

Skeletal Surgery for Patients with Cerebral Palsy

by
James Gage, M.D.

Skeletal Surgery for Patients

with Cerebral Palsy

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James R. Gage, M.D.

4/22/07

Let's go back 75 years...

- Polio was rampant and it featured:
 - Cognitively normal kids with normal motor control, balance, and sensation who had asymmetrical weakness or paralysis
 - Despite the lack of technology, surgeons of the polio years observed well and knew a lot about gait; whereas currently there is little knowledge and/or instruction about gait during the course of an orthopaedic residency
 - As such, it was fairly easy for the surgeon to figure out the problems and come up with innovative solutions

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In contrast, most children with CP

- Had mixed quadriplegia*, which included:
 - Cognitive delays on the basis of anoxia or global brain injury
 - Mixed tone (spasticity + dystonia)
 - Severe difficulties with selective motor control and balance

*Very premature infants usually died, so spastic diplegia was relatively rare

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Problems with treating CP

- Motor control, balance problems and spasticity dramatically altered normal gait
 - Understanding normal gait started with Inman in 1947
 - The pathophysiology of CP was poorly understood
 - It was difficult to "make a silk purse out of a sow's ear"
- Surgery was a "high risk" procedure:
 - Anesthesia was dangerous – kids could die
 - Infection was a worry – there were no antibiotics
 - Internal fixation was relatively non-existent
 - "Rarifying Osteitis" was a problem caused by the implantation of dissimilar metals
 - Good internal fixation didn't come until 1937 when Venable and Stuck* introduced Vitalium® into orthopaedics

* Venable, CS & Stuck, WG; The results of recent studies and experiments concerning metals used in the internal fixation of fractures. *JBJS* 30-A: 247, 1948.

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A bit of history:

- Surgeons in the 1st half of the last century tried not to operate on children with cerebral palsy
 - Treatment was primarily bracing and PT
 - If surgery was done:
 - Bone surgery was avoided because of problems with internal fixation and "Rarifying Osteitis"
 - Prolonged duration of surgery risked infection
 - Multiple procedures at one time yielded unpredictable outcomes

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So the CP Treatment Standard Became:

- Try to treat with bracing and PT
 - Surgery at last, but not at first
- If surgery was necessary it had to be fast and simple:
 - Minimally invasive
 - Tenotomies rather than lengthenings
 - Just do the muscles, leave the bones alone
 - Isolated surgeries
 - Minimize time under anesthesia
 - One thing at a time
 - Too much at one time yielded an unpredictable outcome

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What Is the Situation Today?

- The primary type of cerebral palsy is spastic diplegia secondary to premature birth
 - These kids are cognitively normal with essentially normal upper extremity function
 - Generally they have "pure spasticity" – mixed tone is uncommon
 - Most have relatively good balance and fairly normal motor control
 - Control is best proximally at the hip and worst distally (foot and ankle)

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What Is the Situation Today?

- Surgery is relatively safe
 - Anesthesia is safe and reliable
 - Infection is rare and good antibiotics are available
 - Internal fixation of osteotomies is now the norm and excellent devices are available
 - Normal and pathological gait are well understood
 - But for the most part they are not taught and attempts to introduce these subjects into the orthopaedic curriculum are often met with frank hostility
 - Excellent results are achievable
 - If you understand the problem

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Consider the following examples:

- A mechanic who didn't "have a clue" about the workings of an engine...
 - *Would you take your car there for repair?*
- A football referee who didn't know the rules of the game...
 - *How long would it be before the fans murdered him?*
- A cardiac surgeon who felt auscultation of the heart was adequate for pre-op assessment
 - *Our HMO's would love him, but would you submit to his planned surgery?*



"You can't act as your own attorney. This kind of trickery and duplicity is best left to professionals."

Or perhaps a difficult legal case?

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So the old traditions continue...

- Tenotomies rather than muscle lengthenings
 - *"If it looks tight, cut it!"*
- Ignore the bone deformities
 - *But these are the levers upon which muscles act*
- "Single event surgery"
 - *With long periods of immobilization & rehabilitation between events*
- Poor and inconsistent outcomes
 - *Which are never critically assessed*

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It strikes me that it's time for a new and better approach to the problem

- Based upon:
 - Knowledge of normal gait
 - An understanding of the pathophysiology of CP
 - Critical pre-operative assessment
 - Static – Clinical exam
 - Dynamic – Gait analysis
 - A thorough critique of outcome
 - Pre- & post-energy cost of walking
 - Gait analysis & clinical exam
 - Appropriate outcome questionnaires
 - Patient/parent satisfaction



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Clinical Advances from G.A.

- In essence, we now have the means for:
 - An entirely new approach to the problem*
 - With much less muscle surgery
 - Spasticity reduction
 - Botox
 - Better therapy
 - ❖ Strengthening
 - And, much more attention to skeletal deformity
 - Lever-Arm Dysfunction (LAD)

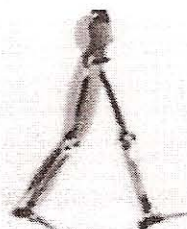
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Recall that during ambulation...

- Muscles &/or Ground Reaction Forces provide the required force for motion
- The skeleton provides the rigid lever-arm for the forces
- The joints provide the action point at which movement occurs



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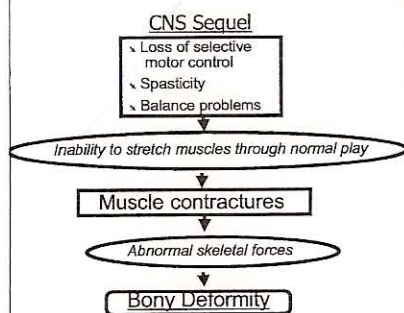
...and normal gait depends upon competing internal & external moments

- Internal
 - ❖ The lever arms of muscles, tendons, ligaments
- External
 - ❖ The lever arms of the ground reaction force & segment weights



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Neurological Injury :

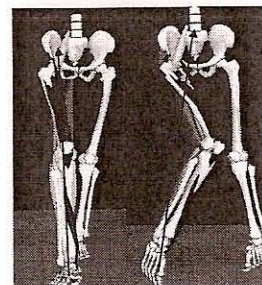


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And we end up with Lever-Arm Dysfunction

But, you can't get normal joint moments through twisted bones !

- If skeletal lever-arms are distorted
 - Because of
 - Abnormal growth forces, or
 - Trauma
 - The effect will be that
 - Muscle forces can not be properly transmitted to the joints
 - Types of lever-arm dysfunction
 - Torsion of the long bones
 - Short lever-arm
 - Flexible lever-arm
 - Unstable fulcrum
 - Positional lever-arm dysfunction
 - Fixed joint contractures



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What have we learned so far?

- Cerebral palsy produces 1^o abnormalities in a child who then, with time and growth, will develop 2^o deformities (muscle contractures and bony deformities)
- Skeletal movements are accomplished via moments which have two components:
 - Force — muscle, ground reaction, or inertia
 - Lever-Arm — part of the skeleton itself

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What have we learned so far?

- The muscle and/or ground reaction forces are neither appropriate nor adequate
 - *Poor selective motor control*
 - *Muscle contractures*
 - *Lever-arm dysfunction*
- In cerebral palsy lever-arm dysfunction is the norm
- It is far easier to correct abnormal levers than abnormal forces!

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What Can Be Done?

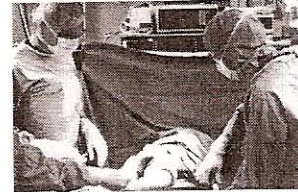
■ Surgical Options

- Lengthen muscles
 - e.g., tendo-Achilles lengthening
- Shorten/tighten muscle
 - e.g., patellar tendon advancement
- Transfer muscle insertions/origins to change their action
 - e.g., distal rectus femoris transfer
- Reduce spasticity
 - e.g., selective dorsal rhizotomy or baclofen pump)
- Correct lad: i.e., skeletal deformity
 - "Lever restoration" — "Fix the bones!"

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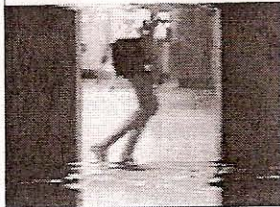
What is Multi-Level Surgery (MLS)?

- The correction of all or most of the deformities present during the course of a single anesthetic
 - Usually done with two teams of surgeons working simultaneously
 - Gait analysis is routinely used as part of pre-operative decision-making process



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What is required for successful MLS?



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- Knowledge/Understanding of the:
 - Physiology of normal gait
 - Pathophysiology of cerebral palsy gait
- Measurement tools to accurately define the abnormal gait before & after the intervention
 - Clinical examination & appropriate X-rays
 - Dynamic examination (i.e., video and gait analysis)
 - Anesthesia examination to differentiate static versus dynamic contracture

What is required for successful MLS?

- A team with the surgical knowledge & ability to carry out the procedures
- A protocol (care pathway) to manage:
 - Pain control
 - Rehabilitation



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The orthopaedic procedures begin with an examination under anesthesia...

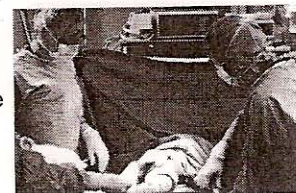
- This exam is important because it lets you differentiate between static and dynamic contracture
- It also allows determination of the degree of contracture since much of the surgery is done prone



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Our present orthopaedic M.L.E.P.

- Generally starts with the patient prone
- The bulk of the surgery is done in this position
- Bilateral cases are done simultaneously with team surgery
- Usually the feet are done first and we work our way up to the hips



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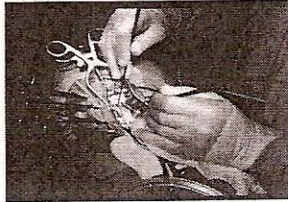
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The amount of multilevel surgery done probably peaked in the late '80's

- Peacock introduced the selective dorsal rhizotomy into the U.S.A. in 1986
- We did our first rhizotomy at Newington in 1988
 - *Spasticity reduction & Botulinum toxin have allowed us to do much less muscle surgery*
- Importance of L.A.D. requires more bone surgery
 - The tradition is to do muscles & leave bones – *that needs to change*



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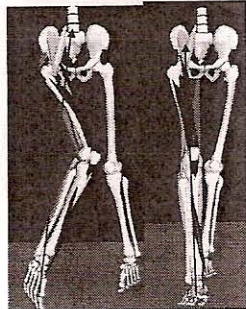
The Importance of L.A.D.

- Can affect all major lower extremity joints
 - Hip
 - Rotational LAD
 - Short LAD
 - Unstable fulcrum
 - Ankle & Foot
 - Rotational LAD
 - Flexible LAD
 - Knee
 - Rotational LAD
 - Fixed joint contracture
 - Positional LAD

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Mal-rotated Lever-Arm:

- Examples
 - External tibial torsion
 - Femoral anteversion
- Effect
 - Primary moment is reduced (The knee extension moment)
 - Unwanted moments are introduced – *External rotation, Valgus*



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Short Lever-Arm:

- Examples
 - Midfoot amputation
 - Coxa valga or coxa breva
- Effect
 - Since $M = F \times A$, If the lever-arm length is cut in half ($A/2$), Then M is cut in half as well.



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Unstable Fulcrum:

- Example
 - Dislocated or subluxated hip
- Effect
 - Since there is no stable pivot point, no effective moment can be generated



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Anteversion is the rule in spastic diplegia...

- These children have "Persistent Fetal Alignment" because they never stand erect & fetal anteversion doesn't remodel
- Further postnatal deformity from spastic internal rotators of femur
 - Anterior gluteals
- Anteversion produces lever-arm dysfunction at the hip and internal rotation gait at the knee



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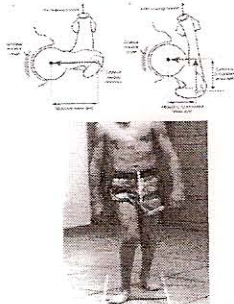
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Persistent fetal alignment is almost always part of the problem

■ Femoral anteversion

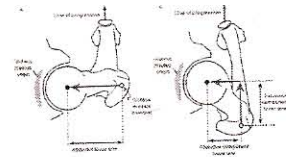
- Distorts normal hip moments
- Produces pseudo-adduction deformity
- Is usually associated with external tibial torsion &/or pes valgus
- Is easily corrected, but usually ignored



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Femoral Anteversion

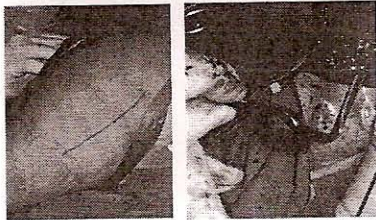
- Compensated by internal femoral rotation and/or excessive pelvic lordosis
- When a child walks with his hips in flexion, the gluteus minimus acts as a hip flexor and internal rotator
- Lever-arm dysfunction 2^o to anteversion reduces the moment of the hip abductors



- ② Arnold, AS, Komattu, AV & Delp, SL (1997) Internal rotation gait: a compensatory mechanism to restore abduction capacity decreased by bone deformity. *Dev Med Child Neurol* 39, 40-44.
- ② Delp, S.L., Arnold, AS, Speers, RA & Moore, CA (1996) Hamstrings and psoas lengths during normal and crouch gait: Implications for muscle-tendon surgery. *J Orthop Res* 14, 144- 151.

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Anteversion correction is best done prone...

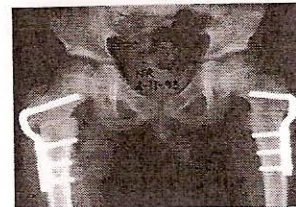


- The lesser trochanter is easily palpated from this incision
- Entry point of plate is just distal to trochanteric apophysis
- A-O plate allows an osteotomy proximal to the trochanter
- Osteotomy is stable enough so that a spica cast is not necessary

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Stable fixation allows early mobility...

- Prone lying one day post-surgery
- Range of motion to hips 3-4 days post surgery
- Weightbearing in short leg walking casts 3 weeks post-surgery
- Child returns home 4-5 days post-surgery with short leg casts tied together with a removable Denis-Browne bar



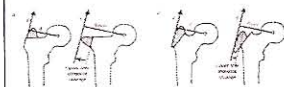
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Short Lever-Arm &/or Abnormal Fulcrum:



■ General principles

- Femoral and acetabular reconstruction are often necessary
- Bilateral femoral osteotomy is usually necessary to preserve equal limb lengths
- Varus derotational femoral osteotomy will restore lever-length but slackens the hip abductors
- Trochanteric transfer may be necessary to lengthen lever-arm &/or re-tension hip abductors



Lengthens lever & tightens abductors

Only tightens the abductors

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The Importance of L.A.D.

- Can affect all major lower extremity joints
 - Hip
 - Rotational LAD
 - Short LAD
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 - Fixed joint contracture
 - Positional LAD

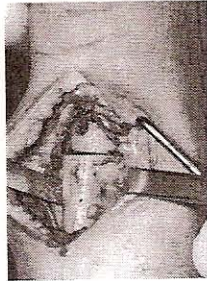
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Tibial torsion is corrected next...

- An antero-medial incision is made
- The plate is located on the bone and a distal hole drilled
- Osteotomy is performed and the plate re-applied
- Two screws are placed and rotation verified
- Fibular osteotomy rarely necessary



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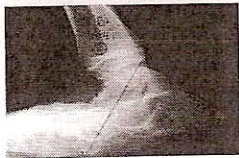
Flexible Lever-Arm:

- Example
 - > Pes planovalgus
- Effect
 - > Imagine trying to lift a stone with a rubber crowbar
 - > The ground reaction force is unable to generate an effective plantarflexion/knee-extension couple



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With os calcis lengthening &/or talo-navicular arthrodesis results have improved...

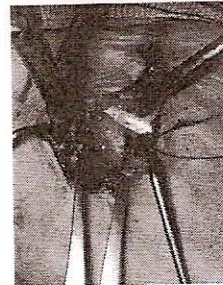


- Subtalar arthrodesis did not correct the forefoot abduction and supination
 - > One needs to be ready to do whatever is necessary to regain a plantargrade, stable, properly oriented foot

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Tibial torsion is hard to assess until pes valgus is corrected...

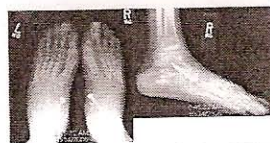
- Pes valgus is corrected by:
 - > Lengthening os calcis with tri-cortical allograft plus
 - > Reefing of the talo-navicular capsule &/or tightening of tibialis posterior
 - > Surgery easily done prone if tricortical allograft is available
- In older children with severe deformity we often add
 - > 1st Cuneiform osteotomy, or
 - > Talo-navicular arthrodesis
 - > Subtalar arthrodesis is done less frequently now



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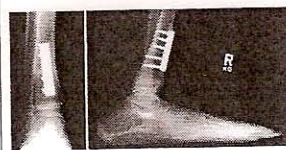
The foot must be realigned & rigidity must be restored

- Goals:
 - > Realign medial column
 - > Correct hindfoot valgus
 - > Correct forefoot varus
- Many ways to do this:
 - > Subtalar arthrodesis
 - > Os calcis lengthening
 - > Talo-navicular fusion
 - > Cuneiform &/or 1st metatarsal osteotomy may be necessary as well



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Corrective Rotational Osteotomies



- General principles
 - > Two team surgery
 - > Firm intertrochanteric osteotomy for femur
 - Lengthens psoas
 - Avoids spica
 - Allow early weightbearing
 - > Distal tibial osteotomy
 - Low risk of vascular complications or nerve palsy
 - Allows early walking in a short-leg cast

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The Importance of L.A.D.

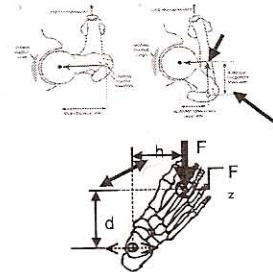
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Malignant Mal-alignment Syndrome



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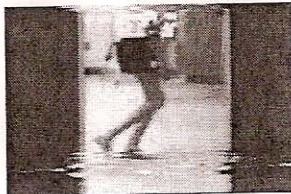


Abnormal moments arise at both ends of the limb

Fixed Joint Contractures

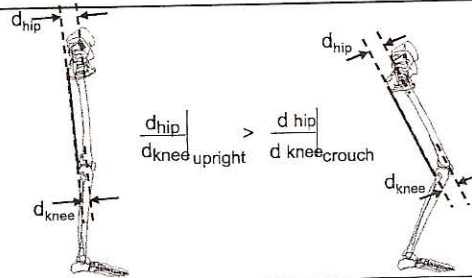
This occurs most commonly at the knee

- A common component of crouch gait that is associated with
 - Patella alta and/or patellar stress fracture in children
 - Degenerative arthritis of the patellar-femoral joint in adults
 - A large increase in the energy cost of walking
 - Contractures, patella alta, and quadriceps lag are remediable with good treatment



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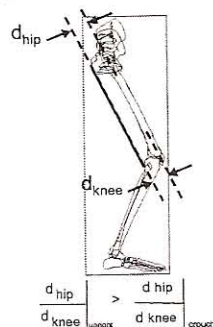
Positional Lever-Arm Dysfunction & Fixed Joint Contractures



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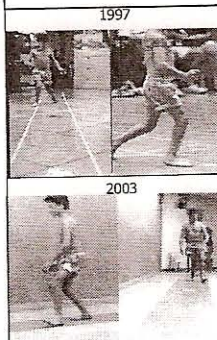
This Is The Most Difficult Of All...

- There are multiple etiologies
 - Muscle contracture
 - Muscle weakness
 - All of the other types of LAD
- The solution to this problem leads right into the solution for crouch gait
 - So we need to briefly talk about crouch gait



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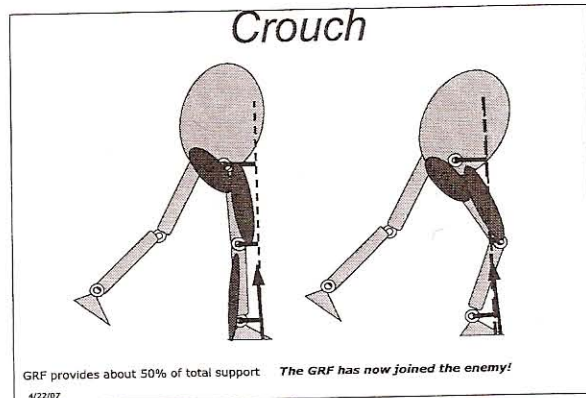
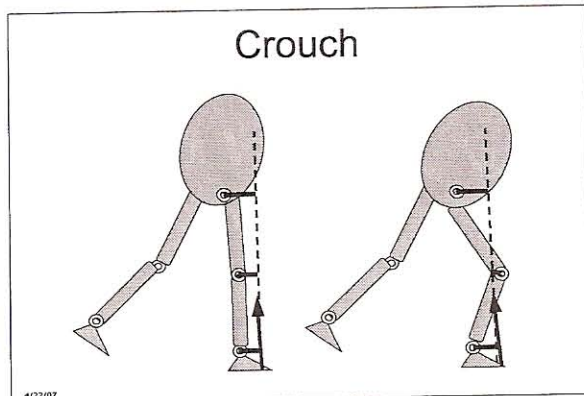
The Role of M.L.E.P. in Crouch Gait



- Crouch gait is progressive
 - Once the PF/KE is lost crouch will invariably progress
 - Progression is most rapid in adolescence when the power to mass ratio falls rapidly
 - I know of no way to get these children up without multiple lower extremity procedures

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Elements of Crouch Gait

- Loss of PF/KE Couple
 - > Lever-arm dysfunction &/or
 - > Soleus insufficiency
 - soleus is too long
 - muscle elongates with time and growth
 - > Gastrocnemius is often contracted (short)
- 2° Contractures of hip and knee flexors
 - > Vastii are long
 - > Rectus femoris is of normal length or contracted
- Contracture of posterior knee capsule develops over time

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When does crouch gait occur?

- Just prior to or during the adolescent growth spurt
- Precipitating factors?
 - > Lever-arm dysfunction
 - > Previous weakening of the plantarflexors
 - ETA
 - Rhizotomy
 - > The law of magnitude
 - Power to Mass Ratio falls as we grow

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Remedy for Fixed Knee Contractures

- Distal femoral extension osteotomy seems to be the best solution
 - > Patella alta almost always has to be corrected with patellar tendon or tibial tubercle advancement
 - > Degenerative arthritis of the patellar-femoral joint in adults
 - > Sciatic stretch can occur
 - > Early motion with CPM prevents contracture

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Method of Extension Osteotomy & P.T.A.

- Deformity is measured
- A distal osteotomy is carried out with an Inverted A-O hip spline
- Tibial tubercle / patellar tendon is advanced to re-tension the quadriceps

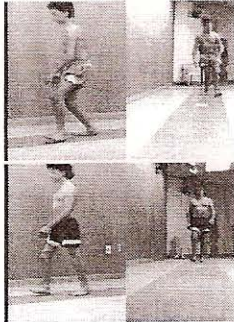
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Surgeries required to correct problem

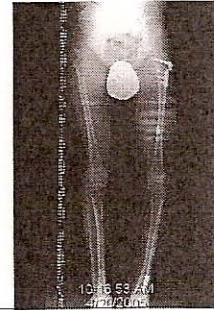
- Surgeries elsewhere <2003
 - Selective dorsal rhizotomy
 - Bilateral med. & lat. hamstring lengthening
 - Rectus femoris transfers,
 - Iliopsoas lengthening,
 - Gastrocnemius recessions
- Our surgeries in 2003 (all bilateral & single-stage)
 - Distal femoral extension osteotomies (incorporating some external rotation)
 - Patella tendon advancements
 - Bilateral supramalleolar derotational tibial osteotomies



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L.A.D. at Multiple Levels

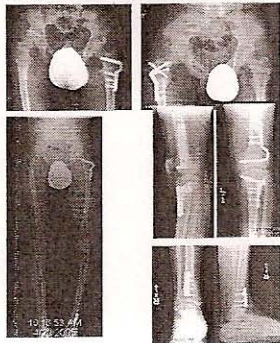
- Problems include:
 - Leg length discrepancy
 - R>L = 2 cm
 - Pelvic obliquity (R↑ & L↓)
 - Hip subluxation with coxa valga and anteversion on right
 - Abductor insufficiency and adductor contracture on right
 - Left knee flexion contracture with patella alta
 - Tibia vara, left
 - Bilateral external tibial torsion



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L.A.D. at Multiple Levels

- *Requires correction at multiple levels*
 - Right femoral derotation and shortening with trochanteric advancement
 - Left distal femoral extension osteotomy with tibial tubercle advancement
 - Correction of tibia vara, left
 - Bilateral distal derotational tibial osteotomies



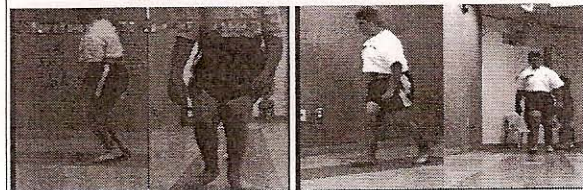
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Things We Have Learned

- Simultaneous correction of multiple lower ext. deform.
- Role of lever-arm dysfunction (LAD)
- The biomechanics of crouch gait

PRE-OP

POST-OP



Post-Operative Radiographs



Pre-operative lateral



Post-operative AP



Post-operative lateral



Post-operative lateral @ 9 months

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Following Surgery...

- Robert Jones dressings are applied to the lower extremities for three days
- Pain control
 - Continuous epidural anesthesia for three days with 90% clonidine (2 micrograms/cc) and 10% ropivacaine (0.1%) plus intravenous valium
 - Toradol (IV) has been a useful adjunct for pain
- Short leg casts are applied on day 3
 - If femoral osteotomies were done we usually use a Denis-Browne bar
- Physical therapy starts on day 3 or 4
- Discharge on day 5

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Rehabilitation - Short term

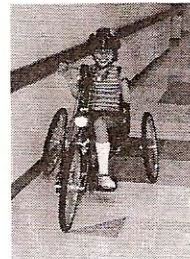
- Prone lying starts on 1st or 2nd day
- Patient is allowed to sit or lie as tolerated, but if osteotomies were done, no standing for 3 weeks
- Parents do range of motion exercises at home for first three weeks
- Braces are molded, walking casts applied and ambulation started in physical therapy (as outpatient) three weeks post surgery
- Casts are removed and braces applied at six to seven weeks post surgery



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Rehabilitation - Long Term

- There are three general stages to the recovery
 - Healing stage ~ 6 to 8 weeks
 - Strengthening ~ 3 to 6 months
 - Re-learning ~ 12 to 18 months
- Physical Therapy
 - Stressing RoM, strengthening, gait & balance training
 - Incidence - 2-3 X / wk for ~ 6 months; then weekly until gait plateaus
- A daily home exercise program
- Reoccurrence of contractures are common in a growing child & must be treated promptly and vigorously



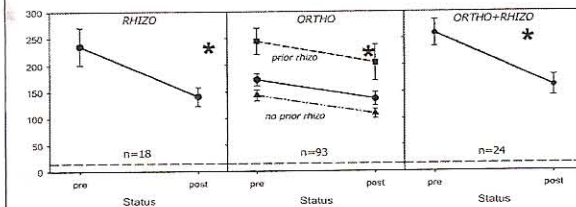
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Outcome Analysis

Schwartz, M.H., Viehweger, E., Stout, J., Novacheck, T.F. & Gage, J.R. (2004) Comprehensive treatment of ambulatory children with cerebral palsy: an outcome assessment. *J Pediatr Orthop* 24, 45-53.

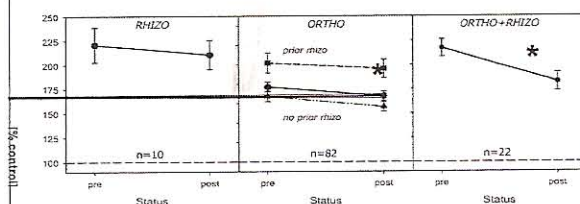
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Normalcy Index (Gillette Gait Index)



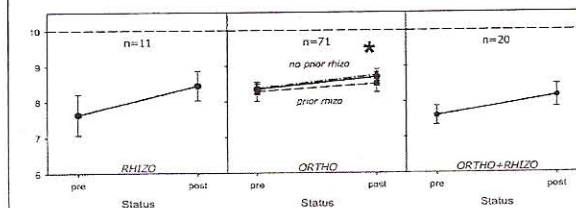
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Normalized Oxygen Consumption



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FAQ 10-Level Walking Scale



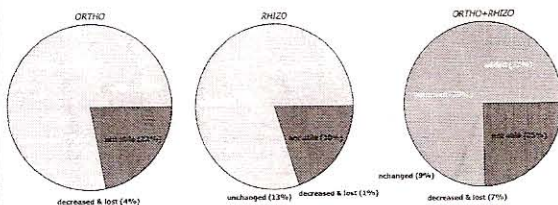
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Skeletal Surgery for Patients with Cerebral Palsy

by

James Gage, M.D.

FAQ 22 Higher-Level Skills



4/22/07

Interpretation of Results*

- Comprehensive treatment is safe and effective
- Gait Analysis provides important information for treatment planning and outcome assessment

*Schwartz MH, Viehweger E, Stout J, Novacheck TF, and Gage J (2004), "Comprehensive Treatment of Ambulatory Children with Cerebral Palsy: An Outcome Assessment" *Journal of Pediatric Orthopaedics*, 24, pp 45-53.

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