Indications and Explicit Guidance for Soft Tissue Surgery Using Gait Analysis

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Purpose

• Role of gait analysis in decision-making for soft tissue surgery in children with cerebral palsy
• Specific indications/contraindications for psoas, hamstring, and gastrocnemius procedures based on gait analysis data
• Surgical techniques
• Assessment of outcomes

Outline

• Introduction
• Previous Research & Biomechanical Models
• Indications (Physical Exam & Gait Data)

Break

• Surgical Techniques
• Outcome
• Adverse Outcomes
• Discussion

A FEW CAVEATS

Lack of explicit indications in the literature
a need for clarity and discussion

Quantitative Gait Analysis

• Spasticity and contracture
  – manifest themselves when maximum elongation rate and total length attainment occur
• Critical to understand this timing

2013 GCMAS Symposium
Goals of lengthening musculo-tendinous contractures

- The goal of muscle/tendon surgery is to allow the joints to achieve a normal joint position during gait without restriction.
- Why? If the length is restricted, compensatory movement patterns are required.

Musculo-tendinous units are the generators of the forces required
- propel body segments
- exert the joint moments necessary to oppose gravitational forces

Caution!!
- Carefully consider other potential causes of abnormal joint position to avoid lengthening a musculo-tendinous unit whose length is not restrictive!

Muscle length vs. tension curve

If this is not the case, then judicious muscle lengthening can be safe and appropriate.

Contraindications and complications of soft tissue surgery

- A lack of recognition that contractures occur primarily due to the effects of spasticity.
  - Therefore, spasticity management should be the primary consideration.
  - While options were not available in the past, many are today.
  - Tendon surgery should be deferred as much as possible.

Contraindications and complications of soft tissue surgery

- Undertreatment
  - The psoas is a prime example.
  - incorrect physical exam technique (underdiagnosis)
  - concerns about complications
    • post-surgical weakness (a residual from the days of complete release of the tendon from the trochanter)
    • N/V injury

Contraindications and complications of soft tissue surgery

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Muscle length vs. tension curve

If this is not the case, then judicious muscle lengthening can be safe and appropriate.
Contraindications and complications of soft tissue surgery

- Overly aggressive surgery to isolated structures.
  - TAL
  - combined medial and lateral hamstring lengthening
  - complete transfer of all of the hamstrings to the femur (Eggers)
  - obturator neurectomy
  - iliopsoas release at the lesser trochanter
- These procedures are rarely indicated for the treatment of gait dysfunction.

Contraindications and complications of soft tissue surgery

- Single level surgery leading to joint imbalance and the need for numerous trips to the operating room

Contraindications and complications of soft tissue surgery

- Inappropriate lengthening of one joint antigravity muscles leading to weakness.
  - tendo-Achilles lengthening
  - release of the iliopsoas tendon at the lesser trochanter

2 joint timing muscles (affected by CP)

- Psoas
- Hamstrings
- Gastrocnemius
- Rectus femoris
INDICATIONS AND EXPLICIT GUIDANCE FOR SOFT TISSUE SURGERY USING GAIT ANALYSIS

Background

Outline

• Muscle structure and pathophysiology
• Treatment options
• Diagnostic tools

Muscle Structure

Muscle contracture in CP

• Causes are multifactorial
  • Innervation
  • Mechanical
  • Growth

Muscle contracture 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

Diagnostic tools

- Physical examination
- Musculoskeletal modeling
- Ultrasound
- Spectrometry

Modeling Muscle Geometry

- Calculate MTL based on joint positions (kinematics)

Muscle-tendon lengths

Fig. 5. Gastrocnemius calf muscle path wrapping over a wrap-cylinder affixed to the tibia
Example

Lengths of Hamstrings and Pecos Muscles during Crouch Gait: Effects of Femoral Anteversion

*Lisa M. Schena, *Grant W. Heyden, and *Maury R. Gage

*College of Engineering, Dept. of Mechanical and Materials Engineering, University of Minnesota, Minneapolis, Minnesota 55455

**Muscle lengths calculated with generic model.

- Muscle lengths calculated with child's specific anthropometry.
- 10 cm extension equal to 90 degrees on the left and 28 degrees on the right.

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?

- Knee flexion does not predict RectFem length in SKG
- MTL and MTV was different from control

Why?

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

Effects of walking speed

- More subjects would have been considered to have adequate length/velocity if walking speed were taken into account

Effects of walking speed

- Muscles function shorter and slower as spasticity increases
Summary

- Pathophysiology of CP muscle is complex
- Several treatment options to lengthen muscles
  - Recurrence
  - Weakness
- Diagnostic tools
  - PE
  - Musculoskeletal modeling

Bibliography


Bibliography

Indications and Explicit Guidance for Soft Tissue Surgery
Physical Exam & Gait Data

Hamstrings

**Physical Exam:**
- Knee Flexion Contracture
- Popliteal angle – Unilateral/Bilateral
- Hamstring Spasticity
- Knee Extensor Lag (for quadriceps insufficiency)

**Gait Data:**
- Pelvis Kinematics
- Knee Kinematics
- Knee Kinetics
- Muscle Length & Velocity
- EMG hamstrings

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

**Beware:**
- Presence of at-length or long muscle-tendon lengths indicates absence of short hamstrings
- Presence of short muscle tendon lengths does not indicate absence of at-length or long hamstrings
**Psoas**

**PCGR 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

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**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
Questions?
Novacheck Surgical Techniques

Hamstrings

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

Psoas

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

Psoas Lengthening at the Pelvic Brim

Two important confounding factors

- apparent equinus
  - many of the above findings can also be seen
- effects of mid-foot breakdown through the talonavicular joint
  - can mask many of these findings
  - If the ankle cannot dorsiflex satisfactorily, then the excessive and premature forefoot loading leads to
    - increased stresses in the mid-foot
    - development of excessive range of motion (dorsiflexion and abduction) through the talonavicular joint
    - We must use a multisegment foot model!

Gastrocnemius

The plantarflexors are very sensitive to lengthening!

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

Delp et al 1995
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).

Strayer gastrocnemius recession

- Midcalf incision @ muscle/tendon junction of gastroc
- Develop interval between gastroc and soleus (beware sural nerve)
- Divide gastroc fascia
- Repair gastroc to soleus fascia
- Baker sometimes in hemiplegia

Baumann

- Medial incision @ muscle belly of gastrocnemius
- Develop interval between gastroc and soleus (beware saphenous vein)
- Divide deep gastroc fascia
- Extend knee & dorsiflex ankle to 0°
- No repair of gastroc fascia

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

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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!"
Surgical Outcomes
Hamstrings | Psoas | Gastrocnemius

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So many studies... so little time

• Psoas, Cerebral Palsy, Surgery = 41 articles
• Hamstrings, Cerebral Palsy, Surgery = 102 articles
• Gastrocnemius, Cerebral Palsy, Surgery = 348 articles

Focus on Themes

Hamstrings

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

- Not stated, but...
  - “The specific clinical measurements reviewed included popliteal angle as an indication of hamstring contracture…”
  - All groups had Knee Flexion @ Initial Contact > 30°

Outcomes

- Peak stance phase knee extension improved (11° - 18°)
- Pelvic tilt changes were heterogeneous
  - “...fundamental determinants of pelvic position during gait postoperatively are the extent of hamstring surgery...and the preoperative position of the pelvis.”

Arnold (2006)

- Retrospective analysis – 152 patients from two centers
  - Gillette Children’s Specialty Healthcare
  - Connecticut Children’s Medical Center
- Patients
  - spastic cerebral palsy
  - able to ambulate without orthoses or other assistance
  - 6 years of age or older
  - at least 20° of knee flexion at initial contact or terminal swing

Indications

- Goal of study to Investigate muscle Length/Velocity as indication
Outcomes

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

Take Home Message

Patients walking in crouch

Sutherland, DH et al. 1997

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

Surgical Indications

- Not stated, but...
  - "representative case” given
  - History
    - Term delivery
    - Mild delay in milestones
    - Persistent bilateral ankle equinus.
    - Bilateral Achilles tendon lengthenings at age 2 years
    - Repeat Achilles tendon lengthening at age 4 years
  - Physical examination
    - Hamstrings contracture (popliteal angles 140°R and 110°L)
    - Passive hip extension was limited by 20° B
    - Deep tendon reflexes exaggerated in the lower extremities
  - Gait study
    - Exaggerated stance phase anterior pelvic tilt and hip flexion, knee flexion
    - Prolonged rectus femoris, hamstring and adductor activity, Iliacus fired continuously

Results

- Pelvic Kinematics
  - Pelvic tilt decreased (26° → 23°), but not significant (p = 0.06)
  - Improved significantly among independent ambulators
  - Significant effect of age
Novacheck TF, et al. 2002

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

Surgical Indications

- Not stated

Morais, M et al. 2006

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

Results

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

Hip Power

Results

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
Truong, W et al. 2011

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

87 Sides

Case vs. Control design

Indications

- Two or more of following:
  - Maximum hip extension <8° (flex)
  - Maximum pelvic tilt >24°
  - Pelvic tilt range-of-motion >8°

- Cases: 2/3 and +psoas lengthening as part of SEMLS
- Controls: 2/3 and -psoas lengthening as part of SEMLS

Results

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

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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

Predicted Outcome

<table>
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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

Surgical Indications

- Not summarized

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

- Recurrent equinus: 0% - 43% (up to 62% in subgroups)
- Calcaneus: 0% - 36% (up to 80% in subgroups)
- "...greater incidence of recurrent equinus in children with hemiplegia regardless of procedure, and greater incidence of calcaneal gait and deformity in children with diplegia, particularly following procedures on the Achilles tendon."

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
    - Equinus gait
    - 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 pre-operatively and at one, two to three, five, and ten years post-operatively.
    - No further surgical treatment of equinus during the followup period.
    - No prior treatment with selective dorsal rhizotomy or intrathecal 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 Achillis [Borton, et al., 2003]"
    - Gough ??%
    - Borton 38%

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
Indications and Explicit Guidance for Soft Tissue Surgery Using Gait Analysis:

Case Study

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Adverse Outcomes

• Be Judicious:
Muscle Lengthening = Muscle Weakening

• Types of Lengthening & Extent of Lengthening make a difference

Tenotomy; Percutaneous Tenotomy; Intramuscular Lengthening; Fractional Lengthening

• Consider alternative ways to maintain length & strength

Meet AF-2011

AF-2007

2005 Surgeries
• Bilateral percutaneous adductor tenotomies
• Bilateral percutaneous semitendinosus & gracilis tenotomies
• Bilateral semimembranosus fractional lengthening

AF-2008

2008 Surgeries
• Left semitendinosus intramuscular tenotomy
• Left semimembranosus fractional lengthening
• Bilateral gastrocnemius aponeurotic lengthening

AF-2010

2010 Surgeries
• Bilateral ethanol obturator nerve block
• Bilateral biceps femoris percutaneous tendon lengthening
• Bilateral semitendinosus percutaneous tendon lengthening
• Bilateral distal gracilis percutaneous tendon lengthening
• Left medial hamstring scar release
• Bilateral medial & lateral gastrocnemius fractional lengthening
• Bilateral peroneus longus percutaneous tendon lengthening
AF-2011

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- Left medial hamstring scar release
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- Bilateral peroneus longus percutaneous tendon lengthening

AF-2011

2012 Surgeries
- Bilateral intertrochanteric femoral derotation osteotomies
- Bilateral psoas over the brim of the pelvis
- Bilateral rectus femoris transfer to the gracilis
- Right foot reconstruction
- Left Frost posterior tibialis lengthening

Discussion