Indications & Explicit Guidance for Soft-Tissue Surgery Using Gait Analysis

Tom F Novacheck, MD
Gillette Children’s Specialty Healthcare
St. Paul, MN, University of Minnesota
tnovacheck@gillettechildrens.com

Thanks to Jean Stout, Adam Rozumalski, and Mike Schwartz

I have no disclosures.

Schedule
Gait Analysis Guidance for Soft-Tissue Surgery

- General Principles & Biomechanical Models • 10 min
- Specific muscles (PE, gait data, tx, & reported outcomes) • 40 min
  - Hamstrings
  - Psoas
  - Gastrocnemius
- Discussion, Question & Answer • 5 min

Learning Objectives
1. Discuss how biomechanical models contribute to the understanding of surgical indications for soft tissue procedures.
2. Identify specific gait analysis findings which are indications for psoas, hamstring, & gastrocnemius procedures in the child with CP.
3. Recognize common pitfalls in decision-making regarding psoas, hamstring, and gastrocnemius procedures in order to avoid adverse outcomes.
4. Recognize current shortcomings in gait analysis guided decision making for soft tissue procedures.

Muscle Structure

Copyright: The University of Waikato, 2007

2015 AACPDM Breakfast Session
Surgical Tx of Soft Tissue Contractures
Novacheck, Stout, Rozumalski

© 2015 AACPDM Breakfast Session
Surgical Tx of Soft Tissue Contractures
Novacheck, Stout, Rozumalski

I have no disclosures.

Schedule
Gait Analysis Guidance for Soft-Tissue Surgery

- General Principles & Biomechanical Models • 10 min
- Specific muscles (PE, gait data, tx, & reported outcomes) • 40 min
  - Hamstrings
  - Psoas
  - Gastrocnemius
- Discussion, Question & Answer • 5 min

Learning Objectives
1. Discuss how biomechanical models contribute to the understanding of surgical indications for soft tissue procedures.
2. Identify specific gait analysis findings which are indications for psoas, hamstring, & gastrocnemius procedures in the child with CP.
3. Recognize common pitfalls in decision-making regarding psoas, hamstring, and gastrocnemius procedures in order to avoid adverse outcomes.
4. Recognize current shortcomings in gait analysis guided decision making for soft tissue procedures.

Muscle Structure

Copyright: The University of Waikato, 2007
Muscle Structure

Muscle contracture in CP

- Causes are multifactorial
  - Innervation
  - Mechanical
  - Growth

Muscle structure in CP

- In-vivo measurement shows fasicles/sarcomeres that are not short
- Muscles are smaller

Muscle contracture in CP

- Reduced muscle size
  - Volume
  - PCSA
  - Thickness
  - Belly length

Interventions

- Global tone management
- Focal tone management
  - Botox
- Casting/stretching
- Surgery

Modeling Muscle Geometry

Fig 5: Gastrocnemius calf muscle path wrapping over a wire cylinder affixed to the tibia
Muscle-tendon lengths

- Calculate MTL based on joint positions (kinematics)

OpenSim

- Simbios
  - NIH funded project
- 92 muscles
- Extensively validated
- Adaptable for any gait lab
- Lengthening rate (velocity)

Control data

- 83 kids
- Multiple speeds
- Calculate MTL and MTV
- Not all 92 muscles
  - No back/abdominal muscles
  - No foot muscles

Control data - MTL

Control data - MTV
Why?

- More likely to have a satisfactory outcome after hamstring surgery if hamstrings were short/slow before surgery

Effects of walking speed

INDICATIONS AND EXPLICIT GUIDANCE (HAMSTRINGS, PSOAS, GASTROCNEMIUS)

PCGR | Problem Centric Gait Report:
---|---
**Physical Exam:**
Knee Flexion Contracture
Popliteal angle – Unilateral/Bilateral
Hamstring Spasticity
Knee Extensor Lag (for quadriceps insufficiency)
**Gait Data:**
Pelvis Kinematics
Knee Kinematics
Muscle Length & Velocity
EMG hamstrings
Single/Bilateral popliteal angle

Hamstrings

What Are We Looking For?
- Muscle-Tendon Lengths in terminal swing that are short, at-length, or long regardless of knee flexion contracture evidence.

What Are We Looking For?
- Muscle-Lengthening Velocities in mid swing that are slow or typical.

What If You Don’t Have Muscle Lengths?

HAMSTRINGS
Goals of Treatment

- allow extension of the knee in terminal swing without progressive posterior pelvic tilting
- in order to improve step length

Medial hamstrings lengthening

- Semitendinosus
- Semimembranosus
- Gracilis

HAMSTRINGS OUTCOMES

Surgical Indications
- Crouch Gait
- Pelvic Tilt
- Muscle Length and Velocity

Baumann (1980)

- Retrospective analysis
- 34 out of 66 patients

Indications

- Not stated, but…
- "Surgical correction of the spastic crouch gait should lead to good knee extension during the stance phase of walking…"

Outcomes

- Knee extension improved throughout gait cycle
**DeLuca (1998)**

- Retrospective analysis
- 73 patients, spastic diplegia
- Four groups
  - medial hamstrings
  - medial and lateral hamstrings
  - medial hamstrings + psoas over the brim of the pelvis (OTB)
  - medial and lateral hamstrings - psoas OTB

**Indications**

- Goal of study to investigate muscle length/velocity as indication

**Outcomes**

- Postsurgical pelvic position
  - Medial Only: n/c
  - Medial and Lateral: Worse
  - Medial and Psoas: n/c
  - Med + Lati + Psoas: Better

**Arnold (2006)**

- Retrospective analysis – 108 patients from 1993 to 1994
- Goal: to improve gait pattern

**Indications**

- Lengthen short/slow hamstrings → improve knee ext.
- Lengthen adequate hamstrings → worsen pelvic tilt

**Outcomes**

- Improvement in gait pattern
- Reduction in spasticity

Take Home Message
Patients walking in crouch

PSOAS

Psoas
Problem Centric Gait Report:

Physical Exam:
Hip Flexion Contracture (Thomas test)
Popliteal angle – Unilateral/Bilateral
Hip Flexor Spasticity
Gluteus Maximus Strength

Gait Data:
Pelvis Kinematics
Hip Kinematics
Hip Kinetics

Prediction of Outcome:
under development

2015 AACPDM Breakfast Session
Surgical Tx of Soft Tissue Contractures
Novacheck, Stout, Rozumalski
**Goals of Treatment**

attain adequate length
to allow normal hip extension
without increasing anterior pelvic tilt

**Intramuscular Psoas lengthening (IMPL) at the pelvic brim**

• oblique incision
  medial to the ASIS

**Intramuscular psoas lengthening at the pelvic brim**

• pass right angle clamp
  around the psoas tendon
• transect the intramuscular tendon

**Hip Strength**

**Assistive Devices**

**Age**

**Surgical Indications**

**PSOAS OUTCOMES**

Sutherland, DH et al. 1997

– Retrospective repeated-measures design
– 17 patients, 29 hips
– Recession at pelvic brim
– Adductor tenotomy,
  Hamstring lengthening,
  and Rectus transfer on most hips

• Not stated, but…
  – “representative case” given
  – History
    • Twin deliver
    • Mild delay in milestones
    • Persistent bilateral ankle equinovarus
    • Bilateral Achilles tendon lengthenings at age 6 years
    • Reused Achilles tendon lengthening at age 6 years
  – Physical examination
    • Hamstring contractures (popliteal angles 140°R and 110°L)
    • Passive hip extension was limited by 20°
    • Deep tendon reflexes exaggerated in the lower extremities
  – Gait study
    • Exaggerated stance phase anterior pelvic tilt and hip flexion, knee flexion.
    • Sustained rectus femoris, hamstring, and adductor activity, iliac crest
      continuously

2015 AACPDM Breakfast Session
Surgical Tx of Soft Tissue Contractures
Novacheck, Stout, Rozumalski
2015 AACPDM Breakfast Session
Surgical Tx of Soft Tissue Contractures
Novacheck, Stout, Rozumalski

Novacheck TF, et al. 2002

- Retrospective repeated-measures design
- 93 limbs from 56 patients
- Intramuscular psoas lengthening (IMPL) over pelvic brim
  - +/- Hamstrings lengthening
  - +/- FDO
  - No prior Hams./FDO/Rhizotomy

Morais, M et al. 2006

- Retrospective repeated-measures study
- 52 limbs, 26 individuals

Surgical Indications

- Hip Strength
  - 10% loss of hip flexor strength (p<0.05) in Psoas group

Results

- Hip Power

Results

Hip Flexor Index

Hip Power

Hip Extension

Pelvic Tilt

Max

Change in Pelvic Tilt (deg)

A

AGE (Years)

-40

0

10

20

30

-20

-30

-40


Indications

- One or more of following from gait data:
  - Increase of anterior pelvic tilt
  - Increase of pelvic tilt range of motion
  - Lack of hip extension at terminal stance.
- Hamstrings lengthening, used to avoid increased ant. pelvic tilt
- Thomas test NOT part of indications

Results

- Anterior pelvic tilt significantly reduced for independent ambulators, but increased for those using walking aids

<table>
<thead>
<tr>
<th>Surgical Intervention</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std Dev</td>
<td></td>
</tr>
<tr>
<td>Anterior pelvic tilt</td>
<td>0.1</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Flexion range</td>
<td>0.1</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Extension range</td>
<td>0.1</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Truong, W et al. 2011

- Retrospective repeated-measures study
- 87 Sides
- Case vs. Control design

Results

- Kinematics improved (Case v. Control) for GMFCS III and IV
- Reduction in Hip Strength (Case v. Control) for GMFCS III and IV
- No difference in Hip Power (Case v. Control)

Schwartz, MH et al. 2012

- Retrospective repeated-measures study
- 800 limbs
- Case vs. Control design
- Machine learning algorithm to find optimal indications
Indications

- Indications in form of statistical model (Random Forest)
- Variables related to: Age, Speed, Pelvis/Hip Motion, Swing Phase Knee Flexion

Results

- Significantly better pelvic kinematics (Case vs. Control)
- Potential benefit → 14% more good outcomes

Indications

Predicted Outcome

Poor

Good

Gastrocnemius

Physical Exam:

- Plantarflexion Contracture vs. Tightness
- Plantarflexor Spasticity & Ankle Clonus
- Plantarflexor vs. Dorsiflexor Strength
- Foot Deformity
- Knee Contracture

Gait Data:

- Ankle Kinematics
- Ankle Kinetics
- Gastrocnemius/Soleus EMG
- Knee Kinematics
- Knee Kinetics

Gastrocnemius

Physical Exam:

- Ankle Dorsiflexion
- Knee Extension
- Plantarflexion
- Adduction
- Inversion
- Supination
- Anterior tibialis
- Achilles tone

Gait Data:

- Ankle Dorsiflexion
data
- Knee Dorsi/Plantarflexion
- Ankle Dorsi Flexion Moment
- Knee Flexion Moment
- Foot Deformity
- Knee Contracture
Gastrocnemius

Gait Data:

Two important confounding factors

- apparent equinus
  - many of the stated clinical indications can also be seen in this case
- effects of mid-foot breakdown through the talonavicular (TN) joint
  - can mask many of these findings
  - If the ankle cannot dorsiflex satisfactorily, then the excessive and premature forefoot loading leads to
    - increased mid-foot stresses
    - excessive range of motion (dorsiflexion and abduction) through the TN joint

*We must use a multisegment foot model!*

Because of these confounding factors, decision-making for gastrocnemius lengthening cannot be based solely on currently available quantitative gait data!

The plantarflexors are very sensitive to lengthening!

Surgical considerations

*Delp et al 1995*

- one centimeter lengthening of the soleus results in a 50% loss of its force generation capacity
- soleus -- particularly sensitive to lengthening
  - bi-pinnate muscle fiber orientation
  - short muscle fiber lengths
  - Diplegic/quadriplegic, lengthening rarely required
- gastroc -- much less sensitive to lengthening and is typically the only one that requires lengthening.

Special considerations

- In hemiplegia, the soleus may also require lengthening. Fortunately, the risk of overcorrection is lower in hemiplegia than in di- or quadriplegia.
- Baker lengthening is more conservative than tendo-Achilles lengthening and can be considered (Borton et al 2001).
- In late presenting cases, tendo-Achilles lengthening (TAL) may be the only option to achieve the necessary amount of lengthening (rare if a child has been cared for in a coordinated, multidisciplinary center).
**Goals of Treatment**

- Satisfactory length in terminal stance (when it must achieve maximum length)
- Eliminate its deforming effects on the midfoot
- Improve stance phase stability by allowing a plantigrade foot position with the knee in full extension

**Indications**

- Recurrence
- Quality of studies

**GASTROCNEMIUS OUTCOMES**

**Perry 1974**

- Retrospective analysis
- 17 patients

**Indications**

- "clinical stretch test" (no values/ranges given)
- Failure to respond / significant recurrence after casting
- Persistent equinus ...despite bracing

- Additional Study Design Elements
  - cerebral palsy
  - four to eighteen years old
Outcomes

- Improved dorsiflexion range by physical exam
- Improved timing/duration of muscle activation
- Several warnings of possible recurrence

Shore (2010)

- Systematic Review
  
  *equinus deformity, cerebral palsy, orthopaedic surgery*

- 35 Articles, 19 used instrumented gait analysis (avg. follow-up 2.8 years)
- Most studies were level IV quality (case series)

Outcomes

- Systematic Review
  
  *equinus deformity, cerebral palsy, orthopaedic surgery*

- 35 Articles, 19 used instrumented gait analysis (avg. follow-up 2.8 years)
- Most studies were level IV quality (case series)

Surgical Indications

- Not summarized

Svehlik (2012)

- Retrospective analysis, long-term follow-up
- Instrumented gait analysis
- 18 patients, 21 limbs

Surgical Indications

- Not stated, but...
  
  - Inclusion Criteria for Study:
    - Spastic diplegic CP
    - Gross Motor Functional Classification System level I to III
    - Ability to walk barefoot without walking aids at least for short distances
  
  - Additional Study Criteria:
    - Full sets of kinematic and kinetic gait data collected preoperatively and at one, two to three, five, and ten years postoperatively.
    - No further surgical treatment of equinus during the follow-up period.
    - No prior treatment with selective dorsal rhizotomy or intra-thecal baclofen.

Outcomes

- Recurrence @ 10 Years
- "comparable to the short-term results of ...(Strayer technique) in the study of Gough, Schneider and Shortland and those of lengthening of the tendo Achilles [Borton, et al., 2001]"

  - Gough ??%
  - Borton 38%

Outcomes

- Recurrence @ 10 Years
- "comparable to the short-term results of ...(Strayer technique) in the study of Gough, Schneider and Shortland and those of lengthening of the tendo Achilles [Borton, et al., 2001]"

Conclusions

- Extensive history of outcome studies for soft-tissue surgery
  - Mixed outcomes
  - Contradictory reports
  - Controversy continues
- Surgical indications
  - Rarely stated
  - When stated, adherence rates not given
  - Impact of indications on outcomes not assessed
- Future needs
  - Better study designs
  - Prospective studies
  - More long-term outcome studies
  - Indications: state, evaluate, measure adherence
  - Role of gait data

Goals of soft tissue lengthening

- **Psoas**
  - attain adequate length to allow normal hip extension without increasing anterior pelvic tilt
- **Hamstrings**
  - allow extension of the knee in terminal swing without posterior pelvic tilting in order to improve step length
- **Gastrocnemius**
  - Satisfactory length in terminal stance (when it must achieve maximum length)
  - Eliminate its deforming effects on the midfoot
  - Improve stance phase stability by allowing a plantigrade foot position with the knee in full extension

Still struggle with intraoperative decision-making

- Intraoperative assessment
  - Feels "really tight" or "not so tight"
- Goal attainment
  - "Ahh ... that’s much better. That feels looser!"
Diagnostic tools

• Current
  – Physical examination
  – Musculoskeletal modeling
• Future
  – Measuring stiffness (ultrasound, mechanical)
  – Laser diffraction