Indications and Explicit Guidance for Soft Tissue Surgery Using Gait Analysis

Tom Novacheck, MD
Jean Stout, PT, MS
Adam Rozumalski, MS
Michael Schwartz, Ph.D.

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	Novacheck
• Previous Research & Biomechanical Models	Rozumalski
• Indications (Physical Exam & Gait Data)	Stout
Break	
• Surgical Techniques	Novacheck
• Outcome	Schwartz
• Adverse Outcomes	Novacheck & Stout
• Discussion	

A FEW CAVEATS

Lack of explicit indications in the literature

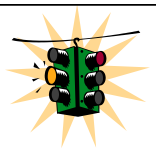
a need for clarity and discussion

Quantitative Gait Analysis

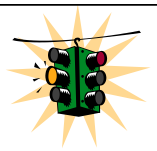
- Spasticity and contracture
  - manifest themselves when maximum *elongation rate* and *total length* attainment occur
- Critical to understand this timing

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.



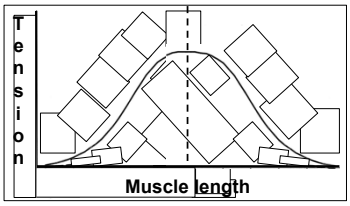
Caution!!



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

in order for a muscle to function well on the length vs. tension curve, the muscle must be functioning at appropriate length with proper tension in the functional position of the joints and body segments.



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

- Inappropriate surgical indications due to ***misconceptions*** regarding the cause of gait pathology.
  - Adductor lengthening for scissoring gait is a good example.
  - The adductors have been inappropriately blamed for scissoring gait.

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

- ***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 [redacted] 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

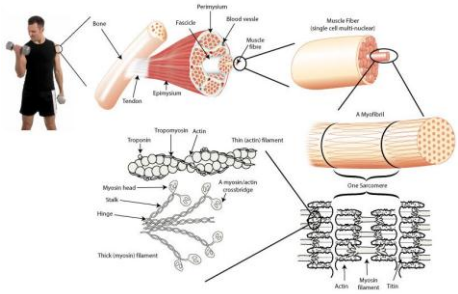
INDICATIONS AND EXPLICIT GUIDANCE FOR SOFT TISSUE SURGERY USING GAIT ANALYSIS

Background

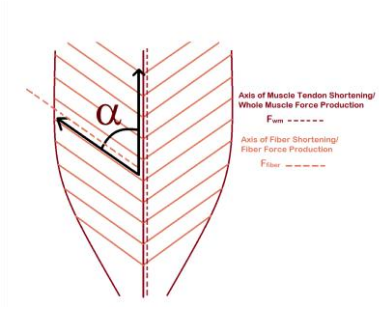
Outline

- Muscle structure and pathophysiology
- Treatment options
- Diagnostic tools

Muscle Structure



Muscle Structure



Muscle contracture in CP

DEVELOPMENTAL MEDICINE & CHILD NEUROLOGY REVIEW

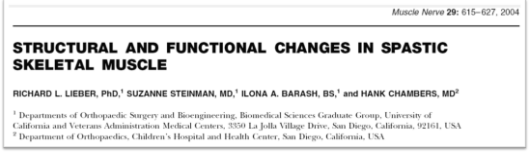
Could muscle deformity in children with spastic cerebral palsy be related to an impairment of muscle growth and altered adaptation?

MARTIN GOUGH | ADAM P SHORTLAND

One Small Step Gait Analysis Laboratory, Guy's Hospital, Guy's and St Thomas' NHS Foundation Trust, London, UK.

- Causes are multifactorial
  - Innervation
  - Mechanical
  - Growth

Muscle contracture in CP



Muscle Nerve **29:** 615–627, 2004

STRUCTURAL AND FUNCTIONAL CHANGES IN SPASTIC SKELETAL MUSCLE

RICHARD L. LIEBER, PhD,[1] SUZANNE STEINMAN, MD,[1] ILONA A. BARASH, BS,[1] and HANK CHAMBERS, MD[2]

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[2] Department of Orthopaedics, Children's Hospital and Health Center, San Diego, California, USA

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

Muscle contracture in CP

DEVELOPMENTAL MEDICINE & CHILD NEUROLOGY REVIEW

Gross muscle morphology and structure in spastic cerebral palsy: a systematic review

ROD S BARRETT | GLEN A LICHTWARK

School of Physiotherapy and Exercise Science, Griffith Health, Griffith University, Queensland, Australia

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

Interventions

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

Diagnostic tools

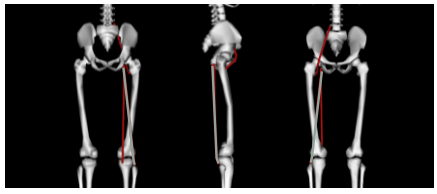
- Physical examination
- Musculoskeletal modeling
- Ultrasound
- Spectrometry

Modeling Muscle Geometry

Ajay Seth et al. / Procedia IUTAM 2 (2011) 212–232

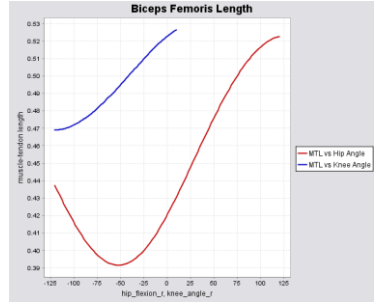
Fig. 5: Gastrocnemii (calf) muscle paths wrapping over a wrap-cylinder affixed to the tibia

Muscle-tendon lengths

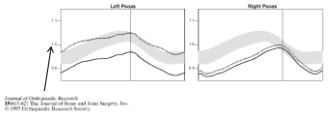


- Calculate MTL based on joint positions (kinematics)

Muscle-tendon lengths



Example



Journal of Orthopaedic Research
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Lengths of Hamstrings and Psoas Muscles during Crouch Gait: Effects of Femoral Anteversion

*†Lisa M. Schutte, *‡Scott W. Hayden, and *†James R. Gage

*Gillette Children's Specialty Healthcare, St. Paul, and Departments of †Orthopaedic Surgery and ‡Mechanical Engineering, University of Minnesota, Minneapolis, Minnesota, U.S.A.

Muscle lengths calculated with generic model

Muscle lengths calculated with model that represents anteversion
(Anteversion equal to 50 degrees on the left and 20 degrees on the right)

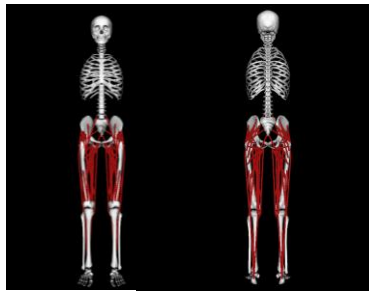
OpenSim

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

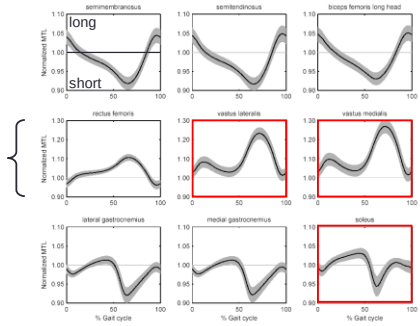
Control data

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

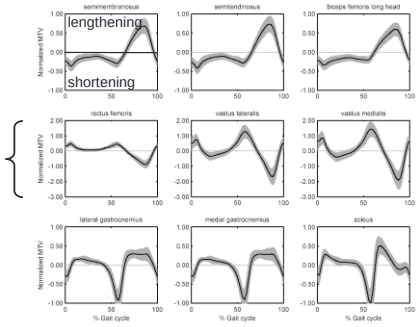
Control data



Control data - MTL



Control data - MTV



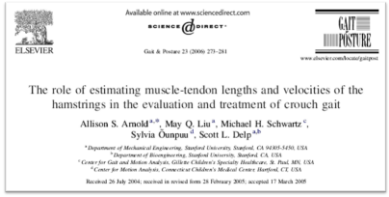
Why?

Musculo-tendon length and lengthening velocity of rectus femoris in stiff knee gait

Ilse Jonkers, Caroline Stewart, Kaat Desloovere, Guy Molenaers, Arthur Spaepen

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

Why?



The role of estimating muscle-tendon lengths and velocities of the hamstrings in the evaluation and treatment of crouch gait

Allison S. Arnold, May Q. Liu, Michael H. Schwartz, Sylvia Õunpuu, Scott L. Delp

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

Effects of walking speed

Journal of Biomechanics

Variation of hamstrings lengths and velocities with walking speed

Kiran J. Agarwal-Harding, Michael H. Schwartz, Scott L. Delp

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

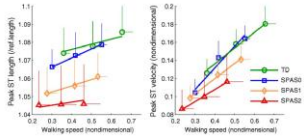
Effects of walking speed

Gait & Posture

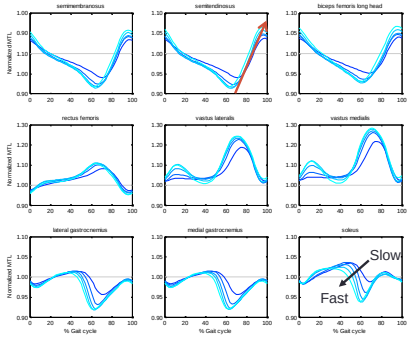
The effect of walking speed on hamstrings length and lengthening velocity in children with spastic cerebral palsy

Marjolein M. van der Krogt, Caroline A.M. Doorenbosch, Jaap Harlaar

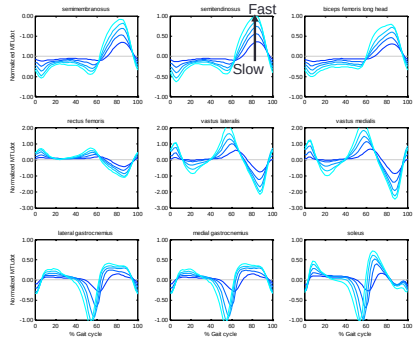
- Muscles function shorter and slower as spasticity increases



Effects of walking speed



Effects of walking speed



Summary

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

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Indications and Explicit Guidance for Soft Tissue Surgery

Physical Exam & Gait Data

Gillette Children's Specialty Healthcare

Hamstrings

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
Knee Kinetics
Muscle Length & Velocity
EMG hamstrings

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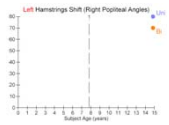
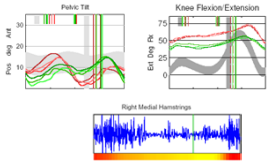
Hamstrings

Physical Exam:

KNEE		
Extension	15	30
Popliteal angle		
unilateral	80	80
bilateral	70	70
HS shift	10	10
Extensor lag	15	20



Gait Data:



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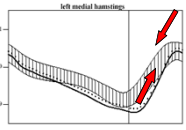
Hamstrings

What Am I Looking For?

- Muscle-Tendon Lengths in terminal swing that are short, at-length, or long regardless of knee flexion contracture evidence.

KNEE		
Extension	15	20
Flexion		
prone	WNL	WNL
supine	WNL	WNL
Popliteal angle		
unilateral	60	65
bilateral	50	50
HS shift	10	15
Extensor lag	20	20
Patella alta	Y	Y



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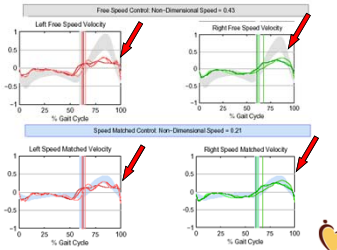
Hamstrings

What Am I Looking For?

- Muscle-Lengthening Velocities in mid swing that are slow or typical.



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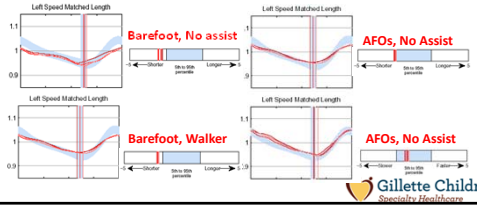
Hamstrings

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



Gillette Children's Specialty Healthcare

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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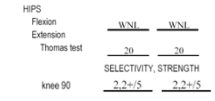
Psoas

Physical Exam:



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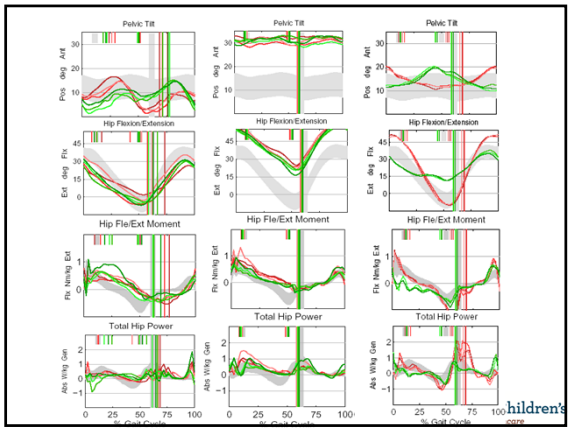

Gastrocnemius

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

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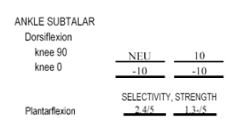
Gastrocnemius

Physical Exam:



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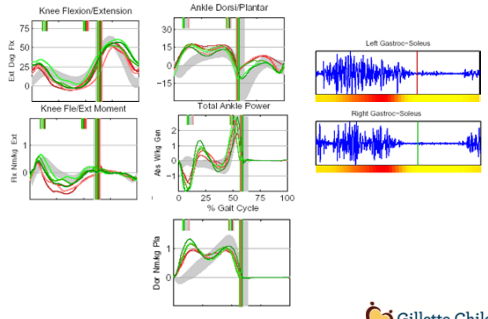
Gastrocnemius

Gait Data:



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Questions?

Hamstrings

Goals of Treatment

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

Medial Hamstring Lengthening

Psoas

Goals of Treatment

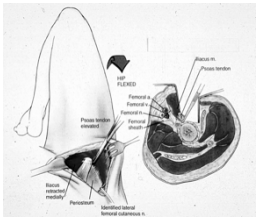
attain adequate length
to allow normal hip extension
without increasing anterior pelvic tilt

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

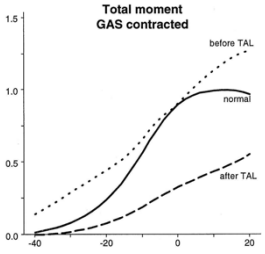
Gastrocnemius

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!

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!



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.

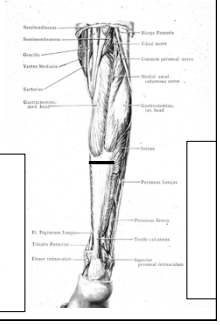
Special considerations

- 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

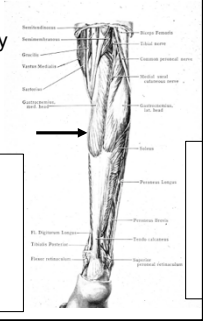
- Midcalf incision @ muscle/tendon junction of gastroc
- Develop interval between gastroc and soleus *(beware sural nerve)*
- Divide gastroc fascia
- Extend knee/dorsiflex ankle to 0°
- Repair gastroc to soleus fascia
- Baker sometimes in hemiplegia

Never Tendo-Achilles lengthening in ambulators!!



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

Strayer Gastrocnemius Recession

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

Michael H. Schwartz, Ph.D.

Director | Bioengineering Research
Gillette Children's Specialty Healthcare

Associate Professor | Orthopaedic Surgery
University of Minnesota

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

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

Baumann (1980)

- **Retrospective analysis**
- **34 out of 66 patients**

Baumann JU, Ruetsch H, Schürmann K. **Distal Hamstring Lengthening in Cerebral Palsy**. *International Orthopaedics (SICOT)*, 3:305-9, 1980

Indications

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

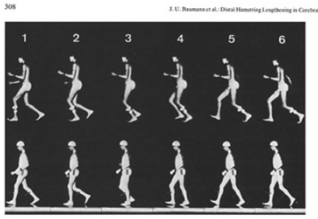
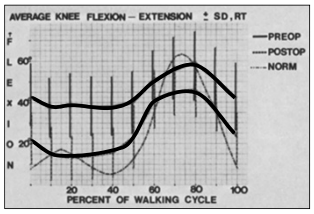


Fig. 5. Upper line: Boy age 15 with spastic diplegia and hamstring contractures. *Lower line:* Gait of the same patient 4 years after distal hamstring elongation

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

DeLuca PA, Ounpuu S, Davis RB, Walsh JHP. **Effect of hamstring and psoas lengthening on pelvic tilt in patients with spastic diplegic cerebral palsy**. *J Pediatr Orthop*, **18**:712-18, 1998

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."***

Postsurgical Pelvic Position		
	PT < 16°	PT > 16°
Medial Only	n/c	n/c
Medial and Lateral	**Worse**	n/c
Medial and Psoas		n/c
Med + Lat + Psoas	**Better**	n/c

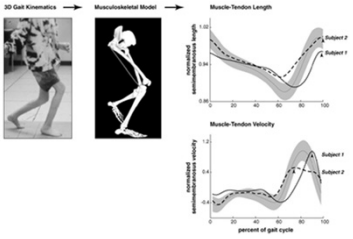
Arnold (2006)

- **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

Arnold AS, Liu MQ, Schwartz MH, Õunpuu S, Delp SL. **The role of estimating muscle-tendon lengths and velocities of the hamstrings in the evaluation and treatment of crouch gait**. *Gait Posture*. **23**:273-81, 2006

Indications

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



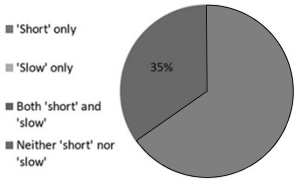
Outcomes

•**Lengthen short/slow hamstrings → improve knee ext.**

•**Lengthen of adequate hamstrings → worsen pelvic tilt**

Take Home Message

Patients walking in crouch



Psoas

Hip Strength

Assistive Devices

Age

Surgical Indications

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

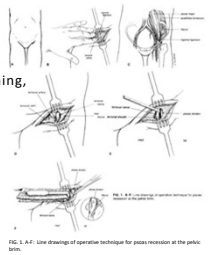


FIG. 1. A-F: Line drawings of operative technique for psoas recession at the pelvic brim.

Sutherland D, Zilberfarb J, Kaufman K, Wyatt M, Chambers, H. **Psoas Release at the Pelvic Brim in Ambulatory Patients with Cerebral Palsy: Operative Technique and Functional Outcome.** *J Pediatr Orthop*, **17**:563-70, 1997

Surgical Indications

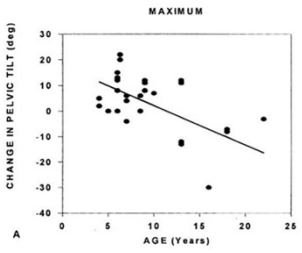
•Not stated, but…

- "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 6 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

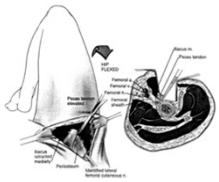
•Pelvic Kinematics

- 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 Hams./FDO/Rhizotomy



Novacheck TF, Trost JP, and Schwartz MH. **Intramuscular Psoas Lengthening Improves Dynamic Hip Function in Children With Cerebral Palsy**. *J Pediatr Orthop*, **22**:158-64, 2002

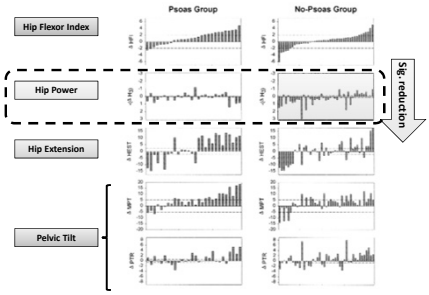
Surgical Indications

•**Not stated**

Results

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

•**Hip Power**



Morais, M et al. 2006

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

Morais MC, Godoy W, Santos C. **Effects of Intramuscular Psoas Lengthening on Pelvic and Hip Motion in Patients With Spastic Diparetic Cerebral Palsy**. *J Pediatr Orthop*, **26**:260-4, 2006

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 2. Mean Values and SDs of 26 Patients Before and After Surgical Intervention

	Preoperative (degrees)		Postoperative (degrees)		Student
	Mean	SD	Mean	SD	*t*
Anterior pelvic tilt	18	5.1	17.1	5.8	0.384
Pelvic range of motion	11.2	3.3	9.1	2.6	0.0001
Hip extension	2.5	10.3	2.8	8.9	0.799

Truong, W et al. 2011

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

Truong WH, Rozumalski A, Novacheck TF, Beatty C, Schwartz MH. **Evaluation of Conventional Selection Criteria for Psoas Lengthening for Individuals With Cerebral Palsy: A Retrospective, Case-Controlled Study**. J Pediatr Orthop, **31**:534–540, 2011

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 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)**

TABLE 3. Summary of the Changes in Outcome Measures

	All GMFCS Levels							GMFCS Levels I and II							GMFCS Levels III and IV						
	Control Mean	SD	N	Psoas Mean	SD	N	P	Control Mean	SD	N	Psoas Mean	SD	N	P	Control Mean	SD	N	Psoas Mean	SD	N	P
FAQ	0.3	1.2	48	0.4	1.3	27	0.805	0.3	1.1	30	0.6	1.5	19	0.455	0.4	1.4	18	0.0	0.8	8	0.466
GDI	11.1	12.3	55	12.9	9.9	32	0.482	13.2	13.5	34	11.4	10.1	23	0.591	7.7	9.5	21	16.7	8.9	9	**0.021**
PHiDI	7.9	11.2	55	11.4	8.9	32	0.130	9.5	12.2	34	12.5	8.7	23	0.313	5.5	9.0	21	9.7	9.1	9	0.535
PMD	1.7	3.9	13	1.7	1.7	9	0.926	1.7	3.9	13	1.7	1.7	9	0.926		N/A			N/A		
HS	0.1	0.6	55	0.2	0.4	9	0.591	0.1	0.6	15	0.2	0.4	9	0.591		N/A			N/A		
RESS	4.4	10.3	55	5.0	8.1	32	0.485	5.0	10.7	34	5.9	7.6	23	0.777	3.2	11.4	18	6.1	2.7	9	0.458
MPT	−4.4	7.6	55	−5.6	8.5	32	0.502	−5.9	7.1	34	−8.0	6.6	23	0.238	−2.0	8.0	21	0.6	10.0	9	0.459
PTR°	−2.3	3.2	55	−1.7	2.6	32	0.368	**−3.1**	**2.4**	**34**	**−1.5**	**2.8**	**23**	**0.027**	−1.1	4.1	21	−2.3	2.1	9	0.427
Step length	−0.01	0.16	55	−0.07	0.15	32	0.089	−0.03	0.15	34	−0.09	0.15	23	0.158	0.03	0.18	21	−0.02	0.15	9	0.505
Speed	**0.01**	**0.10**	**55**	**−0.04**	**0.10**	**32**	**0.011**	**0.00**	**0.10**	**34**	**−0.05**	**0.10**	**23**	**0.038**	0.03	0.10	21	−0.01	0.11	9	0.245
Hip strength	**0.1**	**0.7**	**48**	**−0.4**	**1.0**	**29**	**0.007**	0.1	0.6	29	−0.1	0.6	20	0.183	**0.1**	**0.8**	**19**	**1.1**	**1.4**	**9**	**0.006**

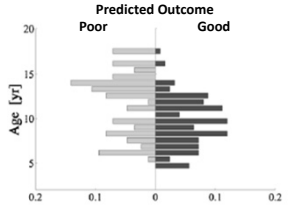
Schwartz, MH et al. 2012

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

Schwartz MH, Truong WH, Rozumalski A, Novacheck TF. **Predicting the outcome of intramuscular psoas lengthening in children with cerebral palsy using preoperative gait data and the random forest algorithm.** *Gait Posture*, **37**:473-9, 2012

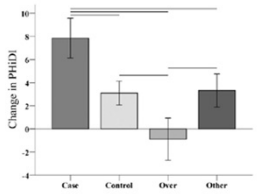
Indications

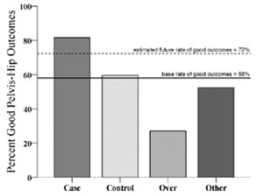
- **Indications in form of statistical model (Random Forest)**
- **Variables related to:**
  Age, Speed, Pelvis/Hip Motion, Swing Phase Knee Flexion



Results

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





Gastrocnemius

Indications

Recurrence

Quality of studies

Perry 1974

- Retrospective analysis
- 17 patients

Perry J, Hoffer M, Giovan P, Antonelli D, Greenberg R. **Gait Analysis of the Triceps Surae in Cerebral Palsy**. *J Bone Joint Surg Am*, **56-A**:511-20, 1974

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

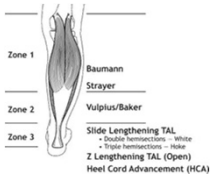
Outcomes

- 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)



Shore BJ, White N, Graham KH. **Surgical correction of equinus deformity in children with cerebral palsy: a systematic review**. *J Child Orthop*, **4**:277-90, 2010

Surgical Indications

- Not summarized

Outcomes

- **Recurrent equinus: 0% - 43% (up to 62% in subgroups)**
- **Calcaneus: 0% - 36% (up to 80% in subgroups)**
- [Evidence is poor, sparse, heterogeneous, short-term, etc….]
- ***"…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)

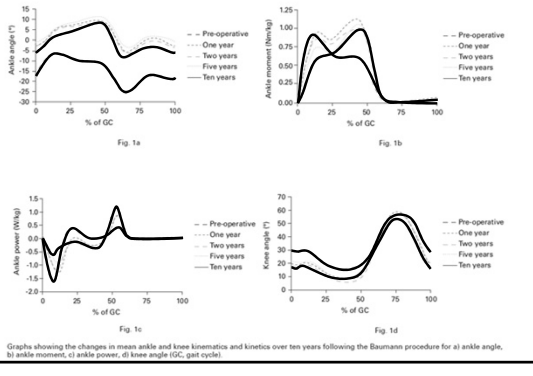
- **Retrospective analysis, long-term follow-up**
- **Instrumented gait analysis**
- **18 patients, 21 limbs**

Svehlik M, Kraus T, Steinwender G, Zwick EB, Saraph V, Linhart WE. **The Baumann procedure to correct equinus gait in children with diplegic cerebral palsy: Long-term results**. *J Bone Joint Surg Br*, **94-B**:1143-7, 2012

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 intra-thecal baclofen.

Outcomes



Graphs showing the changes in mean ankle and knee kinematics and kinetics over ten years following the Baumann procedure for a) ankle angle, b) ankle moment, c) ankle power, d) knee angle (GC, gait cycle).

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., 2001]"***

- 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

Tom F Novacheck, MD; Adam Rozumalski, MS; Jean Stout, PT, MS; Mike Schwartz, PhD

Gillette Children's Specialty Healthcare
St. Paul, MN, University of Minnesota

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 semitendinosis & 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 semitendinosis 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

2005 Surgeries
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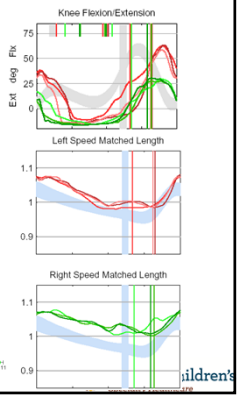
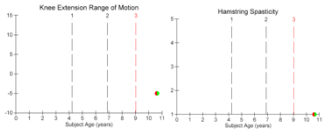
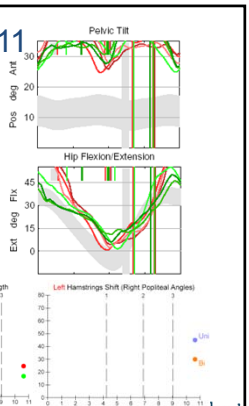
Gillette Children's Specialty Healthcare

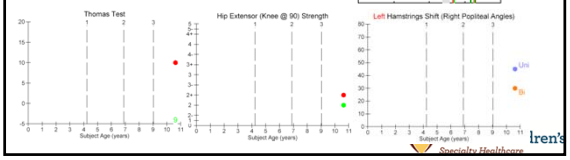
AF-2011





AF-2011





Gillette Children's Specialty Healthcare

AF-2011-2012

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

Gillette Children's Specialty Healthcare

Discussion

Gillette Children's Specialty Healthcare