

## Diplegic Cerebral Palsy

# Kinematics & Kinetics

- Kinematics: 3-D Joint Motion

  8 Digital Motion Capture Cameras Record

  Position of Light Reflective Markers

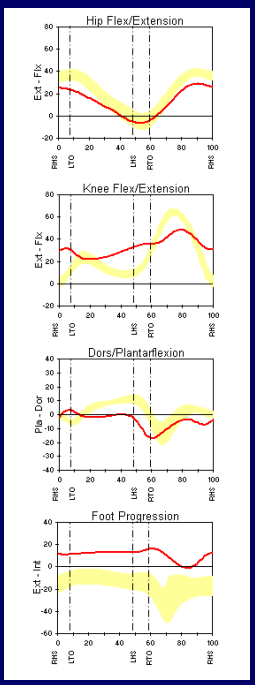
- Kinetics: Forces Passing Through the Joints

  Force Plate Embedded in the Floor Records

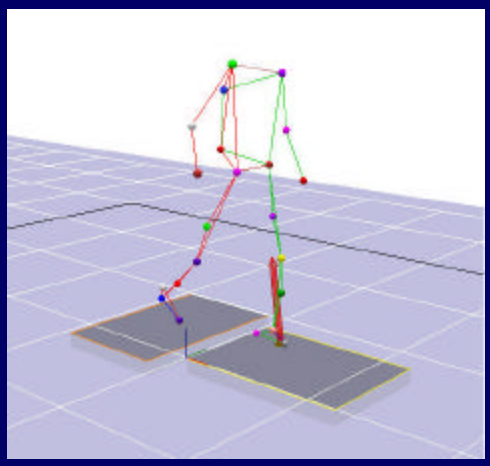
  Ground Reaction Force Vectors

# Kinematics

- Nearly normal hip motion
- Increased knee flexion at IC and stance
- Reduced peak knee flexion in swing
- Increased plantar flexion in terminal stance
- Internally rotated foot progression

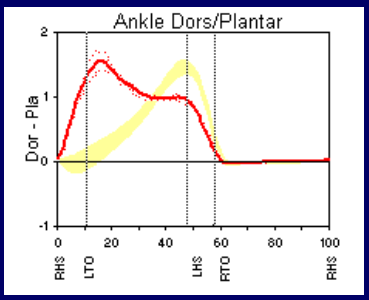


# Kinetics



# Kinetics

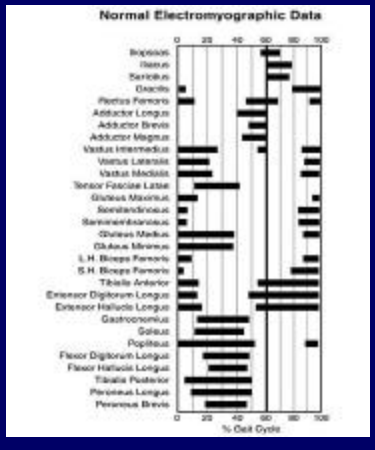
- Normal ankle plantarflexor moment peaks in terminal stance
- Increased plantar flexor moment in loading response “double bump” associated with increased plantar flexion at IC
- Decreased moment in terminal stance associated with a reduced forefoot rocker



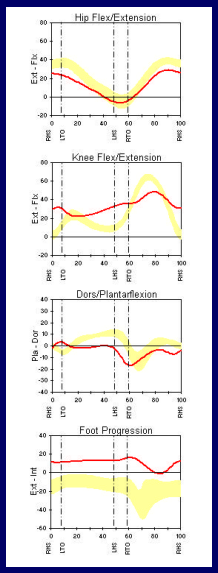
## Dynamic EMG

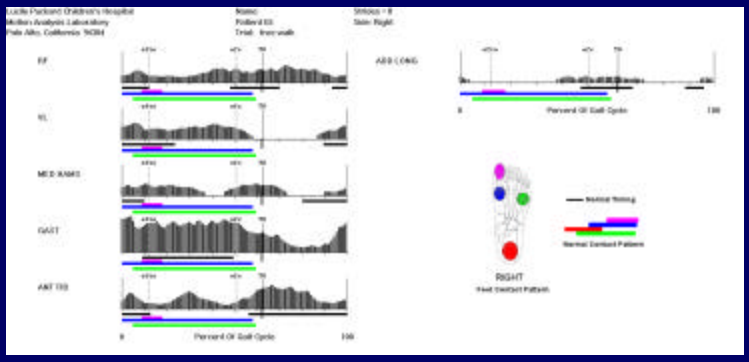
- Footswitch or Markers
- Electrodes
  - Surface
  - Fine Wire
- Interpretation

## Muscle EMG Timing During Gait



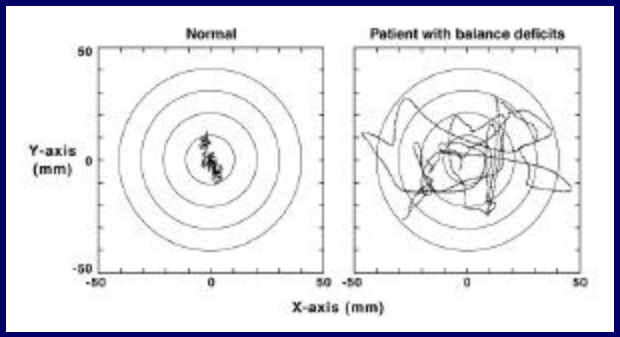

# Dynamic EMG & Kinematics



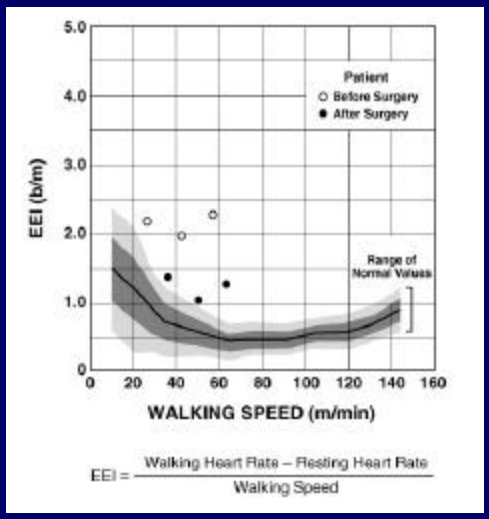

# Postural Balance

- Force Plate Center of Pressure
- Postural Sway with Eyes Open / Closed



# Energy Expenditure

Energy Expenditure Index




# Pathologic Gait

Neuromuscular Conditions

- Equinus
- Equinovarus
- Pseudo equinus (knees bent, ankles at neutral, forefoot contact)
- Jumped (knees bent, ankles true equinus)
- Crouch (knees bent, ankles dorsiflexed)
- Stiff–knee gait

# Pathologic Gait

## Musculoskeletal Conditions

Polio, Dislocation, Arthritis, Muscular Dystrophy

- Pain
- Muscle weakness
- Structural abnormalities (joint instability, short limb)
- Loss of motion
- ***Combinations of above***

# Antalgic Gait

## Pain

- Any gait that reduces loading on an affected extremity by decreasing stance phase time or joint forces

- Examples
  - "stone in your shoe"
  - Painful hip, knee, foot, etc

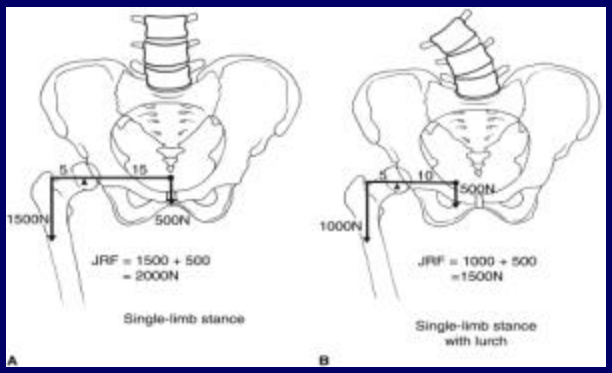
# Pathologic Hip Gait

Painful due to Arthritis

- Coxalgic gait
  - Intact hip abductors; structural stability
  - Lateral shift, hip compression, abductor load
  - Contralateral pelvic elevation


# Hip Biomechanics

Single-limb Stance Lurch Shifts Center of Mass




Hip Joint is Fulcrum: Hip Joint Reaction Force = pull of abductors + body weight

# Antalgic Gait

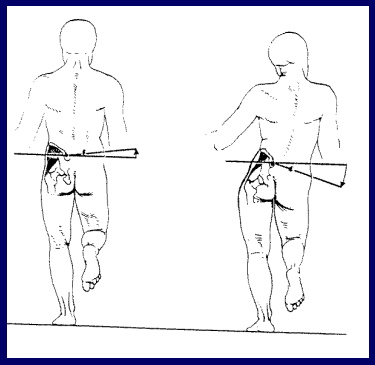
Painful Side:

- Shorten stance phase time
- Lengthen swing phase time
- Lengthen step length

# Pathologic Hip Gait

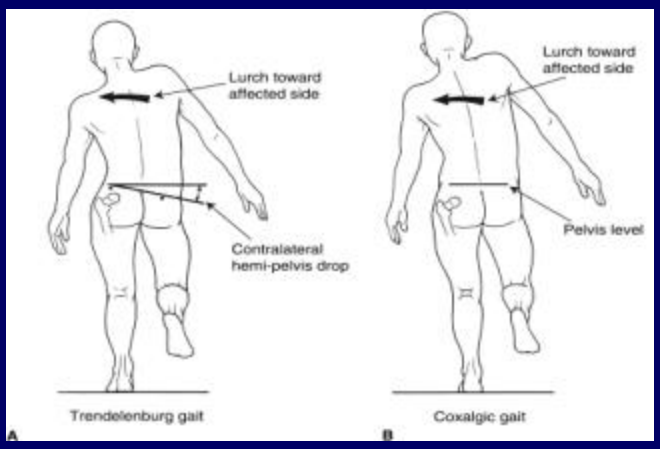
Weakness

- Trendelenburg Gait
  - Weak hip abductors
  - Contralateral pelvic drop



# Pathologic Hip Gait

Trendelenburg Coxalgic Gait




# Pathologic Hip Gait

## Weakness

Gluteus Maximus Lurch muscular dystrophy
- Weak gluteus max no pain
- Lean backwards to prevent falling forward

Quadriceps Avoidance polio, SCI, ACL
- Weak quadriceps no pain
- Increased knee extension

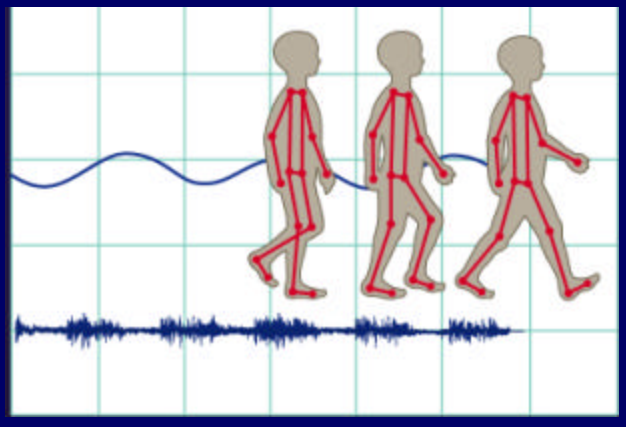
Drop Foot polio, stroke, SCI
- Weak dorsiflexors no pain
- Increased ankle plantarflexion

## Cane & Able

**Cane** is used on **able** side - contralateral side

1. Allows for reciprocal arm swing
2. Widens base of support
3. Reduces demand on affected side - long lever arm

## Motion & Gait Analysis Lab Research



## Spastic Cerebral Palsy

- Loss of Selective Motor Control
- Short Muscle-tendon Length & Joint Contracture
- Muscle Weakness
- Muscle Spasticity

- Mixed CP: Ataxia, Dystonia, Chorea, Athetosis

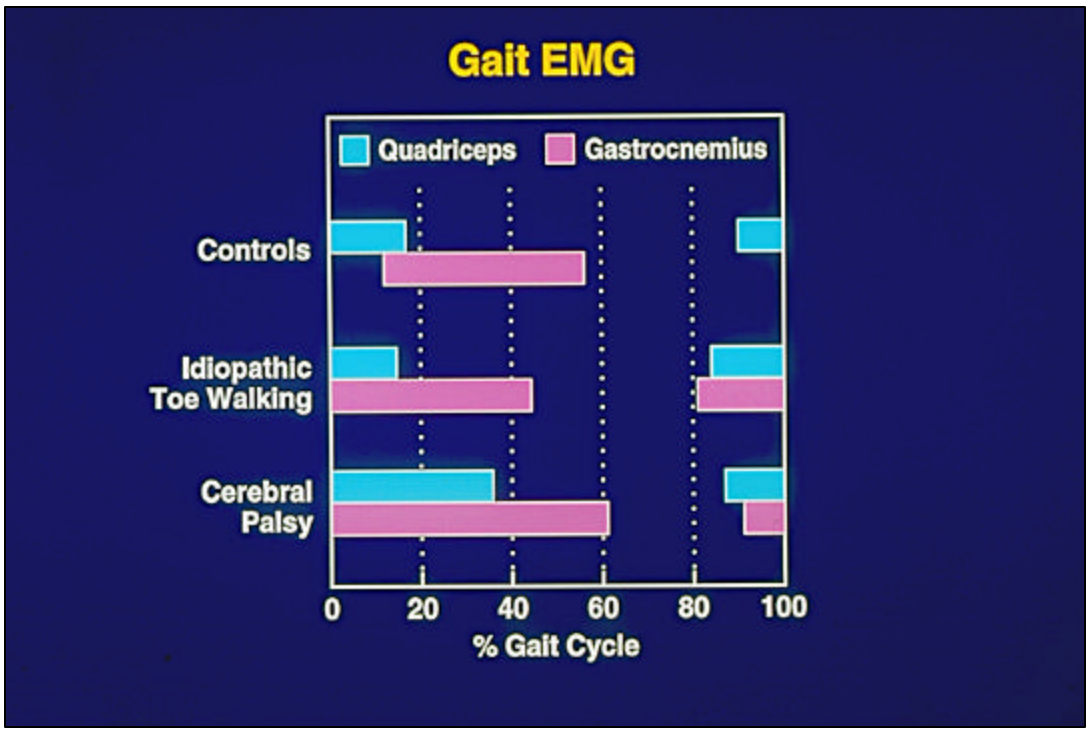
## Neuromuscular Mechanisms underlying Motor Deficits in Spastic Cerebral Palsy

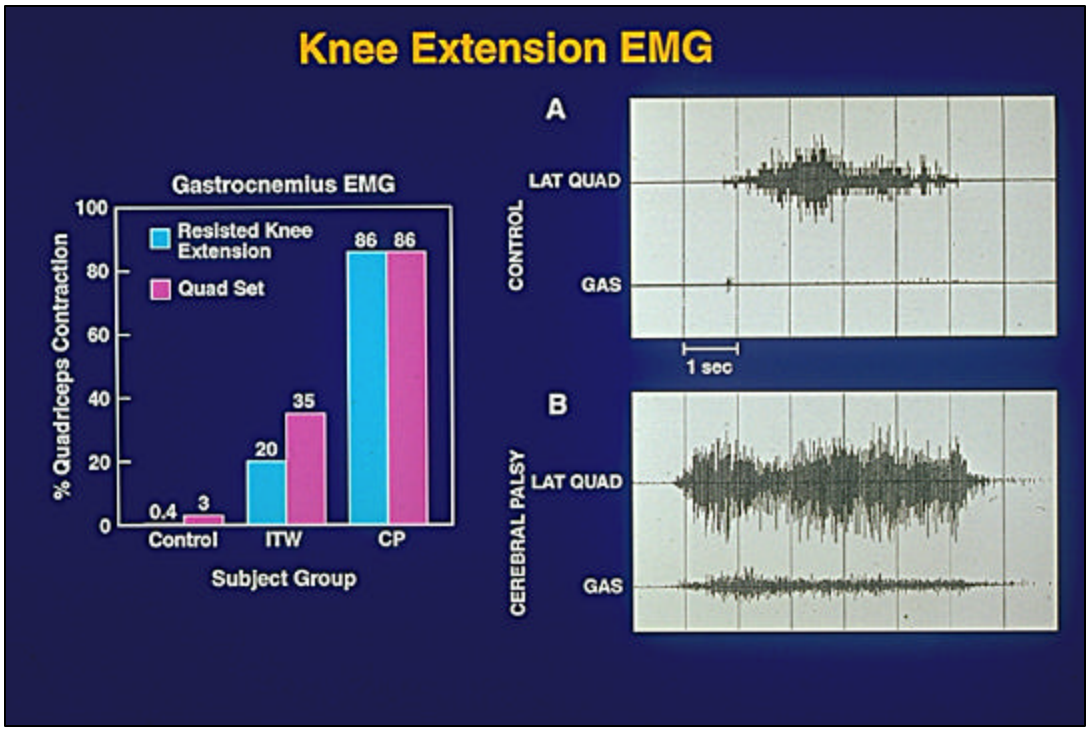
- *EMG Test of Obligatory Muscle Co-activation in Spastic CP*
- *Muscle Pathology in Spastic CP*
- *Neuromuscular Activation & Motor-unit Firing Characteristics in CP*
- Neonatal Brain Abnormalities & Gait Deficits in Preterm Children

# EMG Test to Differentiate Mild Diplegic Cerebral Palsy & Idiopathic Toe Walking

Obligatory Co-activation of Quadriceps & Gastrocnemius

Rose et al. *J Pediatric Orthopaedics (1999)*
Policy et al. *J Pediatric Orthopaedics (2001)*

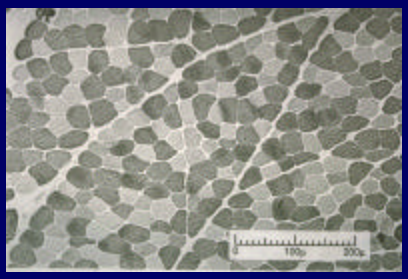


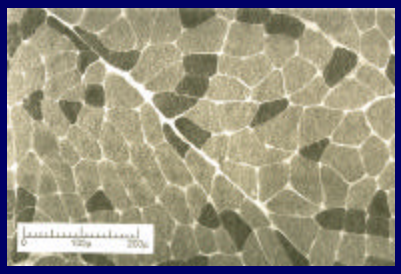



Obligatory Co-activation Quads & Gastrocnemius contributes to Toe-walking & Loss of Selective Motor Control in Cerebral Palsy

# Muscle Pathology in Spastic Cerebral Palsy

Rose et al. *J Orthopaedic Research (1994)*





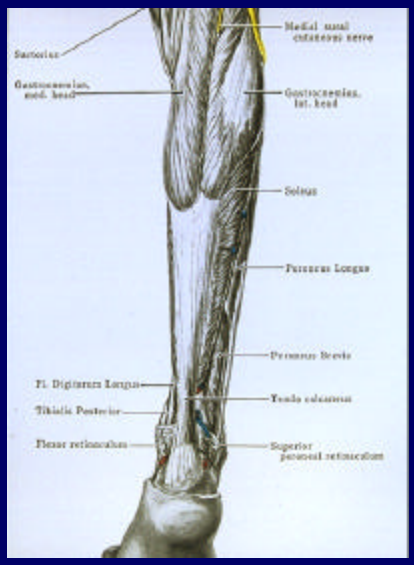
Increased proportion of type-1: type-2 muscle fibers

Increased fiber size variation

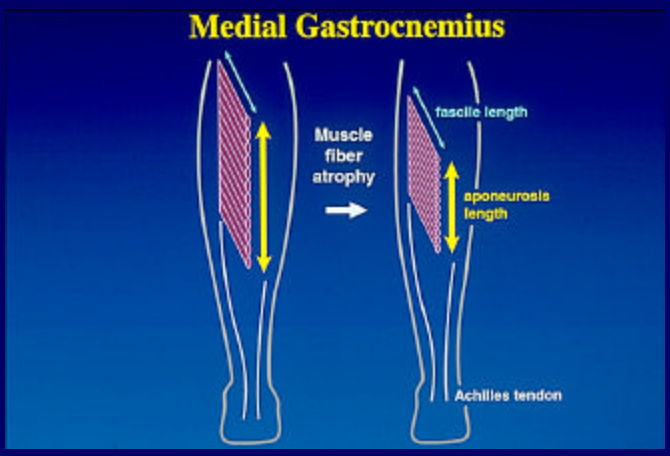
Type-1 fiber proportion vs. EMG prolongation (r=.77,p=.03)

Fiber size variability vs. energy expenditure (r=.69,p=.05)

# Muscle Fiber Architecture

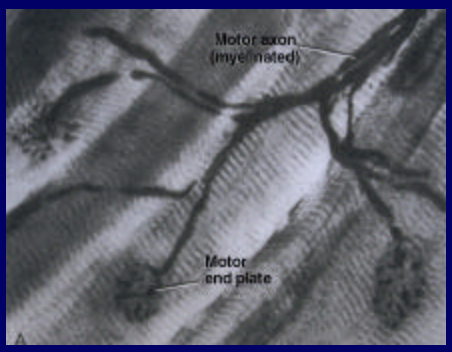


# Muscle Atrophy

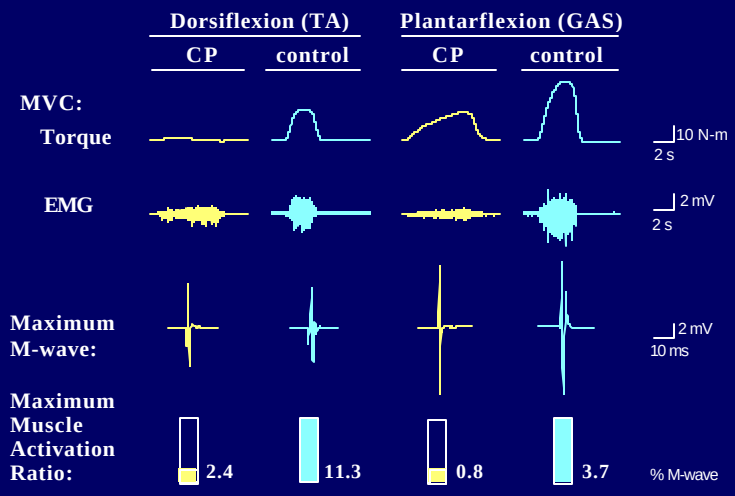



# Neuromuscular Activation & Motor-Unit Firing in Spastic Cerebral Palsy

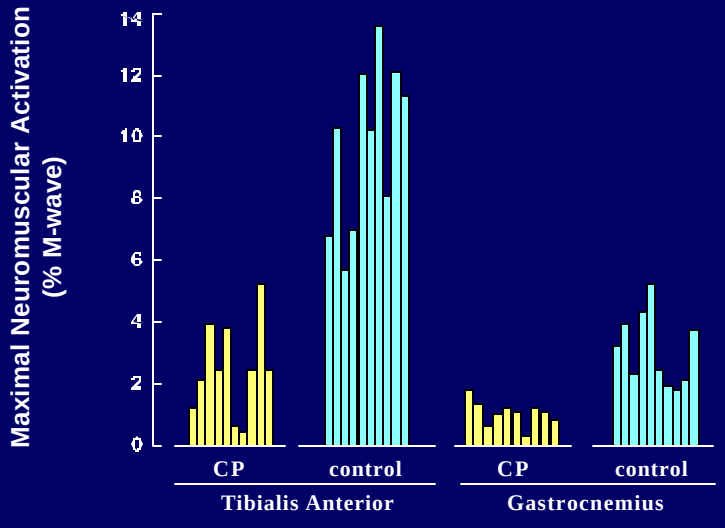
Rose J & McGill KC. *Developmental Medicine & Child Neurology (2005)*




## Torque, EMG, Max M-wave & Neuromuscular Activation




## Maximum Neuromuscular Activation

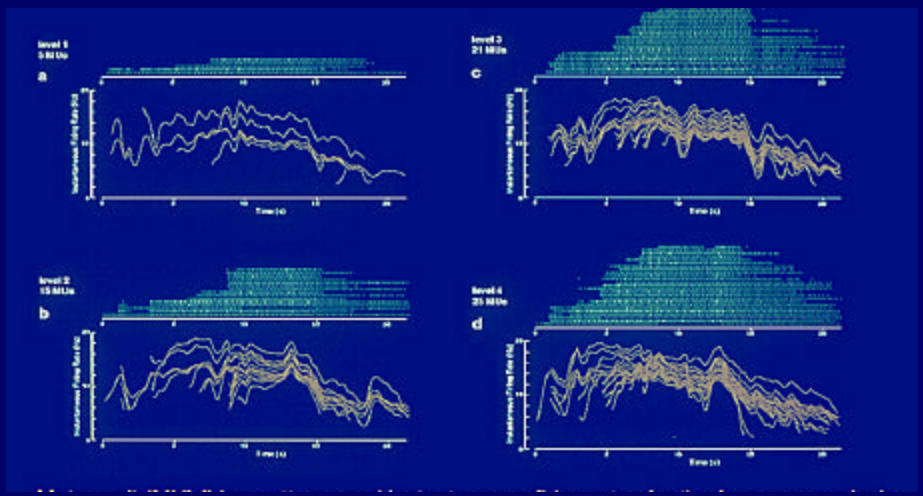


# Sub-maximal Voluntary Isometric Contractions

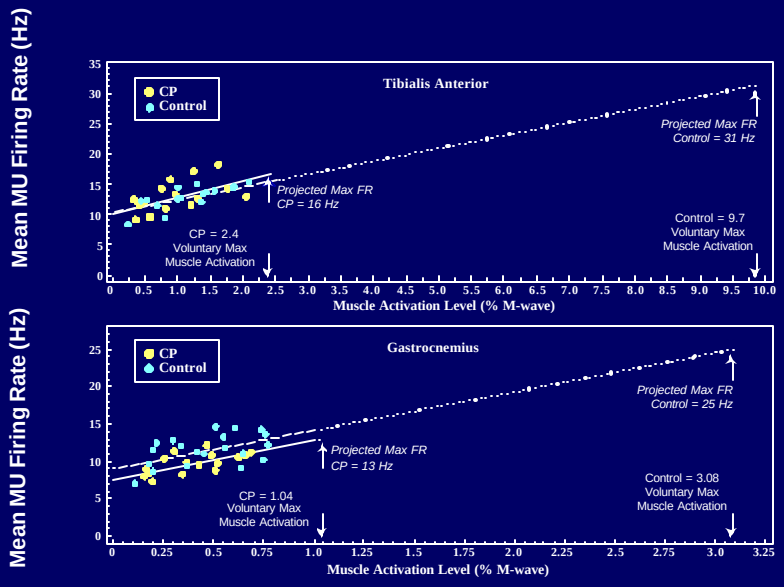
**Neuromuscular Activation Feedback**


# Motor-Unit Firing

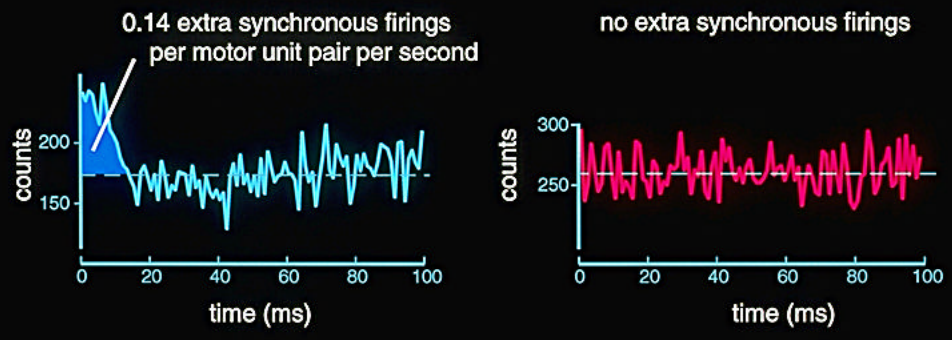
**Submaximal isometric contractions**



# Maximum Motor-Unit Firing Rates in CP




# Short-term Synchronization



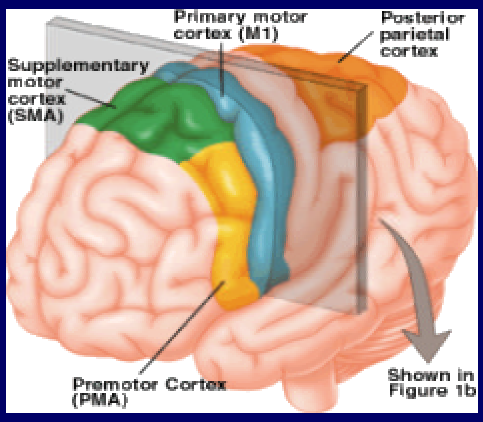
# Neonatal Microstructural Development of Internal Capsule on DTI correlates to Severity of Gait & Motor Deficits in Preterms

J Rose*, M Mirmiran', EE Butler*, CY Lin*, PD Barnes°, R Kermoian* & DK Stevenson'
*Developmental Medicine & Child Neurology (2007)*

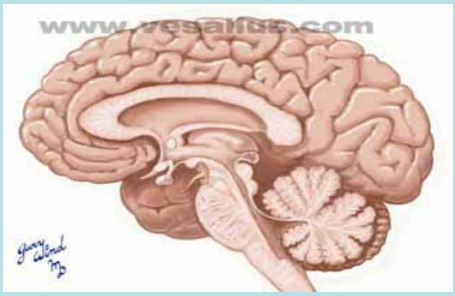
VLBW preterm infants < 32 wks GA, <1500g; 15% have motor deficits

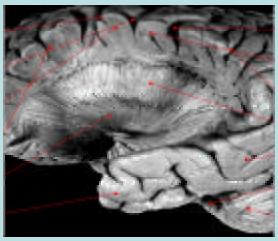
- Neonatal brain MRI-DTI (37 wks PGA)
- Gait analysis at 4 yrs: Gillette Gait Index (NI)

# Motor Cortex



# Sagittal Views of the Brain

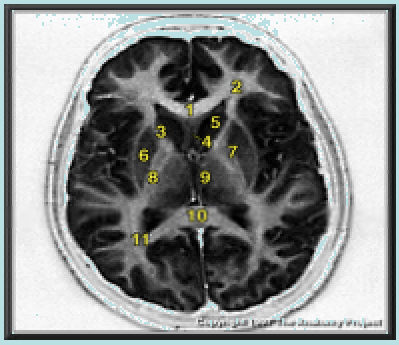




**Internal Capsule**

# Axial View of the Brain

**Anterior**

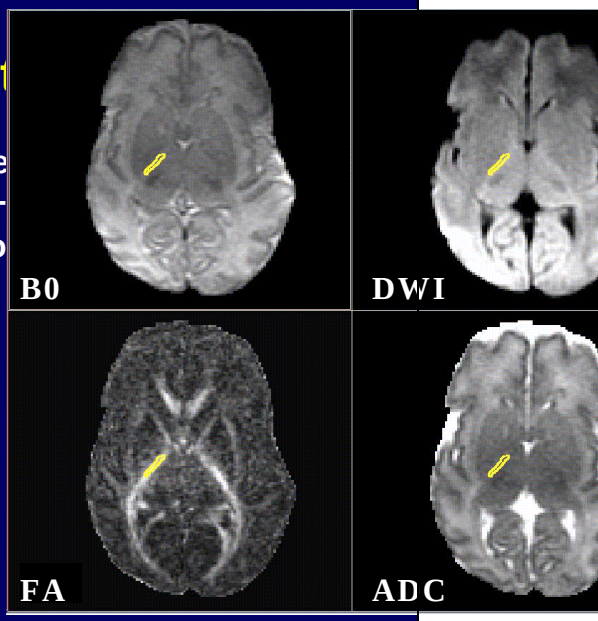



**Posterior**

1. Genu of corpus callosum
2. Forceps minor
3. Internal capsule, anterior limb
4. Septum pellucidum
5. Caudate nucleus
6. Putamen
7. Globus pallidus
8. Internal capsule, posterior limb
9. Thalamus
10. Splenium of corpus callosum
11. Forceps major

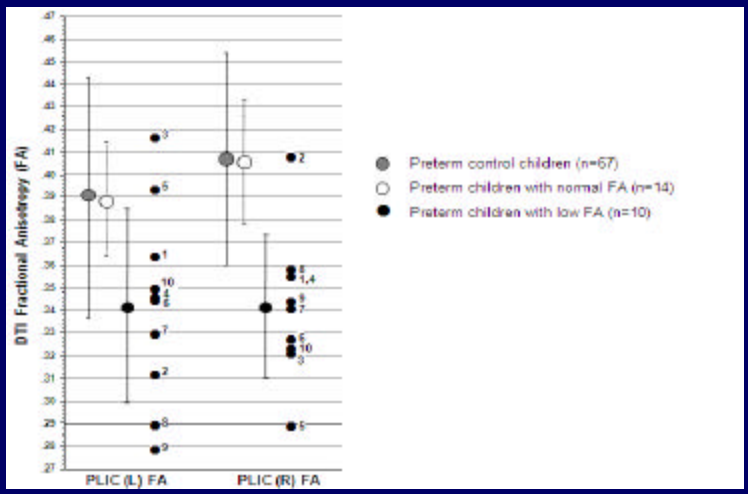
# DTI Fractional Anisot

- Measures directionality of water mole
  relative to neuronal fibers in units, 0-
  (e.g., CSF approaches 0, corpus callo
- Decreased FA in internal capsule
  - Fewer nerve fibers
  - Decrease in thickness of fibers
  - Less myelination
  - Reduced Development




Posterior Limbs of the Internal Capsule (PLIC)

# Neonatal DTI
# Fractional Anisotropy (FA) of PLIC



## Preterm Child with Moderate Gait Abnormalities

## Gillette Gait Index (NI)

- 3D Kinematics - single score for severity of gait deficits
- Principal Component Analysis:
  16 kinematic measures of pelvis, hip, knee & ankle
- Quantifies amount gait deviates from normal
- A higher value indicates more severe gait deficits

# Gait Graphs for Three Children

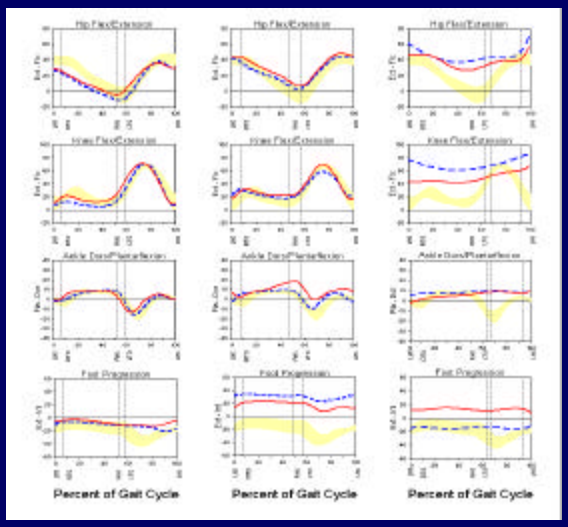
Mild Moderate Severe

Hip

Knee

Ankle

Foot

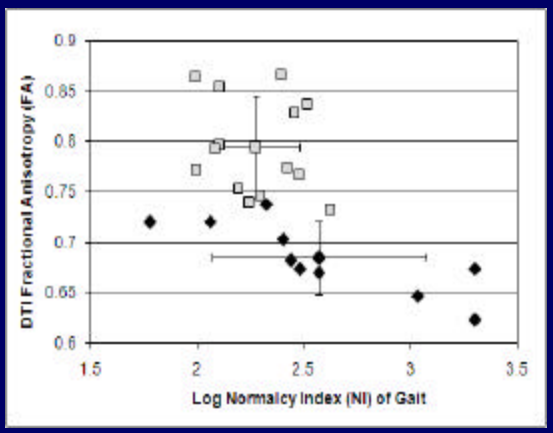



Right leg
Left leg
Normal ± 2 SD

NI = 372, FA = 670 NI = 1083, FA = 647 NI = 2000, FA = 623

# Neonatal Brain MRI-DTI Internal Capsule Posterior Limbs & Gait NI at 4 years of Age

Normal FA (n=14)
Low FA (n=10)



## Acknowledgments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## Thank You