Pediatric Triceps Surae Muscle Tone
Development, Detection
& New Equinus Deformity Management Principles

Presenter: Beverly Cusick, PT, MS, COF/BOC

February 9, 2024

Sponsored by the Virginia Orthotics & Prosthetics Association

Pediatric Triceps Surae Muscle Tone Development, Detection and New Equinus Deformity Management Principles

Instructor: Beverly Cusick, PT, MS, NDT, COF/BOC

TARGET AUDIENCE: Pediatric rehabilitation team members including orthotists, physical therapists, physicians in physical medicine and rehabilitation, and pediatric orthopedists – welcome!

Level: Intermediate.

COURSE DESCRIPTION

Using lecture, videos, and demonstration, Instructor presents a range of topics including postural control acquisition & influence on muscle tone development; gait development and pathology related to whole body center of gravity acceleration; physiologic adaptation of lower limb muscles to routine use - both ideal & pathologic; and contributions of postural control deficits to equinus deformity development.

A review of passive ankle dorsiflexion range of motion (PADFROM) assessment procedures introduces participants to the presence and significance of velocity-dependent resistance to passive elongation with implications for setting ankle position in orthoses and casts. Instructor then presents principles, properties and methods of optimizing postural control development and reducing equinus deformity using below-knee casts and orthoses.

Participants will be provided course handouts and on-site access to a selection of casts, orthoses and flexible skeletal foot models.

COURSE OBJECTIVES

Participants completing this course are expected to be able to:

- Relate the typical acquisition of neck and trunk control of postures to developing limb use.
- Describe the role of the foot & ankle load receptors in balance and gait.
- Describe the location of the whole-body center of gravity (COG) in infants & children.
- Relate bodyweight (COG) distribution on the foot to upright ankle joint function & development.
- Relate COG acceleration to gait development – typical & pathologic.
- Define resting human muscle tone.
- Define R1 end range in passive muscle extensibility testing.
- Relate typical triceps surae muscle use to the development of R1 in passive ROM assessment.
- Discuss the vertical tibia period in typical gait development.
- Relate excessive pronation to equinus deformity development.
- Discuss the evidence that R1 end range in passive extensibility testing of the triceps surae muscles indicates the presence of spasticity.
- Name 3 physiologic & structural changes that are known to occur in LE muscles & surrounding tissues following a history of routine, tonic recruitment for upright posture maintenance.
- Explain the difference between hypertonic muscle dominance & muscle strength.
- Discuss the growing evidence of Botox-A-induced muscle tissue pathology.
- Name 3 reasons to assess passive ankle dorsiflexion range of motion with the knee joint extended (PADFROM-KE) in prone vs. supine position.
- Describe the method of detection of R1A end range in assessing PADFROM-KE.

COURSE OBJECTIVES, continued:

- Explain the functional relevance of R1A end range PADFROM-KE.
- Discuss the application of R1A end range to the design of a below-knee cast or AFO.
- Determine whether an equinus deformity meets the criteria for intervention with heel-posting orthoses made in ankle plantarflexion or with serial casting,
- Upon discovering a dominant gastrocnemius muscle, name 3 related areas of clinical concern.
- Discuss the evidence of the effectiveness of manual stretching in equinus deformity management.
- Describe the physiology involved in gaining DFROM by immobilizing the ankle in plantarflexion with the heel loaded.
- Discuss the purposes of weight line training in equinus deformity management.
- Explain the rationale for instituting routine ankle muscle strengthening & prolonged night splinting after restoring soft tissue extensibility to the triceps surae muscles & fascia.

PROGRAM SCHEDULE

Start	DESCRIPTION	Contact Min
8:15	Arrive, sign in, settle in	--
8:30	Introduction	15
8:45	1 The Relationship Between Postural Control and Limb Use	15
9:00	2 Triceps Surae Muscle Tone – Typical Development and Detection	55
9:55	Questions…?	5
10:00	Short Break - 10 minutes	--
10:10	3 Source & Physiology of Triceps Surae Hypertonus in CP & ITW	55
11:05	Questions…?	5
11:10	4 Standing and Walking with Center of Gravity Displacements	10
11:20	5 Movement Systems Analysis in Pediatric EQD Management	30
11:50	Lunch – 40 minutes	--
12:30	6 Passive Ankle Dorsiflexion ROM Measurement - Introducing R1A	55
1:25	Questions…?	5
1:30	7 Clarifying Landmarks to Align with Longstanding Computerized Kinematic Gait Analysis and Ankle DFROM Findings	15
1:45	Questions…?	5
1:50	8 News on Botox-A for EQD and an Emerging, Correct, and Safe Alternative	10
2:00	Short Break -10 min	--
2:10	9 EQD Management Principles Using Casts and AFOs	55
3:05	Questions…?	5
3:10	10 AFO Design – Implications for Neuromotor Re-education	20
3:30	Short Break -10 min	--
3:40	DEMONSTRATION: Measuring PADFROM-KE Noting 1 or 2 "Catches"	20
4:00	11 Video Case: G_PADFROM Findings as Evidence of Routine TS Muscle Use	40
4:40	Discussion – *Please complete and submit the course evaluation.*	15
4:55	Adjourn. Didactic contact hours (min):	7.5 / 450

Beverly (Billi) Cusick, PT, MS, NDT, COF/BOC - Brief Professional Bio

EDUCATION:

1972 - BS in PT from Bouve College at Northeastern University (Boston) in 1972, summa cum laude.

1988 - MS in Clinical and College Teaching for Allied Health Professionals - Univ of Kentucky.

WORK EXPERIENCE:

3 years – PT staff and Director for United CP Center, Lawrence, MA
9 years - PT staff at Children's Rehab. Center (later, Kluge Center), Charlottesville, VA.
3 years - PT education faculty, College of Health-Related Professions at MUSC, Charleston, SC, and Director of PT Services for the Div. of Developmental Disabilities at MUSC.
1 year, consultant, Cardinal Hill Hospital's Head Trauma & Pediatrics teams – Lexington, KY.
4 years, assisting in the PT Department at Children's Hospital at Stanford, Palo Alto, CA.
32 years in private practice in California and Colorado.

PUBLICATIONS:

Team Considerations for Managing Equinus Deformity in Children. O&P Almanac, 2022; March: 26-31

Help Patients Manage Equinus Deformity. O&P Business News, 2011; April: 74-77.

Orthotic Management of Low-Toned Children: The Earlier the Better. (Co-author). O&P Edge. 2011; Apr: 24-29.

Serial Casting and Other Equinus Deformity Management Strategies for Children and Adults with CNS Dysfunction (2010), published by Progressive GaitWays.

Foot Talk (2009), a 2-hour lecture on functional foot anatomy and closed chain biomechanics, accompanied by a set of Power Point handouts of the same lecture.

Lower Extremity Developmental Features (2000), a home study monograph _APTA's Orthopedic Section.

Progressive Casting and Splinting for Lower Extremity Deformity in Children with Neuromotor Dysfunction (1990), a full-length text. published by Therapy Skill Builders

Serial Casts: Their Use in the Management of Spasticity-Induced Foot Deformity (1990), published by Therapy Skill Builders

RECORDED TRAINING & WEBINARS (Available at the Cusick Center for Learning: www.gaitways.com):

Legs & Feet: A Review of Musculoskeletal Assessments (1997, revised 2015) (DVD/CD set).

Developmental Orthopedics: A Review of Operating Processes with Implications for Management (Spring, 2022)

The W-Sitting Controversy: Evidence and Science (2020)

A Clinical Golden Rule for Managing Pediatric Orthopedic & Motor Development (2018)

- Program 1: Early Acquisition of Postural Control
- Program 2: Expanding Postural Control into Movement

CLINICAL TEACHING:

Guest lecturer for annual conferences of the APTA, the AAPPT, the NDTA, the AOPA, the AAOP, and the AACPDM in the US and Canada; the ISPO Consensus Conference for Orthotics in CP; and the British APO. She has presented more than 460 courses by invitation only in 19 countries.

Associate Professor (on call) for the Rocky Mountain University of Health Professions – Pediatrics Program – Provo, Utah starting in 2006 to present.

Since 1993 Ms. Cusick has been consulting and practicing privately, generating literature and educational materials in Telluride, Colorado. There, she continues to develop therapeutic products, including her invention, TheraTogs orthotic systems. A curriculum vita is available upon request.

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Disclosure

As the originator of TheraTogs™ Orthotic Undergarment & Strapping Systems, I am financially affiliated with TheraTogs, Inc.

Progressive GaitWays, my clinical training company, has recently become a US distributor of Turtlebrace products.

 2

2

Where are we going in this course?

Into the land of biomechanics, kinesiology, physiology, & sensory-motor learning, where…

Postural control & movement acquisition are influenced by:

- neuromotor system status
- the verticality drive
- functioning torso & joint alignment
- the information provided by the sensory systems
- physiologic adaptation of the soft & boney tissues.

 3

3

In the land of biomechanics, kinesiology, physiology, & sensory-motor learning…

postural control & movement acquisition are essential to healthy & effective limb use & to foot development...

 4

4

In the land of biomechanics, kinesiology, physiology, & sensory-motor learning…

...the foot is our **BODY-GROUND INTERFACE** in standing & walking.

 5

5

…Where are we going in this course?

Into a study of the typical & pathological effects of routine balance & movement strategies on ankle muscle tone.

Why?

Let's have a look at Matthew walking without & with articulated AFOs – issued because he walks – with a 0º plantarflexion stop – issued because he has equinus deformity….

 6

6

Matthew
age 4 yrs 3 mos
diplegic CP
Gait in socks

 7

7

What do we expect from these AFOs?
Matthew has been wearing them daily for almost a year.

Are his gait problems due to spasticity?

Is the source of his gait pathology in his legs & feet?

 8

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Where are we going in this course?

- Into a deeper understanding of the sciences that operate in lower limb muscle tone development & management.
- Onto a higher plane of perception & skill in evaluating muscle tone as evidence of routine function.
- Into a new way of thinking about & managing equinus deformity in children.

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Let's get started!

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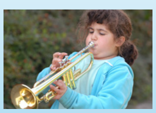
1

Postural Control & Limb Use

1

What is postural control (PC)?

The ability to maintain any posture unassisted while moving & engaging in tasks.



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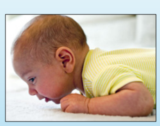
Postural Control Begins in the Verticality Drive

- Apparently innate & life-preserving.

(Hadders-Algra M 2005)

Lay down, stay down → all systems deteriorate.



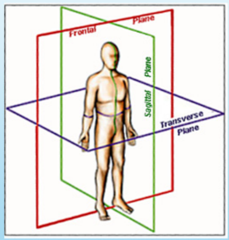
- Fosters early and ongoing antigravity (A-G) muscle activity.

(Bly L 2011; Hadders-Algra M, Brogren E 1998)

3

Antigravity (A-G) muscle action progresses:

- From head → toe
- From proximal → distal (neck & trunk → limbs)
- From A-G extension (EXT) to/ + A-G flexion (FLX)
- From sagittal to frontal to transverse planes.



(Bly L 1994, Bly L 2011, Gignetti F 2011, Hadders-Algra M, Brogren E 1998)

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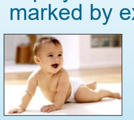
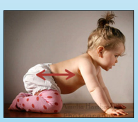
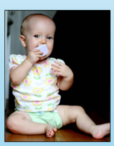
P-C is acquired sequentially over many hours spent in play in each developmental posture, each one marked by exploratory variability.

(Dusing SC, Harbourne RT 2010, Adolph KE 2000)





All movements engage the sensory receptors.




5

A Competent Trunk:
The Foundation for Effective Limb Use

Proximal stability → effective distal mobility.

(Pin TW, Butler PB 2018; Sato NTDS, Tudella E 2018; Rachwani J, Santamaria V 2015 & 2013; Moreira da Silva ES 2016; Hadders-Algra M 2013 & 2010; van Balen LC 2012; de Graaf-Peters VB 2007; Hopkins B 2002; van der Fits IB 1999a & 1999b; Thelen E 1998; Rochat P 1992)

6

A-G Righting Reactions
The First PC Strategy to Emerge & Persist

Direction-specific postural patterns; muscle activations *on the side opposite the perceived body sway, maintaining verticality.*

(Savaadra S 2012; de Graaf-Peters VB 2007; Hadders-Algra M 2005; Assiante C 1998; Hadders-Algra M, Brogren E 1998; Hirschfeld H 1994)

Body sway must be detected.

7

Several Sensory Systems Inform the CNS* of Bodyweight Displacements

VISION
THE VESTIBULAR SYSTEM
THE SOMATOSENSORY SYSTEM
- Proprioceptors
- Mechanoreceptors
- Exteroceptors

Redundancy signals the significance of sensory information in learning to navigate in & engage with the world.

*CNS: Central Nervous System

8

"The brain's response to somatosensory stimuli is essential to experience-driven learning in children."

(Maitre NL, et al 2012, p. 1276)

We are constantly learning.

"What can you do?"
"How do you do it?"

⬇

"What are you learning right now & all day?"

9

Sensory Deficits in Children with CP*

Children with CP often exhibit truncal hypotonia
& show evidence of deficits in perceiving
& processing somatosensory input.

(Jiang H 2019a & 2019b; Pavão SL, Rocha NA 2017; Pavao SL, Silva P 2015; Wang S, Fan GG 2014; Memedyarov AM, Namazova-Baranova LS 2015; Kurz MJ, Wilson TW 2011; Hoon Jr AH, Vasconcellos FA 2010; Riquelme I, Montoya P 2010; Hoon AH, Stashinko EE 2009; Wingert JR, Burton H 2009; Kułak W, Sobaniec W 2006; Shumway-Cook A, Woollacott MH 1985).

Ligament laxity has been associated with reduced joint PPC*.

(Lee HM, Cheng CK, Liau JJ 2009; Myers JB, Lephart SM 2002)

*CP: Cerebral Palsy
*PPC: proprioception

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Functioning Postural & Limb Alignment

- Postural alignment refers to the positioning of operating body segments in relationship to each other & to gravitational forces.
- Optimum postural & functioning alignment minimizes gravitational stress on loaded bones, joints, muscles & other soft tissues.
- Optimum functioning alignment provides optimum somatosensory feedback for upright maintenance & learning.

(Neumann DA 2017; Sahrmann SA 2010; Kendall FP, McCreary EK 2005; Oatis CA 2004; Sahrmann SA 2002; Soderberg GL 1986)

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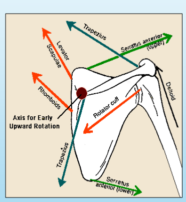
"Alignment is EVERYthing!" - Shirley Sahrmann, PT, PhD, keynote, SOPAC / AAPPT meeting in Cincinnati, OH, 2016

- Muscle balance & functionally-relevant strength are associated with functioning joint alignment:
  - Optimizing alignment improves muscle force vectors & leverage.
  - Optimizing muscle balance improves functioning alignment.



(Sahrmann SA 2002 & 2010; Newmann DA 2017; Oatis C 2004)

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Functioning Alignment Influences Limb Use

Test # 1: Pretend to feed yourself a cookie…

…Rotate your shoulder medially & repeat.

 13

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Functioning Alignment Influences Muscle Recruitment

Test # 2:

Sit up straight at the front edge of your chair.

Take a deep breath.
Lean back until you feel your abdominals activate.

Slump with your head forward.

Take a deep breath.
Lean back until you feel your abdominals activate.

 14

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Postural Alignment Influences Functional Effectiveness & Efficiency

Test # 3: Stand up. Notice the parts of your feet taking pressure from the floor.

Lift one foot… return it to the floor.

Pronate your feet… Where did your bodyweight go?

While pronated, lift one foot…

If you have room to do so, try to walk 6 steps with your feet fully pronated.

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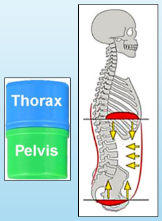
Think of the thorax & pelvis as stackable cups.



Developmental objective:

Align their bases – the diaphragm & the pelvic floor – in sagittal & frontal planes to form a stable structure.

The cups will stack in developing postures when EXT is balanced by FLX.

(Mary Weck, PT and Julie Perfect, DPT; Bly L 2011; Hadders-Algra M, Brogren E 1998)

16

Ideal PRONE Resting Posture at Age ~4 Months

- Symmetrical bilateral trunk EXT.
- Thorax & pelvis are stacked in frontal plane.
- Bodyweight base: **belly & thighs.**
- Attention is on the environment while sustaining the posture = postural control.

(Bly L 2011)

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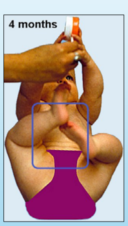
Ideal SUPINE Resting Posture at Age ~4 Months

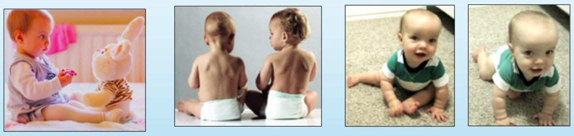


- The cups are stacked, holding midline.
- Symmetrical with limbs elevated & moving together.
- Bilateral extremity motions activate abdominals.
- Attention is on the environment while sustaining the posture = postural control

(Bly L 2011)

18

Ownership of a posture → moving within it & then → moving into & out of it.



Sagittal Frontal Transverse

Ideal, competent infant sitting in sagittal plane → lateral weight shifts & recovery in frontal plane → play & positional transitions in transverse plane.

(Bly L 2011)

19

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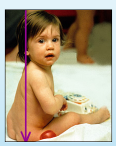
Movement = Competent Displacements of the Body COM

Look at trunk & limb <u>alignment.</u>



Limbs are in use & are <u>not stabilizing</u>.

20

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Fundamental Question for Each Functioning Posture:

Where is the body weight concentrated?

...that stimulates load receptors

...that trigger the verticality drive & righting reactions

...that maintain the posture

...so that the limbs can operate effectively?

21

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Questions?

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2

Observations of Muscle Tone Development in the Triceps Surae Muscles

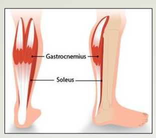
1

1

The Significance of Ankle Plantarflexion in Gait

The primary function of the gastrocnemius & soleus – triceps surae muscles - is to restrain the upright body from falling forward.

(Honeine JL, Schieppati M, et al 2013)



If the tibia were allowed to continue inclining past midstance in gait, the stance knee would flex & the limb would collapse.

(Perry J, Burnfield J 2010; Winter DA 1984)

The building of typical tone in the triceps surae muscles is a 10+-year undertaking.

 2

2

All Body Tissues Adapt to Routine Use History

- Muscle Tissue
- Fascia
- Bone
- Nerve
- Blood Vessels
- Skin
- CNS

Why?

Apparently, to support the continued use of routine postural control & movement strategies & to optimize longevity by minimizing energy cost.

(Lieber RL, Roberts TJ, Blemker SS 2017; Neumann DA 2016; Sahrmann SA 2010; Oatis CA 2004; Frost HM, Schönau E 2000; Robling AG 2009; Salmons S, Henriksson J 1981)

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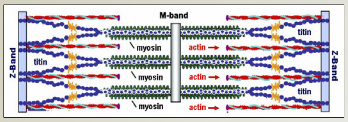
The Sarcomere – Muscle Cell & Contractile Unit



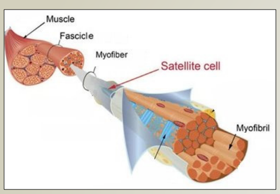
(Adapted from Fig 1 in Buck D 2021)

Actin & myosin filaments overlap with muscle length changes.

Muscle adapts in length by adding or removing sarcomeres in series to optimize sarcomere filament overlap.

4

Satellite Cells Support Muscle Growth & Adaptation (?)



Satellite cell – a type of stem cell – appears to support muscle growth in length & diameter in response to bone growth & to changes in routine loading; & to participate in muscle repair after injury.

(Meiliana A, Dewi NM 2015)

5

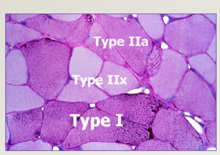
Muscle Fiber Types

TYPE I fibers (tonic, slow-twitch): stabilize, **decelerate, fire 1st,** high endurance, **low-cost**; prevail in 1- joint muscles.

TYPE II A & IIB fibers (phasic, fast-twitch): move, **accelerate,** rapid on/off, powerful, **high-cost;** prevail in 2-joint muscles.

(Scott W, Stevens J, Binder–Macleod SA 2001)

Fiber type proportion is adapted to routine use.



Dark – Type I
Lighter – Type IIA & IIB

Fibers are similar in size & shape.

6

Fascia – All Connective Tissues (CT) in the Body

Fascia within & around skeletal muscles is an elastic, **water-dense,** open 3-D lattice of stretchy & gliding vacuoles & collagen fibers that align to support & accommodate to routine movements.

(Klinger W, Schleip R 2015; Guimberteau JC 2012)

Hyaluronan in the ECM acts as a stabilizing water reservoir & lubricant.

(Balazs EA, Laurent TC 1986; Pratt RL 2021)

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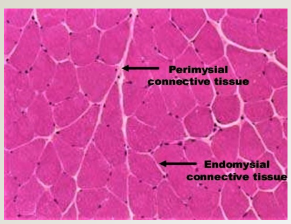
Fascial Share of Muscle Tissue

Fascia comprises ~5% of healthy skeletal muscle.

(Lieber RL, Friden J 2019; Gillies AR, Lieber RL 2011)



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Hereafter, the term "muscle"
will refer to the composite muscle tissue
encountered clinically,
with all accompanying tissues
including fascia, nerves, blood vessels & skin.

9

9

Properties of Resting (Composite) Muscle

Extensibility: elongation capability.

Hypo / hyperextensibility: diminished / increased elongation capacity

Tone: passive compliance; resistance to externally imposed movement about a joint.

Hypertonus: increased resistance to externally imposed movement about a joint**; stiffness.**

(Sanger TD, Delgado MR 2003)

Viscoelasticity: shows greater resistance to rapid than to slow stretch & recovers original length after stretch.

Fascia in skeletal muscle is viscoelastic.

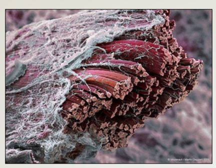
10

10

Hyaluronan in Fascia and Resting Muscle Tone

The hyaluronan component of abundant **perimysium** appears to be the major contributor to its viscoelasticity (a.k.a R_1 catch).

(Cowman MK, Schmidt TA 2015)



Pinterest.com

Crimped collagen fibers uncrimp under stretch.

(Gadjosik RL 2001; Purslow PP 1989; Rowe RWD 1981 & 1974; Borg TK, Caulfield JB 1980)

11

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Normal Adult R_1 (Catch) End Range – Triceps Surae

Observed in prone with knee extended to 0º & foot joints congruent

12

12

TD DFROM-KE - R1-R2

DFROM-KE
Typically developing girl
Age 3 years

13

13

What is R1 end range?

- The joint angle at which a gentle stretch at ≥180°/s encounters resistance at a relatively consistent length 3 times in succession. *(Love S, Gibson N 2016)*
- "Resistance-1", "spasm-free" resistance *(Maitland DH 1977, pp 345-347)*
- "First catch" end range
- Functional end range *(Lin JP, Brown JK 1997; Reimers J 1974)*
- "Initial end range" & "A_o" with peripheral nerve activity eliminated by circulatory constriction. *(Tardieu G, Tardieu G 1987)*
- Slack in connective tissues (CT) removed *(Hoang PD, Herbert RD 2007)*
- L_o or L_1 *(Lieber RL 1993, Lieber RL 2010)*

14

14

Does the R1 angle of the Modified Tardieu Scale consistently detect "spasticity" (hyperreflexia) with an EMG response?

Yes - Elbow flexors; No - Ankle plantarflexors *(Patrick E, Ada L 2006)*

No - Low association with EMG response *(Lynn B-O, Erwin A 2013)*

No - No significant relationship between peak EMG activity & the quality of muscle reaction or of the R2-R1 values. *(Alhusaini AA 2010)*

No - High velocity tests of hamstrings, soleus, & gastrocnemius in 20 children with CP showed <100% incidence of EMG activity. *(van den Noort JC, Scholtes VA 2010)*

So, no.

Test force used in these studies is unknown.

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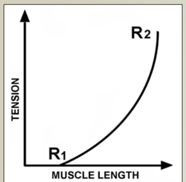
Mature Human Resting Muscle Tone



THE "CATCH",
resting muscle length,
optimum length, R_1

The modulus of resistance
of a group of innervated & relaxed muscles
to rapid, passive stretch.

Tone is illustrated by the passive
length-tension relationship *(shown left).*

Why rapid stretch?
Because most routine movements are quick.

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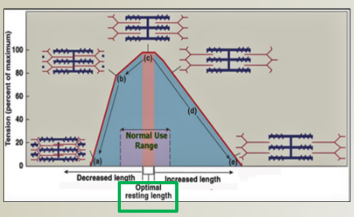
Functional Significance of Resting Muscle Length - the R_1 "Catch"

Sarcomere Length-Tension Relationship



At optimal resting length
(R_1 zone), actin &
myosin filaments overlap
for greatest possible,
rapid cross-fiber linkage
& force generation.

The "sweet zone".

(Lieber RL, Theologis T 2020)

17

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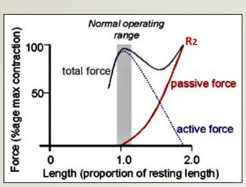
R_1 Indicates the Normal Operating Range

The strongest length
around the catch
comprising ~10%
of full muscle length
under stretch.

Note force capacity
at R_2 end range.



1.0: **[R_1]** normal operating length
2.0: 2 x that length

https://www.bristol.ac.uk/phys-pharmneuro/media/plangton/ugteach/ugindex/m1_index/nm_tension/page1.htm

18

18

Normal Development of Muscle Tone in the Gastrocnemius & Soleus Muscles

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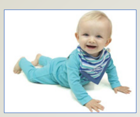
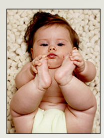
Early Resting Postures

In typical development, infants acquire predictable postures, maintain them, explore & play within them, & move out of them into new postures.

(Bly L 2011)





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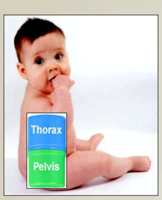
Ideal SITTING Posture – Age ~8 Months



Ideal infant sitting typically occurs without hand propping & features a <u>VERTICAL sacrum & spine.</u>

Straight spine promotes cup-stacking with effective A-G FLX for upright maintenance → postural control.

(Bly L 2011)

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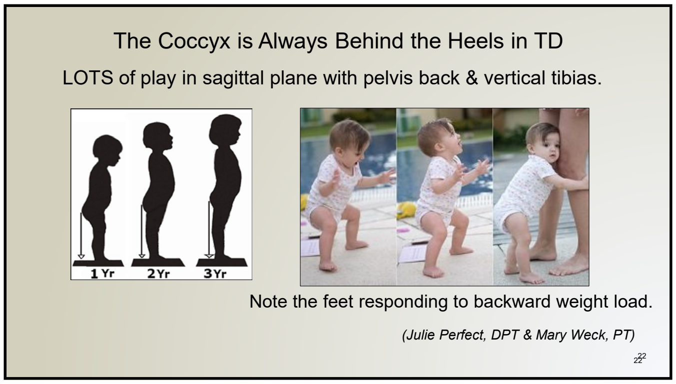
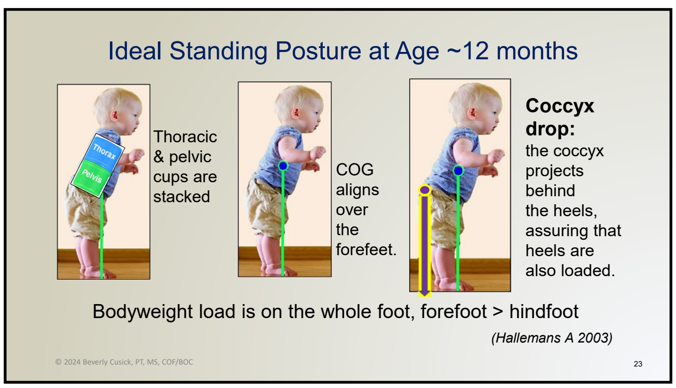

The Coccyx is Always Behind the Heels in TD
LOTS of play in sagittal plane with pelvis back & vertical tibias.
1 Yr
2 Yr
3 Yr
Note the feet responding to backward weight load.
(Julie Perfect, DPT & Mary Weck, PT)
22

22


Ideal Standing Posture at Age ~12 months
Thorax
Pelvis
Thoracic & pelvic cups are stacked
COG aligns over the forefeet.
Coccyx drop:
the coccyx projects behind the heels, assuring that heels are also loaded.
Bodyweight load is on the whole foot, forefoot > hindfoot
(Hallemans A 2003)
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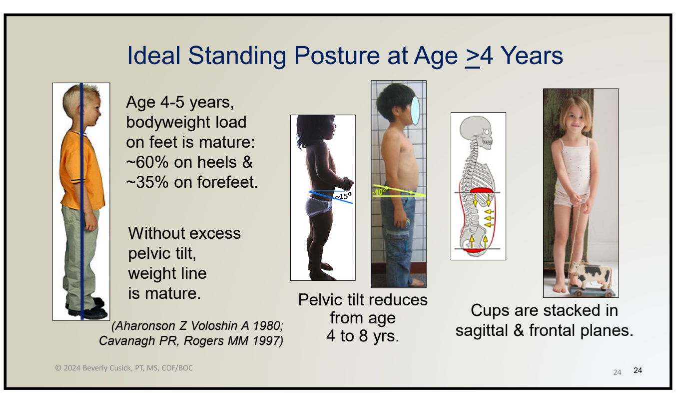
Ideal Standing Posture at Age >4 Years
Age 4-5 years, bodyweight load on feet is mature: ~60% on heels & ~35% on forefeet.
Without excess pelvic tilt, weight line is mature.
(Aharonson Z Voloshin A 1980; Cavanagh PR, Rogers MM 1997)
Pelvic tilt reduces from age 4 to 8 yrs.
Cups are stacked in sagittal & frontal planes.
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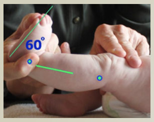
Early Developmental Changes in Ankle DF ROM

Newborn ankle DFROM: mean 59º (range: 37º-72º)

(Waugh KG, Minkel et al 1983)



Audrey
age 2 months

Triceps surae muscle use begins with belly crawling, using the foot for propulsion & continues with quadrupled play.

*KE: knee extended

25

25

Cruising Benefits Motor Learning & Lower Limb Muscle Strengthening

16 TD* prewalkers & new walkers were shown to shift bodyweight from foot-to-foot 500-1500 times per waking hour.

(Adolph KE, Avolio AM et al 1998)

New walkers showed a mean ankle DFROM-KE* of 38º – a reduction of ~20º in 12 months.

(Wong S, Ada L 1998)

This process of losing extensibility – "tuning" plantarflexor muscle length to accommodate routine use – continues for ~10 years.

*TD: typically developing *KE: knee extended

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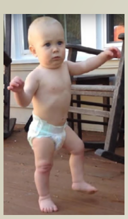
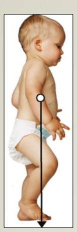
New Walker's Challenge: Manage Body COG Acceleration





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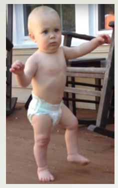
Acceleration-Control Aide in Early Walking: Vertical Tibias & Really Big Feet

Braking Mechanism

The BIG baby foot + **tonic triceps surae muscle activity** completely control tibial inclination & knee hyperextension while the infant builds bodyweight control & proximal muscle strength.



During the vertical tibia period, the new walker uses 0 of the available 40º of ankle DFROM.

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Charlie
TD New Walker

Stands Up & Works Out with Vertical Tibias

29

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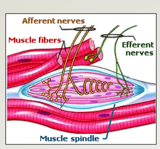
Soleus Muscle Proprioceptors

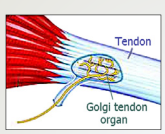
Spindles sense the rate & extent of muscle fascicle length change.

Golgi Tendon Organs sense change in tension in the tendon.

Both receptors appear to help to trigger contractions that <u>stabilize the stance limb trajectory at the tibia</u> & contribute to the generation of ankle PF moment.

(Dietz V et al 2000)





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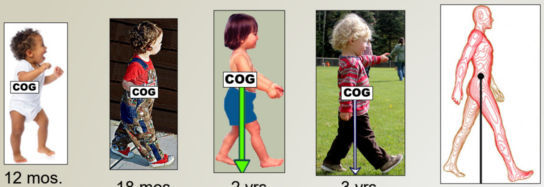
Resolution of COG acceleration occurs over 6 years.

(Dierick F, Lefebvre C 2004)



12 mos. | 18 mos. | 2 yrs. | 3 yrs. | $\geq$7 yrs.

- Soleus muscle recruitment limits tibial inclination from 0 to 10º.
- Gastrocnemius muscle recruitment increases at heel rise.

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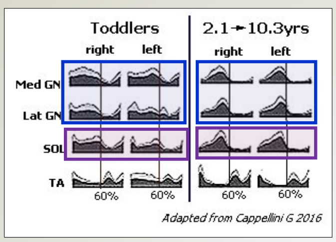
Toddler's Muscle Recruitment Strategies in Gait

Typical toddlers coactivate LE muscles for stability in both swing & stance phases of gait.

Note changes in gastrocnemius (GN) & soleus recruitment. →



(Cappellini G 2016; Okamoto T 2003, 2001; Okamoto T, Kumamoto M 1972; Leonard CT, Hirschfeld H 1991)

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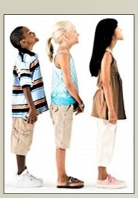
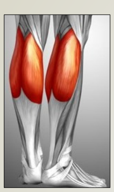
32

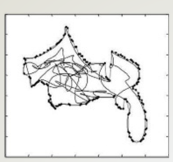
R1 DFROM – GN: At what ankle angle (AA) do the triceps surae function most routinely & with the greatest force?

Standing features constant motion.



Standing – AA ~0º





COP trajectory & sway area.

(Kim GT, Ferdjallah M 2009)

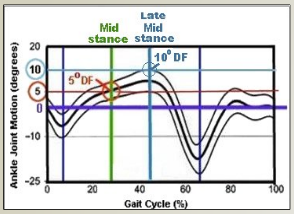
Continued…

33

33

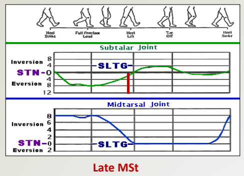
Ideal Ankle & Subtalar Kinematics at Late Midstance

Ankle:



(adapted from Winters DA 1987)

Subtalar Joint:



Late MSt

STN: Subtalar "neutral = congruity
Ideal congruent calcaneal position is 0°

(Michaud TC 1977 & 2011)

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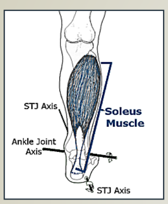
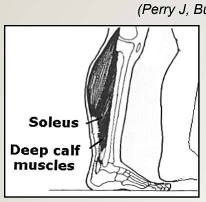
Mature Rocker 2: The Triceps Surae

Leg inclination past vertical is controlled.

Often described as a function of the soleus, both the soleus & gastrocnemius (GN) are active during this phase of gait.

(Perry J, Burnfield J 2010)





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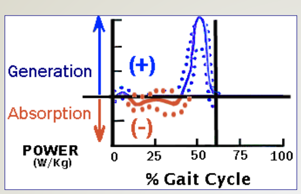
R1 DFROM-GN, continued.

Ankle PF at propulsion generates ~36-45% of acceleration energy in gait.

(Robertson DG, Winter DA 1980; Winter DA 1980; Gage JR 1994)



Adapted from Stout J 2006

36

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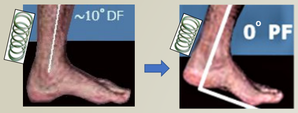
R1 DFROM – GN, continued.

Routine maximum gastrocnemius (GN) force – 4th Rocker

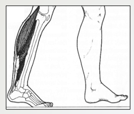


Quick move of tibia → ~10° inclined preloads the GN & fascia for elastic rebound → plantarflexion (PF).

(Perry J, Burnfield J 2010)

"4th Rocker": Body rolls over metatarsal heads & toes **when the plantarflexing ankle angle (AA) = ~0° → builds R1 at ~ 0°.**

At 4th rocker with AA = 0°, metatarsal heads & toes carry 100% of body weight x ~5000/day.



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Emergence of Typical R2 DFROM - KE

The soleus stops the tibia at **~10° incline = 10° DF ~5000 x/day.**

At that moment, the foot joints are ideally congruent. SLTG → pronation is resolved and supination with heel rise follows.

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Cusick's Observations: Developmental Changes in passive ankle DFROM-KE*

AGE	R1 DFROM KE - Prone	R2 DFROM KE - Prone
12→30 mos	~35°	~35°
30→42 mos	~15°→20°	~30° → 35°
3.5 thru 6 yrs	~5°→15°	~20° → 25°
7→10 yrs	~0°→5°	~15° → 20°
11 yrs→	~0°	~10° → 15°

*DFROM-KE: Dorsiflexion range of motion with knee extended - in prone, foot joints congruent

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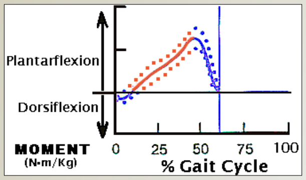
***R1 DFROM-KF:** At what AA does the **soleus** function most routinely & with the greatest force?*



Soleus works hardest to stop the tibia inclined **~10°.**
R1 = ~10°DF when measured with the knee flexed.

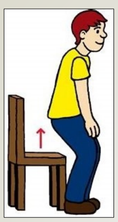
40

40

***R1 DFROM-KF:** At what AA does the **soleus** function most routinely & with the greatest force?*

Sitting down on a chair, & rising to stand again both require that the legs incline ~10°.

→ R1 ~10° DF when measured in knee flexion.



Try to stand up while keeping your torso nearly erect & knees aligned directly over your heels…

41

41

Cusick's Observations:
Developmental Changes in Passive Ankle DFROM-KF*

AGE	R1 DFROM KF - PRONE	R2 DFROM KF - PRONE
12→30mos	~35°	SAME
30→42mos	~30°→35°	
3.5 thru 6yrs	~20°	~25°→30°
7→10yrs	~15°	~25°
11 yrs→	~10°	~20°

*DFROM-KF: Dorsiflexion range of motion with knee flexed - in prone, foot joints congruent

42

42

Hypotheses Concerning R_1 Formation:

The R_1 "catch" reveals a strengthening adaptation of fascial tissues that:

- Increases the speed of effective, maximum, routine muscle use.
- Supports load-bearing, hard-working LE muscle fibers (bundles of sarcomere chains)
- Reduces the muscle cell workload with viscoelastic assistance at the heaviest use lengths
- Conserves energy
- Prolongs muscle tissue usefulness (longevity).

We do not use our UE muscles for this type of daily work.

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Questions?

Discussion..?

44

3

Relating Equinus Deformity
to Routine Use History
with Deficits in Postural Control
& Sensory Processing

1

1

New Interest in Muscle Pathology Causes & Treatments

Emerging evidence challenges the role of spasticity as a determinant of gross motor function & in the development of fixed muscle contractures.

The time has come *[finally!]* to investigate the underlying mechanisms responsible for muscle alterations in CP.

This knowledge could help clinicians to understand & apply relevant treatment modalities for muscle pathomorphology - altered form & structure - on an individual basis.

(Howard JJ, Graham HK, Shortland AP 2022)

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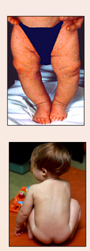
Healthy P-C* acquisition features these resting postures:



A competent trunk is
the foundation for effective limb use & movement.

*P-C: postural control

3

3

Deficits in Postural Control Acquisition & Maintenance in Children with CP & Periventricular Leukomalacia (PVL)

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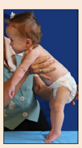
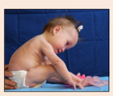
4

Postural Shortfalls in Prematurity with Diffuse WM* Lesions

No newborn flexion.

Legs & feet in LR





Most children with CP lack the primary building block of fundamental, symmetrical A-G EXT.

*WM: white matter

(Hoon AH Jr, Stashinko EE 2009; Nagae LM, Hoon AH 2007; Bly L 2011)

5

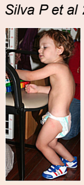
5

Evidence of Sensory Deficits

Children with CP are <u>less responsive</u> to sensory input than their TD peers.

(Pavao SL, Silva P et al 2015)

Children with CP show significant deficits in somatosensory perception & cortical processing.



(Kurz MJ, Wilson TW 2011; Hoon AH Jr, Stashinko EE 2009; Wingert JR, Sinclair RJ 2010; Wingert JR, Burton H 2009; Riquelme I, Montoya P 2010; Kułak W, Sobaniec W 2006)

6

6

Impacts of Sensory Deficits

- Sensory input informs postural control & movement acquisition & maintenance.
- Sensory input from faulty postures & movements informs faulty postural control & movement acquisition & maintenance.
- In the presence of an innate drive for verticality, practice engaging in faulty postural control & movement strategies alters white matter tract formation.

(Chaturvedi SK, Rai Y 2013; Ceschin R, Lee VK 2015; Papadelis C, Ahtam B 2014, Hoon AH, Stashinko EE 2009)

7

7

"Trunk control in cerebral palsy: are we ready to address the elephant in the room?"

The limbs have prevailed over the trunk as a focus of research & treatment of children with CP. *(Saavedra S 2015)*

Poor control of trunk postural muscles is a primary impairment in children with CP.

(Heyrman L, Desloovere K 2013; Heyrman L Desloovere K 2014; Prosser LA 2010; Davis MF, Worden K 2007; Rosenbaum P, Paneth N 2007)

8

8

Trunk Control in Sitting has been Associated with Gross Motor Function

- SATco scores & GMFM & PEDI scores
  (Curtis DJ, Butler P, Saavedra S 2015)

- Trunk Impairment Scale (TIS) (in sitting)
- Trunk Control Measurement Scale (TCMS) (in sitting)
- Control of COG* accelerations in gait
  Both sitting trunk control total scores showed moderate to good correlation with trunk accelerations – AP, ML, & V – as evidence of balance in gait.
  (Sæther R 2015)

*COG: center of gravity

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Building Hypertonic Muscles with Routine, Compensatory, Tonic Recruitment

10

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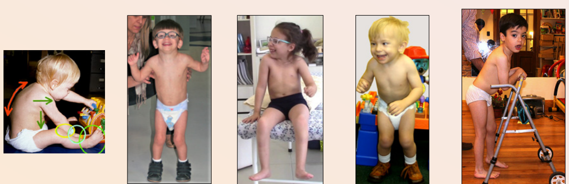
Compensatory Postural-Control Strategies Recruit Limbs



Hypothesis:
With poorly developed trunk & hip control, upright maintenance wins over purposeful limb use as limb muscles work tonically for stability.

(Cappellini G, Ivanenko YP 2016; Woollacott MH, Shumway-Cook A 2005)

11

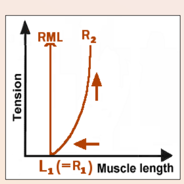
11

Hypertonus is Not Spasticity

Hypertonus is stiffness – increased resistance to externally imposed movement about a joint.

(Sanger TD, Delgado MR et al 2003)

Muscles used tonically in shortened state adapt to support continued tonic use in shortened state by shortening & stiffening.



(Howard JJ, Herzog W 2021; Lieber RL, Theologis T. 2020; Lieber RL, Roberts TJ 2017; Riad J, Modlesky CM 2012; Smith LR, Chambers HG 2012; McDowell BC 2012; Sahrmann SA 2002 & 2011; Salmons S, Henriksson J 1981)

12

12

Developmental Gastrocnemius (GN) Muscle Stiffness

41 children with CP; 45 TD peers

Outcome measures:
Freehand 3-D ultrasound used to evaluate the volume of the medial gastrocnemius muscle.

Biomechanical & electrophysiological (EMG) measures were used to determine passive & reflex mediated stiffness of the triceps surae muscle tendon unit (MTU).

RESULTS: TD & CP groups showed the same GN volume increase until age 12 months.

(Willerslev-Olsen M, Choe Lund M, Lorentzen J 2018)

Continued.. 13

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Developmental Stiffness, continued

- >age12 mos., CP group showed significantly reduced growth rate.
- TD children showed a linear increase in passive stiffness with age.
- Children with CP >age 27 months showed significantly greater passive stiffness than the TD group.
- 4 of 41 children with CP (<10%) showed reflex-mediated stiffness (EMG during stretch).

Conclusion: Reduced muscle growth may be involved in the pathophysiology of contractures in children with CP.
(Willerslev-Olsen M, Choe Lund M, Lorentzen J 2018)

… And chronic, tonic, stability-seeking GN use in shortened state might influence reduced growth rate by physiologic adaptation…?

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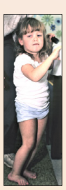
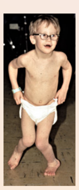
Chronic, Excessive Pronation Unloads the Heels





LE muscles used to remain upright are the same as those that shorten in children with diplegic CP.

Excessive pronation draws body COG forward, rotates the LEs medially, inclines the tibias, & reduces heel loading.

Let's try this together. Please stand up & follow my instructions.

15

15

Effects of Foot Pronation on LE S-P Gait Biomechanics

Kinematic & kinetic data of 22 adults (10F & 12M) were collected while they walked wearing flat sandals (control condition) & laterally wedged sandals to induce foot pronation (study condition).

Results: The study condition increased:

- FF ROM ($p < 0.001$; effect size = 0.73)
- Ankle PF angle ($p < 0.001$; effect size = 0.96)
- GRF in the anterior direction ($p = 0.003$; effect size = 0.60).

The study condition:

- Reduced ankle PF moment in mid & terminal stance phases
- Delayed & increased ankle PF moment in late stance ($p<0.001$; effect size 0.72)

Continued…

(Resende RA, Pinheiro LSP, Ocarino JM 2019)

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16

Effects of Foot Pronation on LE S-P Gait Biomechanics, continued.

Significance: Increased foot pronation compromises stance-phase LE mechanics in the sagittal plane, apparently because foot pronation increases foot segments flexibility & compromises foot lever arm function.

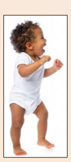
(Resende RA, Pinheiro LSP, Ocarino JM 2019)

17

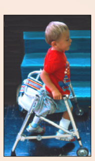
17

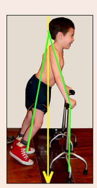
Common Gait Strategy - Anterior COG Carriage

Many ambulatory children with bilateral CP live in a chronic A-G RR* to immature forward carriage of body COG.



TD 1 yr.





Hypothesis: Chronic reliance upon hamstrings and triceps surae muscles to remain upright → contractures in those muscles.

*A-G RR: Anti-gravity righting reaction

18

18

Considering the Gastrocnemius Specifically

Key Resource

Weck M, Sisson GA Jr.,
Prihoda W, Vankoski, et al
The effect on gait of an anterior placement of the whole-body center of mass.
(Gait Posture. 1994. 2(1):56. Poster.)

(Weck M, Sisson GA 1994, edited & reissued as a course handout)

Continued…
19

19

Tomas
Diplegic CP
Age 4 years

20

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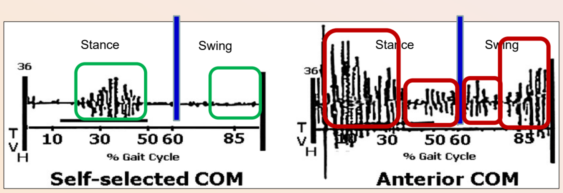
Right Medial Gastrocnemius - EMG - **TD Child**, Age 10 yrs



(Weck M, Sisson GA 1994, edited & reissued as a course handout)

Continued…
21

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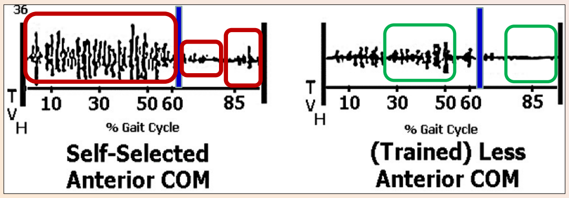
Left Medial Gastrocnemius – EMG - Diplegia, Age 10 Yrs



(Weck M, Sisson GA 1994, edited & reissued as a course handout)

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22

Excess COG Acceleration: Compromised Components

1. Inadequate fundamental A-G extension in the neck, trunk & hips → excess trunk & head inclination
2. Overloaded medial forefeet with immature ligaments → pronation
3. Excess foot pronation → anterior COG displacement & excess tibial inclination
4. Soleus capacity to decelerate the tibias is overwhelmed by anterior COG displacement
5. No vertical tibia period, no early exaggerated braking mechanism.

23

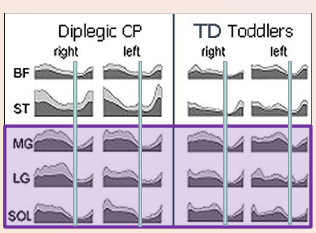
23

Immature Muscle Recruitment in Diplegic Gait

- 35 with CP ages 2-12yrs, GMFCS Levels I & II
- 33 TD ages 1-12 yrs

Compared with the TD group >age 2 yrs, those with CP showed <u>very little age-related change in EMG activity.</u>

Note gastrocnemius & soleus activity in stance & swing phases.



(Cappellini G, Ivanenko YP 2016)

24

24

Chronic E-Stim Effects on Muscle Structure Resemble Use History in CP & Stroke

Features of altered muscle structure in children with CP
& in adults with UMN lesions
are consistent with experimental studies
showing that chronic, tonic electrical stimulation
of muscles at low frequencies →
transformation toward type I muscle fibers.

(Salmons S, Henriksson J 1981; Kernell D, Eerbeek O et al 1987; Donselaar Y, Eerbeek O, et al 1987; Rose J et al 1998)

25

25

Increased Tonic Muscle Recruitment in Gait Correlates with Muscle Pathophysiology in CP

10 children with CP, ages 5-14 yrs – mean age 7.8 yrs

5 TD children, ages 5-13 yrs – mean age 7.8 yrs

CP group: muscle action **prolonged** by (mean) **2.74 times:**

- 5 children: **GN** activity: mean **69.4%** (TD mean 35%)
- 1 child: **Hamstring** activity: mean **78%** (TD mean 22%)

(Rose J, Haskell WL 1994)

Continued…

26

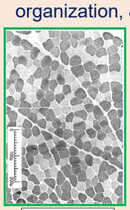
26

Rose et al 1994, continued.

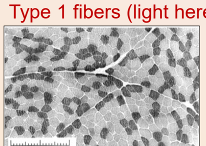
Comparing % of EMG Activity in Gait Cycle to Biopsied Muscles

Biopsies from the CP group showed muscle fiber changes in type, organization, & size that correlated with prolonged (tonic) activity.

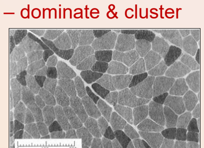
Type 1 fibers (light here) – dominate & cluster



7yo TD



5 yo CP- GN



10 yo CP-med HS

(Rose J, Haskell WL 1994)

27 27

27

Muscle Pathophysiology in CP: Excellent Resources:

Howard JJ, Graham K, Shortland AP. Understanding skeletal muscle in cerebral palsy: a path to personalized medicine?. Devel Med & Child Neurol. 2022 Mar;64(3):289-95.

Howard JJ, Herzog W. Skeletal muscle in cerebral palsy: from belly to myofibril. Frontiers in Neurology. 2021 Feb 18; 12:620852.

Lieber RL, Theologis T. 2020. The muscle-tendon unit in children with cerebral palsy and pathophysiology of muscle. In: Novachek T (Ed): *Improving Quality of Life for Individuals with Cerebral Palsy through Treatment of Gait Impairment.* MacKieth Press, Clinics in Developmental Medicine: 103-120.

Lieber RL, Roberts TJ, Blemker SS, Lee SSM, Herzog W. Skeletal muscle mechanics, energetics and plasticity. J Neuroeng Rehabil. 2017 Oct 23;14(1):108.

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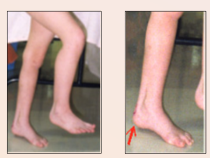
Functional Consequence of Hypertonic Muscle Pathophysiology



Weakness!

(Kruse A, Schranz C 2017; Stackhouse SK, Binder-Macleod SA 2005)

29

29

Children with CP Show Generalized Muscle Weakness

- Wiley ME, Damiano DL 1998
- Damiano DL, Quinlivan J 2001
- Elder GC, Kirk J 2003
- Rose J, McGill KC 2005
- Stackhouse SK, Binder-Macleod SA 2005
- Givon U 2008
- Eek MN, Tranberg R 2011
- Chen CL, Lin KC, Wu CY 2012

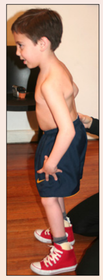
Data acquired with dynamometry.

30

30

Hypothesis:

Postural control status influences lower limb muscle tone, selective motor control, & ROM findings ← in TD children (favorably) & in children with diplegic CP (unfavorably). →



31

31

Idiopathic Toe Walking (ITW)

Walking on toes for more than 50% of the day for >6 months after age 2 years.

(Radtke S Karch N, 2019)

ITW may be the result of some very mild neurological changes that we still don't understand.

(Williams CM, Tinley P, Curtin M 2010)

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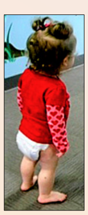
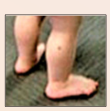
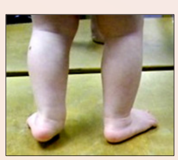
ITW might follow Excessive Foot Pronation → Faulty Heel Loading & PPC

TD 12 months







loading on the anterio-medial foot → off-loading of the heel & lateral column.

Continued….

33

33

A Systematic Review of Methods for Quantifying LE ROM & Gait Changes in Children with ITW

- 27 studies collectively reported 27 different measurement tools used to quantify joint ROM, gait, muscle activity (EMG), strength, neurological status, & radiologic status. *How can they compare data?*
- No study drew a significant association between the ROM findings & gait or any other outcome data ($p > 0.05$). *(Did they assess R1 ranges?)*
- Many reported outcome measures carried limited reliability & validity.

The ITW literature is a mess. *(Caserta A, Morgan P 2019)*

34

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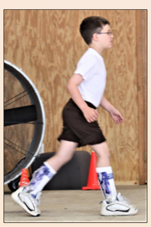
Clinical Observation:

In ITW, bodyweight is displaced <u>more vertically than TD peers.</u>



Bodyweight is carried <u>more anteriorly</u> than in TD peers & <u>less anteriorly</u> than in <u>peers with CP</u>.

35

35

Some Children with ITW Lose DFROM

Equinus (raised-heeled) toe walkers had notably less DFROM (mean finding -5.2^{o}) than those who toe walked intermittently (mean finding 16.9^{o}), $p < 0.01$.

Children ages 1-2 years: mean DFROM: 12^{o}

Children ages 6-15 years: mean DFROM: -4^{o}

(Sobel E, Caselli MA 1997)

What about the incidence of DFROM deficits <u>at R1</u>?

36

36

Some Children with ITW Lose DFROM

60 children with ITW, ages 1 to 15 years

90% stood plantigrade.
88% were able to demonstrate a heel-toe gait.
68% toe walked intermittently.
32% toe walked consistently.

(Sobel E, Caselli MA 1997)

…Did these children pronate their feet in plantigrade?

37

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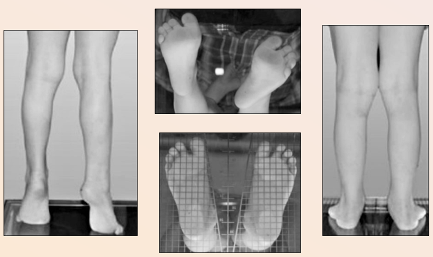
…Is this how they stood plantigrade?



(Szopa A 2016)

38

38

ITW – Incidence of Ability to Strike the Heel in Gait

51 “neuro-normal” children with ITW, mean age 9.3 yrs.

When asked to attempt a normal heel-toe gait:

- 17% could “normalize” both stance & swing variables.
- 70% could “normalize” some - but not all – of the stance & swing variables. *(Westberry DE, Davids JR 2008)*

…Really? What happened to their foot & knee alignment in the “normalized” condition?

39

39

Comparing ROM - CP & ITW & TD

8 children with mild diplegic CP, ages 5-9 yrs;
8 with ITW, ages 3-10 yrs; 8 TD, ages 3.5 to 9 yrs.

DFROM ROM values *(method not described, assume R2)* were similar in those with **CP (-1.3°)** & **ITW (-1.9°)**. **TD (+20°)**

Hamstrings length test

- **CP** mean **-51°** +/-7.4
- **ITW** mean **-22.5°** +/- 13.6
- **TD** mean **-18°** +/-14.7

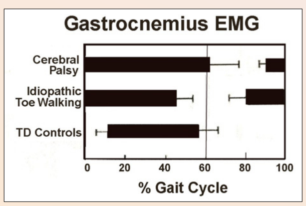
(Policy JF 2001)

...WHY?

Continued…

40

Comparing GN EMG Data in CP, ITW, & TD, continued



(Adapted from Policy JF 2001)

Gait EMG showed premature GN firing in swing in the CP > ITW groups.

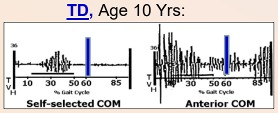
Is uninvestigated bodyweight acceleration a factor here?

Continued…

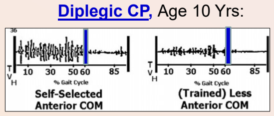
41

Premature EMG in Late Swing Phase – TD & CP

Right Medial GN - EMG
TD, Age 10 Yrs:



Left Medial GN – EMG
Diplegic CP, Age 10 Yrs:

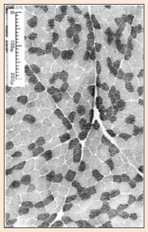


Note the appearance of premature EMG firing in late swing phase in both children – TD & CP - when their body weight was displaced anteriorly.

(Weck M, Sisson GA 1994, edited & reissued as a course handout)

42

Hypertonus: Pathophysiologic Adaptation - ITW



Example from CP biopsy.
Type I fibers stained lightest.

25 children with ITW underwent triceps surae muscle biopsies.

The most common abnormality was an increased proportion of Type I fibers with fiber type grouping (clustering).

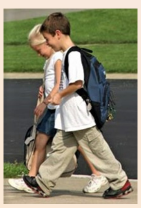
This transformation resembles that seen in biopsies of children with hypertonic, bilateral CP *(shown left).*

(Eastwood DM 1997)

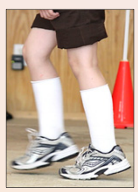
43

43

New Hypothesis:



Postural control status influences lower limb muscle tone, selective motor control & ROM findings ← in TD children (favorably) & in children ITW → (unfavorably).



44

44

Summary - ITW

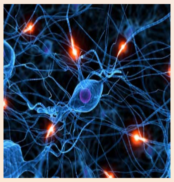
Children who walk on their toes for unknown reasons:

- Apparently carry their COG more vertically than TD & CP peers.
- Apparently carry their COG more anteriorly than TD peers.
- Demonstrate gastrocnemius (GN) muscle recruitment strategies that resemble those of CP peers.
- Develop physiologic changes in hypertonic GN muscle tissue that resemble those seen in children with CP who walk with excessively anterior body COG.

45

45

Neuromotor Mapping Proceeds



With an innate drive for verticality intact, routine practice engaging in faulty strategies alters white matter tract formation in the developing brain.

(Chaturvedi SK, Rai Y 2013; Ceschin R, Lee VK, 2015; Papadelis C, Ahtam B 2014; Kesar TM, Sawaki L 2012; Hoon AH, Stashinko EE 2009)

46

46

Standard computerized gait analysis routinely omits assessment of the body COG projection onto the base of support as a potential source factor in gait kinematics, kinetics, & EMG recordings of muscle recruitment patterns in children with CP.

Ignorance of this factor leads to unquestioned attention to the LE muscles as the cause of gait pathology with surgery & toxin injections that increase existing weakness → disappointing long-term outcomes.

47

47

Summary of Working Hypotheses

Favorably or not:

- Postural alignment delivers body segment weight to loaded joints.
- Somatosensory input informs & influences postural control & movement strategies.
- Postural control status influences limb use.
- Use history - massed practice – influences learning & sensorimotor mapping in the CNS.
- Use history models bone & joints & influences muscle extensibility.

Continued…

48

48

Summary of Working Hypotheses, continued

- Early compromise of fundamental A-G components - EXT & FLX – fosters atypical movement experiences, P-C & motor development, & brain mapping.
- Deficits in achieving the fundamental components compromise functioning postural alignment.
- Deficits in achieving the fundamental components alter somatosensory experiences & related motor learning.
- If P-C is inadequate, the verticality drive wins over purposeful limb use as limb muscles work for upright maintenance → formation of common soft-tissue contractures in children with CP via physiologic adaptation.

Continued…

49

49

Questions?

50

50

4

Simulating Gait with Whole-Body COG Displacements

Let's try this:

 1

1

Walking with Excess Foot Deviations

Stand up with room to take 4 steps.
Take 3 steps. Note knee extension in swing.

1. *Pronate both feet excessively.*
   Take 8 steps.
   Pay attention to knee extension in swing.
2. *Supinate both feet excessively.*
   Take 4 steps.
   Pay attention to knee extension in swing.

 2

2

Walking with Excess COG Displacements

3. *Raise your heels & body COG vertically.*
   Take 3 steps.
   Pay attention to knee extension in swing.
4. *Stand with your body COG aligned over your toes.*
   Take 3 steps.
   Pay attention to knee extension in swing.

 3

3

5

Applying Movement Systems Analysis to Equinus Deformity Management

Derived from the work of Shirley A. Sahrmann, PT, PhD

Diagnosis and Treatment of Movement Impairment Syndromes (2002)

Movement System Impairment Syndromes of the Extremities, Cervical and Thoracic Spines (2011)

1

Muscles serve purpose.

Purpose prevails over the kinesiologic ideal.

And, I say…

Upright maintenance prevails over purpose.
(Stay upright or die.)

 2

2

Muscle Balance

Muscles operating in antagonistic or synergistic couples operate with optimum strength at optimum functional length, maintaining joint & soft tissue longevity.

Routine use history influences muscle balance.

 3

3

MSA* – Assessment Targets / Considerations for EQD

- Muscle extensibility as evidence of routine use - range of motion (ROM) & resting muscle tone
- Hypermobility strains related to functioning with shortened muscles at primary joints
- Skeletal design & joint mobility factors
- Routine balancing & moving strategies

* MSA: Movement Systems Analysis

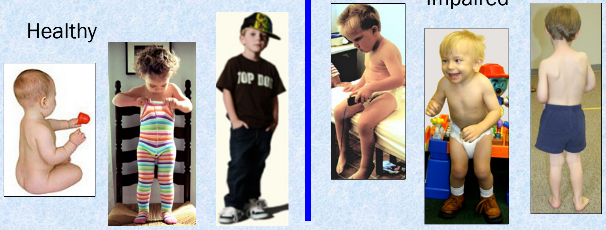
 4

4

Resting Postures

Healthy

Impaired



Resting postures offer clues about the status of postural control & of the features of the musculoskeletal system.

 5

5

Typical Walking Strategies

12 months

24 months

48 months

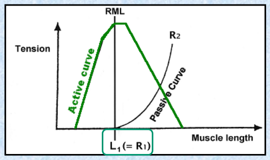
7 years

Postural alignment & gait kinematics indicate the status of weight loading, stability & muscle length & strength.

 6

6

Optimum Positional Strength (R_1)



Positional strength is related
to routine use history → development of the "catch,"
R_1, resting muscle length (RML).

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7

Muscle Imbalances & Pathomechanics

Routine muscle recruitment
in the context of postural & joint malalignment
alters muscle lengths, functions, strength,
& physiological features.

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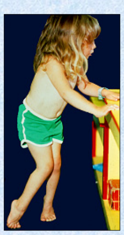
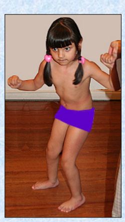
Identify Sources of Muscle Imbalances in Routine Use…





Identify muscles used LONG & SHORT relative to weight line.

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9

...in Pathologic Walking Strategies

- Anterior displacement of the body COG → excess dorsal muscle recruitment for upright maintenance
- Excess or diminished tibial inclination in midstance
- Lateral lurching on the loaded side

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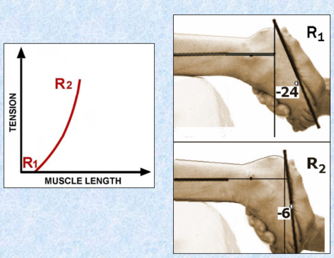
Passive muscle & fascial extensibility is a product of routine use.

 11

11

Detect Altered Muscle Length / Extensibility



Dominant gastrocnemius (GN)

Evidence of pathologic tissue adaptation to routine, tonic recruitment in shortened state.

 12

12

Muscle Imbalance

Chronic overuse of one muscle group prevails *(dominates)* over others *(dominated)* in the couple.

Example: Gastrocnemius (shortened) ***dominates over*** *tibialis anterior & extensor digitorum longus* ***(dominated, overlong).***

Dominant muscle eventually loses functional length &/or extensibility.

Dominated muscle eventually gains functional length & loses sensory responsiveness at appropriate length.

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13

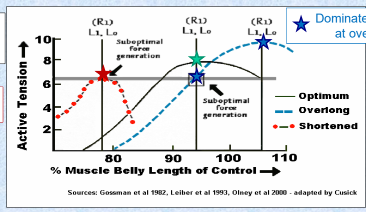
Myth: Dominant Muscles Are Too Strong

R1 catch (passive length test) indicates strongest length in routine function.

★ Optimum muscle force with R1 catch at optimum functional length

★ Dominant: Less force at shorter R1 length.

★ Dominated: Greater force at overlong R1 length.



Both members of imbalanced couples – dominant & dominated - are weak in .

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14

Children with CP Show Generalized Muscle Weakness

- Wiley ME, Damiano DL 1998
- Damiano DL, Quinlivan J 2001
- Elder GC, Kirk J 2003
- Rose J, McGill KC 2005
- Stackhouse SK, Binder-Macleod SA 2005
- Givon U 2008
- Eek MN, Tranberg R 2011
- Chen CL, Lin KC, Wu CY 2012

Data acquired with dynamometry.

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Identify Hypermobility Strains
Related to Moving
with (& Despite)
Shortened Muscles

 16

16

Relative Hypermobility Strains

…So your ankle does not DF, and you're moving…
Where is the motion occurring?

Midtarsal Joint

MTPs

Fasciitis

Posterior knee capsule

Plantar aponeurosis 2º propulsion over a flexible, pronated foot x thousands/day.

 17

17

MSA-Based
Equinus Deformity
Management Principles

 18

18

MSA → *a **major redirection** in my thinking about & approach to managing EQD.*

I used to operate this way:

1. Find shortened & stiff soft tissues →
2. Focus on them to increase extensibility (gain/regain length)
3. Work to put new length to use.

 19

19

Sahrmann says:

If you find dominant, shortened muscles, **"Listen"** to them.

They tell a story about the existing – and past – functional recruitment strategies.

 20

20

Directing efforts toward lengthening the short muscles (stretching, BTX-A, surgery) temporarily depletes the effectiveness of the known strategy.

…So…?

 21

21

With no better strategy in place,
& no knowledge of how to build one,
the ***same strategies persist,***
contractures recur
& lax ligaments worsen.

…So…?

 22

22

Use physiologic adaptation to routine use by changing the muscle use strategy.

Stop stretching, poisoning, & cutting short muscles.

They are ***not the source of EQD.***

 23

23

New EQD-Management
Sequence Inspired
by Sahrmann

 24

24

Sahrmann says:

FIND SHORTENED SOFT TISSUES →

1. ***Determine*** their role in routine P-C & movement.
2. ***Optimize the base of support*** *(BOS).*
3. Identify & ***protect relative strain / hypermobility sites.***
4. Identify & work to ***shorten dominated, underused muscles*** that are functionally long.
5. ***Introduce more effective*** balance & movement ***strategies.***
6. ***Address shortened muscles last.***

Each element of this sequence overlaps with the others.

 25

25

Sahrmann says…

Optimize the Usefulness of the Base of Support (BOS)

 26

26

Optimize the Sitting Base & Alignment

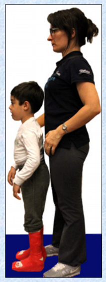
 27

27

Improve Alignment at the Ankle & Foot Before the Trunk.

Specialized cast boots, tuned AFOs, TheraTogs.

Agustin

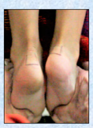


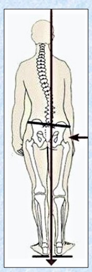
(c) 2024 Beverly Cusick, PT, MS, NDT, COF/BOC

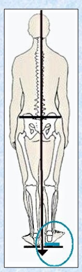
28

28

Address Limb Length Discrepancy







1. Increase loading on the shorter-side foot.
2. Level the pelvis.
3. Reduce joint strains on the longer lower limb & foot.

(c) 2024 Beverly Cusick, PT, MS, NDT, COF/BOC

29

29

Sahrmann says…

Protect Relative Hypermobility Sites at the Feet & Ankles

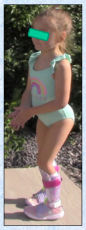
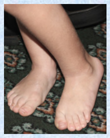
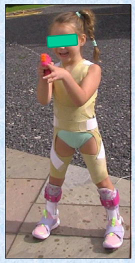
Optimize loaded foot joint alignment & stability before attempting to control the ankle joint.

(c) 2024 Beverly Cusick, PT, MS, NDT, COF/BOC

30

30

Improve Alignment at the Foot & Ankle Before the Trunk

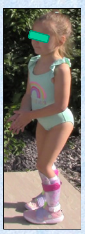
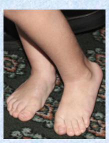
Sophie - 5 yo -diplegic CP

 31

31

Improve Alignment at the Foot Before the Ankle

Posted Insoles, Tuned AFOs & Shoes

Sophie - 5 yo -diplegic CP


Reverse toe wedges

 32

32

Sahrmann says…

Shorten & Assist
Dominated (Overlong) Muscles

 33

33

Shorten dominated muscles to reduce the workload on the dominant muscles.

PRONATION-RELATED DOMINANT MUSCLES?

Lumbar extensors
Iliopsoas
Rectus femoris
Vastus lateralis
Adductors

Hamstrings
Peroneals
Gastrocs Lateral > Medial
Toe flexors

PRONATION-RELATED DOMINATED MUSCLES?

Abdominals
Gluteus maximus
Vastii
Vastus medialis
Glut Medius + Max & TFL on the IT Band
Vastii
Tibialis Posterior
Tibialis Anterior
Toe extensors

 34

34

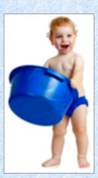
Sahrmann says…

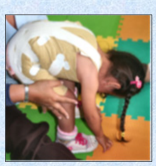
Introduce More Effective
Balance & Movement Strategies

 35

35

Getting the Body COG BACK





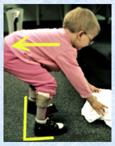
Babies teach us how to treat.
They practice backward weight shifts with tibias vertical.

 36

36

Train to align & displace the whole-body COG in sagittal & frontal planes effectively while playing.

Activities in "Sports Stance" posture



Strive to keep tibias vertical. Here, aided by long stiff shoes & specialized AFOs.

Weight shifting practice

37

TheraTogs Can Increase Body Awareness & COG Control

1. Align feet & load heels if needed.
2. Stack the thorax & pelvis in sagittal & frontal planes:
   a) Align upper trunk in EXT if needed.
   b) Shorten abdominals.
   c) Shorten long hip extensors.

Use abdominal & gluteal straps to draw the COG back over the heels.

38

Train in Upright Postures

- Here, specialized cast boots → enhance distal alignment & stability → tuned & posted AFOs & shoes
- TheraTogs & straps shorten & assist long, dominated muscles at trunk, scapulae & hips.
- Pursue massed practice to build optimum mastery (years of routine use if needed).

39

RCT* - TheraTogs Improve Spinal Alignment & Balance

38 children w/ diplegic CP ages 8-10 yrs, divided into 2 groups

All children received 2 hrs of a conventional exercise protocol for modulating thoracic kyphosis, 3 x week, 12 successive wks.

The study group wore TheraTogs with strapping daily, 8 hrs/day for 12 wks.

Primary outcome measures: thoracic kyphotic angle & spinal ROM.
2nd ary measures: Stability Index of Fall Risk test & Pediatric Balance Scale (PBS) score.

RESULTS: Compared to controls, the study group showed significant improvements in all measures *($P < 0.05$)*.

(El-Kafy EM, El-Shamy SM 2022)
Free via Google Scholar

* RTC: randomized control trial

40

RTC - TheraTogs to Improve Gait

30 children with <u>dyskinetic</u> CP were randomly assigned to either:

(1) A group that received TheraTogs orthotic undergarment (12 hrs/day, 3 days/week) plus traditional PT for 3 successive months.

(2) A control group that received traditional PT for the same duration.

Gait parameters were measured at baseline & after 3 months of Rx using Pro-Reflex motion analysis system.

RESULTS: Children in both groups showed significant improvements in the gait parameters *($P < 0.05$);* TheraTogs group showed significantly greater improvements than the control group.

(El-Shamy SM, El-Kafy EM 2021)

41

Change functional strategies…

G R A D U A L L Y…!

1. Prioritize the alignment of the feet & trunk.
2. Build postural control as the foundation for optimum limb use & movement.

 42

42

Sahrmann says:

Integrate *optimum performance during activities* into the therapy program & daily life.

Experience optimum,
Practice optimum,
Learn optimum.

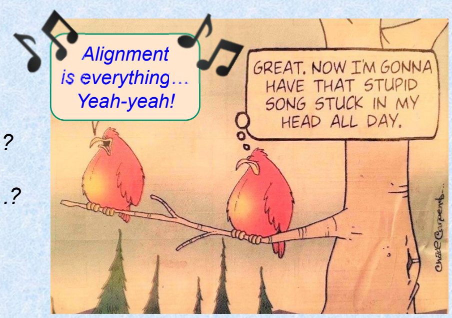
Expect neuro-musculo-skeletal tissues *to adapt to support the new use history.*

 43

43

Questions…?

Discussion…?



 44

44

6

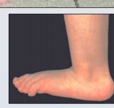
Science-Based Assessment
of Passive
Ankle Dorsiflexion
Range of Motion

1

Assessing DFROM in children with CP
demands a high level of mindfulness & precision.

Young, developing foot ligaments strain easily
under weight loads whether typical or pathologic.



Physiologic adaptation to routine
loads is always underway.

 2

2

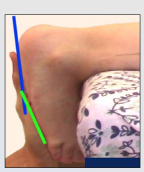
Relative Hypermobility is Rampant

If ankle DFROM is inadequate, & you stand or walk, from where are you getting the DF motion?

…The midfoot?

Occurs at the MTJ oblique axis
with pronation.

...The cuboid-5th metatarsal joint?



Can occur with supination or pronation.

 3

3

Relative Hypermobility Consequences of Wearing 0º-PF AFOs with an Ankle DFROM-KE Deficit

Skin lesions tell tales of war with plastic & straps.

 4

4

Measuring Ankle DFROM – Reliability Concerns

Variation prevails in these aspects of DFROM measurement:

- Test positions
- Measurement tools
- Landmarks & grip on the foot
- Loading force into DF
- Rates of passive ankle DF speed
- Attention to forefoot-hindfoot alignment discrepancy

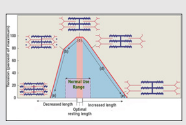
(Gatt A, Chockalingam N 2011; Martin RL, McPoil TG 2005)

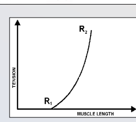
 5

5

Why assess passive ankle DFROM?

- To "read a report" on routine triceps surae muscle use.
- Detect the length of optimum contractile force generation (R1)
- Detect signs of hypertonus as evident in resistance past R1
- Determine the capacity of the PF tissues to lengthen for optimum routine gait function.





Most movements are quick.

6

It's a JUNGLE out there!!!...

 7

7

Standardizing measurement procedures
is necessary for optimizing reliability
& relevance.

Why optimize reliability?

To be able to identify & report
status changes confidently.

(Gatt A, Chockalingam N 2011; Martin RL, McPoil TG 2005)

 8

8

Executing the Measurement
of
Passive DFROM-Knee Extended
(PDFROM-KE)

 9

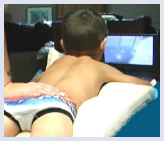
9

Positioning the Child
& Yourself for Testing

 10

10

Why assess in prone position on a soft pillow?



- To offer a distraction to reduce anxiety.
- To eliminate the potential extension-promoting influence of the tonic labyrinthine reflex in supine lying.
- To access replicable measurement landmarks on the lateral leg & foot.
- To allow a competent, relevant, & replicable grip on the foot while measuring.
- To keep the knee joint at 0º extension.

 11

11

Assure that the knee joint is not hyperextended.

If needed, insert a tightly rolled & taped hand towel or a piece of a Styrofoam swimming noodle with a shallow dip cut out to cradle the lower leg & to align the knee joint.

 12

12

Optimize Your Point of View

No.

Yes.

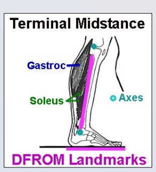
Tester's visual orientation to the ankle joint influences the accuracy of placing & reading the goniometer.
Move down beside the tested limb segments.

13

Always use the same reference arms.

14

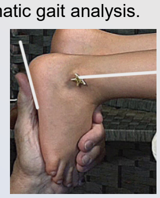
Gait-Analysis-Related Landmarks



DF to terminal midstance occurs ideally on a congruent foot with the heel still on the floor.

The fibula connects the knee & ankle joint axes used in standard computerized kinematic gait analysis.

(Perry J et al 2010)



Reference arms for DFROM measurement:

- Flattened plantar heel pad
- Fibula.

15

Always Landmark the Fibula



Palpate the anterior & posterior borders of - & bisect - the fibular head & the lateral malleolus.

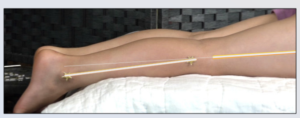
If your goniometer is too short to reach the fibular head, draw a line connecting the palpation marks that begins ~1” (2.5cm) proximal to the lateral malleolus.

Check the line for accuracy.

 16

16

Correct Knee Hyperextension



Reduce tension on the proximal gastrocnemius that would limit DF at the ankle.

The folded mat cover was used here…

 17

17

Handling the Foot

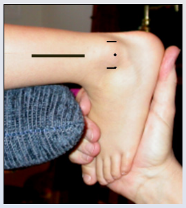
 18

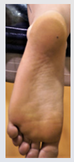
18

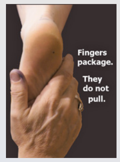
The Grip on the Foot Mimics Loading in Gait

The heel & lateral column are the ideal loadbearing foot segments.

The grip should apply DF load to the lateral column & to metatarsal heads #4 & #5 while packaging the congruent foot.







19

Move to the side of the foot & grip it, setting your thenar eminence on the plantar met heads # 4 & 5.

20

Aligning the Foot

 21

21

Set the Foot Joints in Congruity

Ideally, the foot joints are congruent at terminal midstance when pronation is ended & supination is about to begin.

Pronation permits the calcaneus to DF with eversion under the talus & the forefoot to DF with ABD on the hindfoot.

Pronation is biomechanically affiliated with ankle DF.

Supination is biomechanically affiliated with ankle PF, restricts DF, & is not functionally relevant to DFROM.

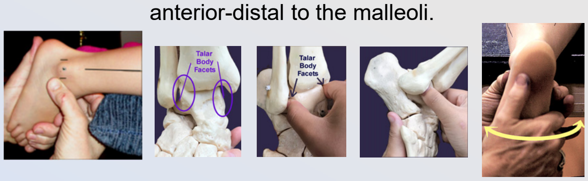
(Michaud TC 1997)

 22

22

Set the Foot Joints in Congruity

Grip the foot & palpate the anterior talar body facets lying anterior-distal to the malleoli.



Pronate & supinate the foot until the sulci on the facets feel equal in depth & the arc of foot motion flattens.

 23

23

Set the Foot Joints in Congruity
Neither Supinated nor Pronated

 24

24

Execute the ROM Test – R1

 25

25

Detect & Measure R1 End Range

Set foot joints in congruity.

→

Quickly ***LIFT*** (do not push) the foot toward the patella → R1

Take the slack out of the tissues without force.

R1 is in DF in TD preschoolers.

 26

26

Lift the congruent foot
quickly & lightly
toward the patella
--> 1st catch (R1).

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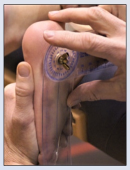
UG Placement

Because most joint axes shift with joint motion, the UG axis should not be placed first on the anatomical joint axis. *(p. 258)*



The common placement of the UG axis on the lateral malleolus forces the distal UG arm off of the heel area.

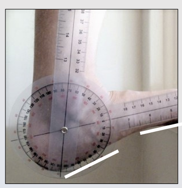
(Margaret L. Moore. The measurement of joint motion. Part II – The Technic of goniometry. Phys Ther Rev. 1949. 29(6): 256-264.)

 28

28

The 5th metatarsal shaft is not an ankle bone.

It articulates with the cuboid & belongs to the forefoot.

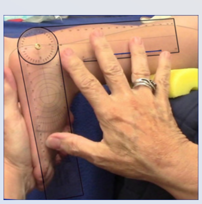


The heel prevails in measuring the ankle.
Consider the forefoot to be a separate concern.

 29

29

Choosing & Handling a Universal Goniometer (UG)



- Choose a UG that is easy to handle as shown. (No enlarged axis dial.)
- Adapt the goniometer with an arm extension if needed to reach the fibular head.
- Execute the test.
- Apply the UG as shown *(left)*.
- Your thumb aligns the distal edge with & close to the flattened plantar heel pad.
- Your fingertips align the proximal arm on or parallel with the fibula line.

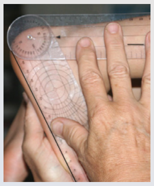
 30

30

UG Placement

The UG should be applied
to the body segments
at the time of measurement
to improve accuracy.

Then, the axis falls
at the intersection
of the reference arms.
(p. 258)



R1

R2

(Margaret L. Moore. The measurement of joint motion. Part II – The Technic of goniometry. Phys Ther Rev. 1949. 29(6): 256-264.)

 31

31

Let's Get Moving!

https://www.youtube.com/watch?v=Qz37kIMx14I

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Execute the ROM Test – R2

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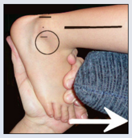
Detect & Measure R2 (Maximum) End Range



***PUSH rapidly** parallel with the floor and toward the knee to R2.* Discomfort at R2 is rare.

Do ***NOT pull the foot down*** toward the floor.

Keep foot joints congruent; sinus tarsi open (circled); & knee extension at 0°.

Resistance past R1 is normally light.

We use this length very quickly after midstance in gait→ heel rise.

 34

34

Cusick's IDEAL Ankle DFROM-KE - R1 / R2

Experienced-based expectations.

AGE	R1 DFROM KE - Prone	R2 DFROM KE - Prone
12→30mos	~35°	~35°
30→42mos	~15°→20°	~30° → 35°
3.5 thru 6yrs	~5°→15°	~20° → 25°
7→10yrs	~0°→5°	~15° → 20°
11 yrs→	~0°	~10° → 15°

R2 end range is ≥10° when measured in prone with a congruent foot.

35

Why Not Assess Ankle DFROM in Standing Position?

This test is not relevant to gait.

Assuming subtalar neutral position is 0°.

1. Prolonged standing in stretch position does not happen in gait. Full ankle DF at terminal stance lasts ~ a millisecond.
2. The connective tissues are viscoelastic – they elongate under prolonged stretch & recover original length within 20 sec.
3. There is no way to detect R1 end range to learn about functional use history.

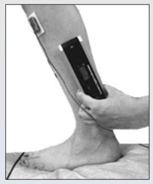
 36

36

What about Measuring with an iPhone App?

The standing-in-DF condition is irrelevant to ankle function.

No way to detect the catches.



 37

37

Early Detection

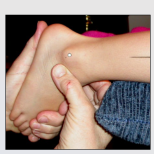
Early Intervention

 38

38

Detection of R1 at any ankle angle at age < 30 months suggests a pathologic use history in standing & gait:

- Excess foot pronation → COM forward
- Early routine toe walking
- P-C deficit → excessive tonic TS* muscle use for stability
- Intoeing – shortens the foot → weight forward
- Excess anterior carriage of the body COM.



*TS: triceps surae

 39

39

Early EQD Prevention - Night Splinting in ≥10° DF

Turtlebrace can meet this need for infants relatively inexpensively with growth-related remolding & for growth.


Surestep PullOver assists DF, allows PF

Babies don't mind.

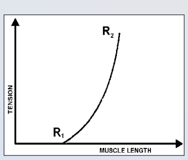
Sleeping splints must be comfortable!
I recommend that caregivers pull large socks over them.

40

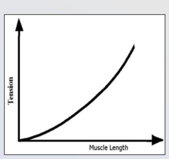
Hypertonic DFROM - KE

41

The Clinically-Detectable, Passive L-T Curve is about Tone in Composite Tissues

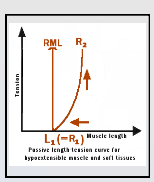


Normal > age 2 years



Hy**PO**tonia

No R1 →
little resistance to R2



Hy**PER**tonia

42

Keya
Age 7 years
Left unilateral CP

 43

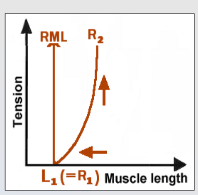
43

Keya - age 7 yrs
Left hemiplegic CP

44

Keya's Passive Length-Tension Relationship

- R_1 occurs at a significantly reduced muscle length.
- Resistance encountered at R1 end range is magnified.
- $R_1 \rightarrow R_2$ stiffness curve would be steep with heavy resistance throughout the range & no notable variation in stiffness.



(Tardieu G, Huet de la Tour E 1982; Sinkjaer T, Magnussen I 1994)

45

Detecting & Reporting Levels of Stiffness in Passive DFROM-KE

 46

46

New Development – R_1A

In stiff tissues, R_1A is the 2nd "catch" that occurs at <+10º DFROM-KE & after a stiffer-than-normal R_1 end range.

At R_1A the examiner encounters a hard "wall" of resistance to further ankle DF.

Unforced ROM to R_1A should be accessible to the client in function.

TD children show no R_1A end range.

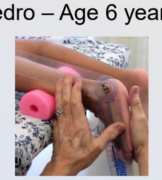
DFROM past R_1A is NOT functionally accessible.

 47

47

Pedro – Age 6 years – Diplegic CP

Pedro
Age 8 yrs
Diplegic CP
w/ severe
knee
hyperEXT



Light resistance to R_1 catch: -25º

Moderately heavy resistance to R_1A end range: -15º

Examiner can talk normally to R_1A.

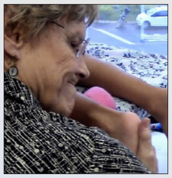
R_1A is unforced, so it operates like R_2 in function.
Pedro should be able to access -15º DF with a congruent foot.

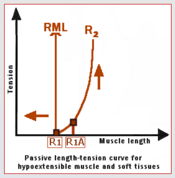
48

Pedro, continued

Examiner strains to talk past R1A.

R1A → R2 must be forced.





So, R1A → R2 with a congruent foot is not useful to Pedro.

Measuring R2 is irrelevant.

L-T Curve is less vertical between R1 & R1A than it is after R1A to R2.

*L-T: length-tension

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Pedro
Age 6 years
Bilateral CP

 50

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Pedro - age 6 years
Diplegic CP
Left DFROM - KE

 51

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Recording Pedro's Findings & Relevance

Ankle (Talocrural Joint)		LEFT R1 / R2
Passive Dorsiflexion ROM Knee Extended (KE) Foot Congruent	Fibula / flattened plantar heel	-25 / NT
	Fibula / flattened plantar heel	R1A : -15
COMMENTS: STIFFNESS IS HIGH PAST R1A AND IS UNAVAILABLE IN FUNCTION.		

Impression: Pedro needs to undergo serial casting before transitioning to AFOs.

52

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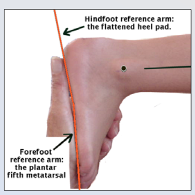
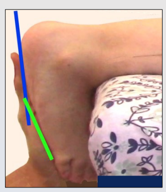
Forefoot DF ROM – Less or More than HF



Forefoot Equinus


Subluxed 5th metatarsal

Measure FF at plantar 5th metatarsal shaft at R2 or R1A end range & record.

53

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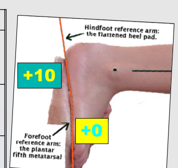
Example: Recording Findings for FF EQ

		LEFT	RIGHT
Passive Ankle Dorsiflexion ROM (KE)	Fibula / flattened plantar heel *(Hindfoot)*	R1 / R2 0 / 15	R1 / R2 0 / 10
	Fibula / plantar 5th met shaft *(Forefoot)*	R1A or R2 5	R1A or R2 0
Comments: HF finding minus FF finding → a forefoot EQD of 10º.			



Why R2? Because second catch occurs after 10º DF.

54

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Recording Findings for Excess 5th ray FF DF - Subluxation

		LEFT	RIGHT
Passive Ankle Dorsiflexion ROM (KE)	Fibula/ flattened plantar heel *(Hindfoot)*	R1 / R2	R1 / R2 -4 / NT
	Fibula/ flattened plantar heel *(Hindfoot)*	R1A:	R1A: +4
	Fibula/ plantar 5th met shaft *(Forefoot)*	R1A or R2	R1A +16

Comments: FF finding (+16) minus HF finding (+4) = **12º of 5th ray subluxation**

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DFROM-KE
FF > HF

 56

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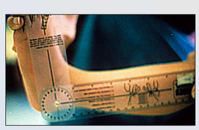
Why not assess DFROM-KE in supine position?

- How do you grip the foot to reflect loading in standing position?
- How do you hold & read UG?
- Holding the foot, it is difficult to keep the knee joint at 0º.
- Supine position can provoke a sense of vulnerability & anxiety → active LE EXT + PF.
- Residual Tonic Labyrinthine Reflex → PF muscle activation.

.....W T Heck?



 57

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Quick Review…

R1A DFROM-KE:

- Is not evident in TD & ND individuals with ideal foot alignment for age.
- Is evident as a heavy "wall" of resistance that the examiner encounters while applying moderate (unforced) DF load with the foot joints congruent.
- Examiner can still talk normally to R1A end range.

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R1A DFROM-KE, continued:

- R1A ROM is < 10º DF
- R1A is functionally available to the client.
- R1A → R2 is not functionally available with foot joints aligned.
- R2 or R1A DFROM to 0º is pathomechanical at all ages.

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Passive DFROM-Knee Flexed

 60

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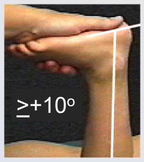
Ankle DFROM - Knee Flexed ~ 90°

Set congruency.

R1



R2

The 3-joint gastrocnemius is off tension in knee flexion. R1 & R2 end ranges are typically greater in KF vs. KE at all ages ≥4 years.

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Cusick's Ideals Ankle DFROM-KF - R1 / R2

AGE	R1 DFROM KF - PRONE	R2 DFROM KF - PRONE
12→30mos	~35°	SAME
30→42mos	~30°→35°	
3.5 thru 6yrs	~20°	~25°→30°
7→10yrs	~15°	~25°
11 yrs→	~10°	~20°

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Reliability factors include the evaluator's skills in:

- Positioning the child comfortably
- Setting & keeping the knee joint at 0° extension
- Detecting foot joint congruity
- Detecting R1 end range reliably
- Detecting R1A – the next wall in ROM – if present
- Detecting R2 end range while maintaining foot joint congruity
- Using a UG suitable size, condition, & accuracy
- Handling & reading the UG
- Having reading glasses close by if needed.

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What is "dynamic equinus"?

Normal muscle extensibility used in shortened position while walking on toes?

If so, how is it found?

- in sitting with knee flexed? extended?

- in prone with knee flexed? extended?

- with foot joints congruent? Pronated? Supinated?

If not explained in detail, all studies using this term cannot be replicated, and so, are bogus.

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A Call for Research

R1 end range - strongest length – is more functionally relevant than R2 (maximum) end range.

Most "normative" data is about R2 +/- 2SD around means, commonly embracing pathology. "Normal" subjects do not have brain injury…?

No published R1 norms for children or adults.

"Normal" R1 findings should be acquired without coexisting excess foot pronation, supination, in-toeing or out-toeing in TD populations.

R1 findings for those with pathomechanics should be compared to those from TD subjects without issues.

I will coach researchers….

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Summary

- Ankle DFROM & extensibility/stiffness adapt to use history.
- Ankle DFROM diminishes with age in developing children.
- R1 DFROM-KE:
  - Indicates Resting Muscle Length & CT status.
  - Is developmental, emerges in DF, & is apparently set by routine use in standing & during heel rise in gait.
  - Is ideally 0° ($\leq$ 2° PF) after age 10 years.
- R2 & R1A end ranges show the capacity to incline the leg quickly at the ankle joint at terminal midstance on a congruent foot.
- The catches illuminate the adaptation to use history.

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Clarifying Landmarks
Used in ROM Assessment,
Kinematic Gait Analysis
&
Orthotic Tuning

 1

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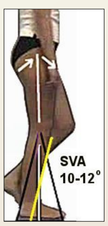
SVA: Shank-to-Vertical Angle



Owen's tripod at midstance (MST)
is the main goal of her "Tuned AFOFC".

Optimize the MST Shank-to-Vertical Angle

The proximal anterior tibia (a.k.a. "shank")
is ideally inclined ~10-12º at MST.

(Owen E 2010)

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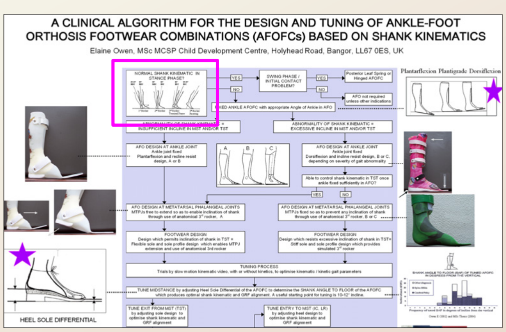
Owen's Tuning Algorithm

(Owen E 2005)



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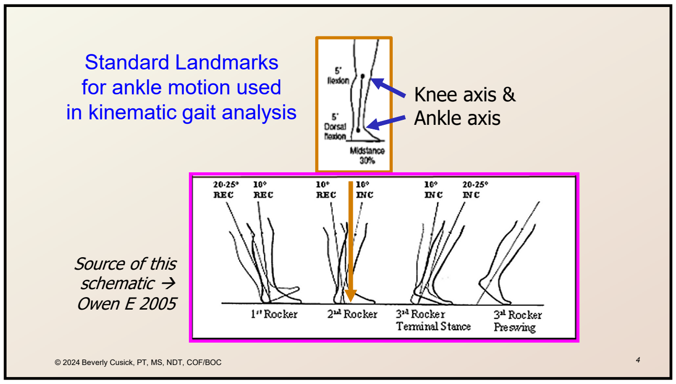

Standard Landmarks for ankle motion used in kinematic gait analysis
Knee axis & Ankle axis
5° flexion
5° Dorsal flexion
Midstance 30%
20-25° REC
10° REC
10° REC
10° INC
10° INC
20-25° INC
1st Rocker
2nd Rocker
3rd Rocker Terminal Stance
3rd Rocker Preswing
Source of this schematic → Owen E 2005
© 2024 Beverly Cusick, PT, MS, NDT, COF/BOC
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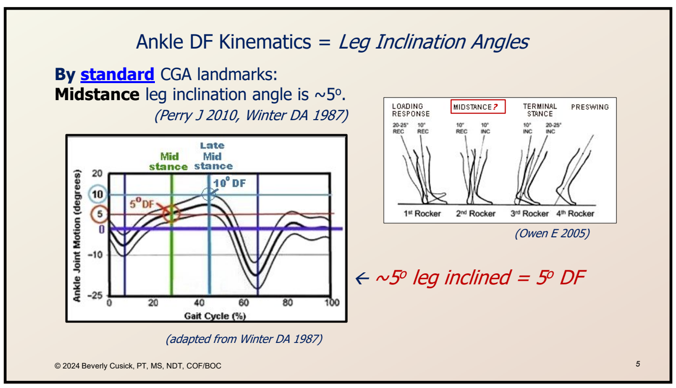

Ankle DF Kinematics = Leg Inclination Angles
By standard CGA landmarks:
Midstance leg inclination angle is ~5º.
(Perry J 2010, Winter DA 1987)
Mid stance
Late Mid stance
10° DF
5° DF
Ankle Joint Motion (degrees)
Gait Cycle (%)
(adapted from Winter DA 1987)
LOADING RESPONSE
MIDSTANCE
TERMINAL STANCE
PRESWING
1st Rocker
2nd Rocker
3rd Rocker
4th Rocker
(Owen E 2005)
← ~5º leg inclined = 5º DF
© 2024 Beverly Cusick, PT, MS, NDT, COF/BOC
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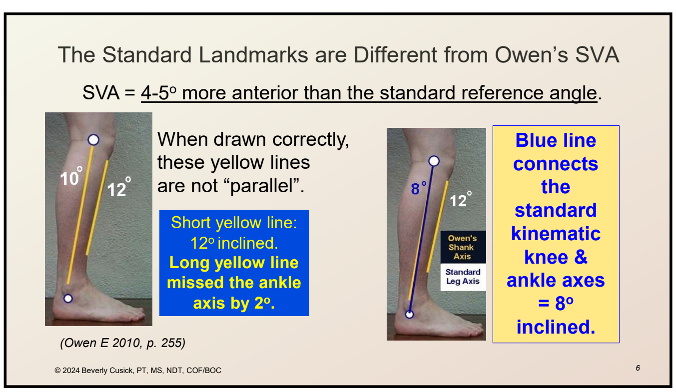

The Standard Landmarks are Different from Owen's SVA
SVA = 4-5º more anterior than the standard reference angle.
10°
12°
When drawn correctly, these yellow lines are not "parallel".
Short yellow line: 12º inclined.
Long yellow line missed the ankle axis by 2º.
(Owen E 2010, p. 255)
8°
12°
Owen's Shank Axis
Standard Leg Axis
Blue line connects the standard kinematic knee & ankle axes = 8º inclined.
© 2024 Beverly Cusick, PT, MS, NDT, COF/BOC
6

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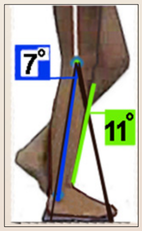
Owen's Reference for "Shank" Inclination?

Blue line is the **standard landmark** →
for leg inclination at midstance / midswing.

Owen's green SVA landmark is the anterior tibia.



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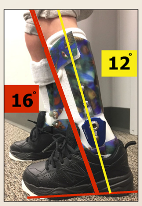
Landmarking confusion can → errors in orthotic design.

Good ideas: motion control joints, tuned shoes.

Owen's 12º was placed at the **standard location →** 16º at anterior tibia.

The leg is inclined too much → crouch.



Correction: Standard axis ~7º = Owen's SVA = 11º

(Correction is photo-shopped)

 8

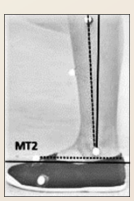
8

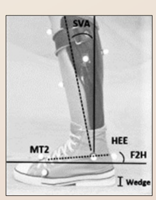
Tuned AFO-FC Research on 0º-PFd AFOs

No DFROM measures.
0º-PF AFOs w/ heels inclined incrementally with wedges.

Results: Increasing heel height → increased knee flexion, more inclined SVA.

(Oudenhoven LM, Kerkum YL et al 2021)





Leg landmarks…? … HUH?

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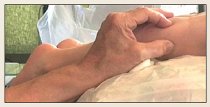
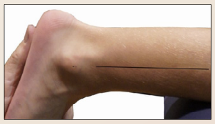
Assessing Ankle DFROM-KE: Always Landmark the Fibula

Palpate the anterior & posterior borders of – & bisect - the fibular head & the lateral malleolus. Use both.



Why?
It is relevant to standard gait analysis.

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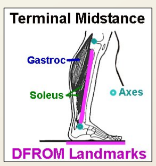
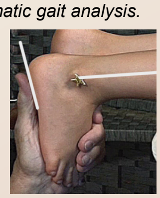
Gait-Analysis-Related Landmarks



DF to terminal midstance occurs ideally on a congruent foot with the heel still on the floor.

The fibula connects the knee & ankle joint axes used in standard computerized kinematic gait analysis.

(Perry J et al 2010)



Reference arms for DFROM measurement:

- *Flattened plantar heel pad*
- *Fibula.*

 11

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Where does the SVA fit in this relationship between ankle DFROM – KE and ankle motion in gait?

Are we to move the proximal UG arm further away from the landmark on the anterior proximal tibia?
Or should we estimate an additional 4-5 degrees of DFROM?

Why? To disregard the standard gait kinematic reference axes and try to align with one outlier?

We need more standardization of perspective and procedures, not less.

 12

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8

Long-Term Shortfalls of Botulinum Toxin-A for EQD Management

What's New?

1

1

Botulinum toxin-A (BTX-A) for Equinus Deformity (EQD)

The most lethal toxin known.

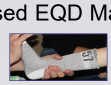
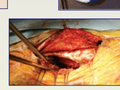
A Centers for Disease Control & Prevention Category-A bioweapons threat

The most widely used medical intervention in children with cerebral palsy

2

2

Typical Myths-Based EQD Management Stream

1. Start manual stretching 
2. Inject BTX-A for "spasticity"
3. Prescribe 0º-PF AFO(s) 
4. Inject BTX-A
5. Add casting to BTX-A + 
6. Proceed to SEML surgery stop & reporting outcomes after 2 years. 

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A Shift in Focus is Underway

"Irrespective of the neurological or musculoskeletal origins of these [musculoskeletal] *impairments, clinicians continue to focus on treating the level of 'deformity' and/or 'spasticity' rather than the pathophysiological processes that give rise to them.*

This may explain the moderate outcomes associated with these treatments…"

(Howard JJ, Graham HK, Shortland AP 2022, p. 1 (or p 289)

4

4

Why Use Neurolytic Injections?

Treatment of limb muscles in children with CP using "antispastic" (i.e. denervating) agents e.g., BTX-A **is based upon these unproven assumptions**:

- Spasticity (hyperreflexia) is present.
- Spasticity produces deformity & gait pathology.
- Injected muscles are too strong & should be weakened.

If a target muscle is stiff, spasticity is not apparent. Hypertonus might be the main problem.

 5

5

BTX-A & its derivatives *denervate* the muscle by inhibiting the release of acetylcholine at the neuromuscular junction.

EXCELLENT CURRENT SOURCES ON HOW BTX-A WORKS:

Salari M, Sharma S, Jog MS. 2018. Botulinum toxin induced atrophy: an uncharted territory. Toxins (Basel). 10(8):E313.

Multani I, Manji J, Hastings-Ison T, et al. 2019. Botulinum Toxin in the Management of Children with Cerebral Palsy. Paediatr Drugs. 21(4):261-281

Multani I, Manji J, Tang MJ, Herzog W, et al. 2019a. Sarcopenia, cerebral palsy, and botulinum toxin type A. JBJS reviews. 7(8):e4.

 6

6

Challenges to Using BTX-A for EQD

Safety

Reversibility

Effectiveness

Source: Hastings-Ison T, Khot A, Graham HK
"Botulinum Toxin and spastic equinus. Re-Treat or Retreat?"
AACPDM 72nd Annual Meeting, October 13, 2018.

 7

7

Reports of Injury to Injected Mammalian & Human Muscle

Schroeder AS, Ertl-Wagner B 2009 – 2 ND adults, 1 injection to lateral GN.
1 yr later: atrophy, recovery failure, degenerative changes in n-ms junction.

Van Campenhaut A, Verjaegen A 2013 – 7 children, CP, IP injections.
2 months & 6 months later, 20% atrophy. No pre-injection data re atrophy.

Williams SA, Reid S 2013 – 15 children with CP; 1 injection to GN.
5 wks later, 5% atrophy masked by soleus hypertrophy.

Lieber RL, Ward S 2013 – healthy rabbit TibAnt. 2 injections, 3 months apart.
6 months later, fibrosis appeared with CT & fat increased from 5% to 20%.

Fortuna R, Vaz MA 2011 – healthy rabbit quads; monthly injections →
increasing fatty tissue & CT infiltration (fibrosis), atrophy with losses of muscle fiber & strength, and same in contralateral muscles.

Continued…

 8

8

Injury to Injected Mammalian & Human Muscle, continued

Fortuna R, Vaz MA 2015 - A clinically relevant BTX-A injection protocol using healthy rabbits → 6 months of weakness & contractile material loss.

Minamoto VB, Suzuki KP 2015 - compared effects of 1 & 2 injections into healthy rat tibialis anterior. A 2nd injection after 3 months caused a profound & persistent loss in muscle function, fiber type change & grouping, & fat accumulation.

Multani I, Manji J, Tang MJ 2019 - injecting hypertonic CP muscle with atrophy and other pathologies with BTX-A only adds atrophy & more pathology.

Hart DA, Fortuna R, Herzog W 2018 – After 3 injections into healthy rabbit muscle, mRNA levels for inflammatory molecules, proteinases, adipokines elevate, impeding muscle recovery & promoting fatty tissue infiltration.

 9

9

Reports of Adverse Events (AEs) & Toxin Migration

Swinney CM, Bau K 2018 - 22% of 2219 injection episodes led to systemic adverse events at follow-up in children in GMFCS levels IV & V.

Blaszczyk I, Foumani NP 2015 – Questionnaire. 95 AEs & side effects occurred in 54 (51%) of 105 BTX-A injections in 45 patients. 50 Aes. were generalized and/or focal distant. Severe AEs occurred in three patients (4%)

Ramirez-Castaneda J, Jankovic J 2013 - Most local & remote complications are thought to be due to unwanted diffusion of the toxin's biologic activity into adjacent & distal muscles. This process is underinvestigated.

Matak I, Riederer P 2012 - Axonal transport of BTX-A to the spinal cord occurs commonly following low-dose, peripheral injection.

Frick CG, Fink H, 2012 - A single injection of botulinum toxin decreases the margin of safety of neurotransmission at local and distant sites in rats.

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After >25 years of increasing, worldwide use by pediatric orthopedists and physical medicine physicians, where is the data on the muscle health of hypertonic muscles of children with cerebral palsy before and after BTX-A injection?

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Evidence of the Effectiveness Challenge

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Reports of Insignificant BTX-A Effects on Function & Gait

Schasfoort F, Dallmeijer A 2017 – No significant gain vs. comprehensive rehab

Schasfoort F, Pangalila R 2018 – Not cost effective

Williams SA, Reid S 2013 – 15 children with CP. 5 wks after 1 injection (not their first) → no changes in TUG, 6-minute Walk Test or strength.

Huntley JS, Bradley LJ 2017 – After 1 yr, no evidence of clinical benefit

Chaturvedi SK, Rai Y, Chourasia A 2013 - the effects of BTX + PT vs. PT alone on dMRI & GMFM. BTX-A does not influence the FA on dMRI or functional outcome at 6 months in children with similar insult in full-term diplegic spastic CP.

 13

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Reports of Effects of BTX-A on EQD after 1 Year

Studies past 6 months following injection do not exist.
Most studies report that immediate ankle DFROM gains following injection last ~3 months –
longer for younger children, shorter for older children.

Kay RM, Rethlefsen SA 2004 - BTX injection combined with BK casting led to *earlier recurrence of "spasticity", contracture, & equinus during gait.*
Serial casting alone is preferable to BTX-A + casting for fixed EQD in CP.

Tedroff K, Granath F 2009 – 94 children with CP, 2 to 8 injections each. Median follow-up time 1.5yrs, range → 3yrs 7mos. Brief improvement in ROM occurred after 1st injection & ROM declined thereafter. BTX does not prevent the development of contractures in "spastic" (stiff) muscles.

 14

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Reports of Age-Related Decline in BTX-A Effectiveness

Children become unresponsive to BTX-A injection at a younger age than previously thought.
(Read FA, Boyd RN, Barber LA 2017; Hastings-Ison T, Sangeux M 2018)

Most clinically significant improvements are seen in children with equinus in spastic hemiplegia at less than age 4 years.
(Love SC, Novak I, Kentish M 2010)

The response to BTX-A reduces between the ages of 4 & 6 years. After age 6 years, studies including Edinburgh Visual Gait Scale & 3D gait analysis confirm little or no benefit from continued use of BTX-A therapy.
(Read FA, Boyd RN, Barber LA 2017; Hastings-Ison T, Sangeux M 2018)

 15

15

Is BTX-A Worth the Muscle Tissue Damage?

"BTX-A causes muscle atrophy and upregulation of fibrofatty connective tissue in animal models, consistent with the lack of functional improvement seen in recent human studies." p 121

(Howard JJ, Graham HK, Shortland AP 2020)

…"Do no harm"?

16

16

Antispastic medications that are directed to reduce clinical signs of spasticity, such as exaggerated reflexes and muscle tone, do not improve the movement disorder.

Medication can even increase weakness which might interfere with functional movements, such as walking.

(Dietz V, Sinkjaer T 2012, p. 197)

17

17

"Given that the CP muscle is short and small already, this [pathophysiology] calls into question the use of such agents for spasticity management given the functional and histological cost of such interventions." p.1

(Howard JJ, Herzog W 2021)

18

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Thinking Again….

Improvements in gait function after BTX-A injection are not consistent, are small in magnitude, & are short-lived. Some gains in clinical trials may relate to use of adjunctive interventions e.g. serial casting, orthoses, night splints & intensive therapy.

(Multani I, Manji J, Hastings-Ison T 2019)

Continued…

 19

19

"We conclude that there is a need to revise clinical protocols by using BTX-A more thoughtfully, less frequently and with greatly enhanced monitoring of the effects on injected muscle for both short-term and long-term benefits and harms." p. 261

(Multani I, Manji J, Hastings-Ison T 2019)

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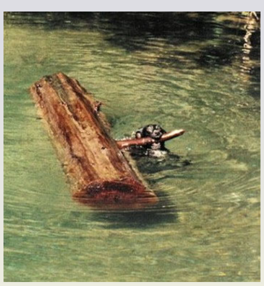

"Good judgment comes from experience, and a lot of that comes from bad judgment."

\- Will Rogers

 21

21

So, what's new?

Attention to the fascia vs. muscle!

The physiology of fascial hyaluronan is a rising topic of interest in the study of hypertonus.

 22

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Hyaluronan (HA)

- Present in a large variety of tissues and fluids including, but not limited to, connective, epithelial and neural tissues.
- Provides mechanical stability in the connective tissues while acting as a water reservoir & lubricant.
- A biological "Jell-O" - a ground substance in the extracellular matrix (ECM).
- Facilitates muscle & fascial layer & fiber sliding & myofascial force transmission within & between muscles.

(Balazs EA, Laurent TC, Jeanloz RW. Nomenclature of Hyaluronic Acid. Biochem J. 1986; 235: 903.)

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- HA concentration – "densification" - can increase in muscle & fascia after cerebral injury & with prolonged immobility.
- At high concentrations, "densified" HA can dramatically increase the viscoelasticity of the ECM, causing the muscle fibers & fascicles to stick to one another, reduce fiber gliding during movement & increasing stiffness.
- Further densification may lead to fibrosis in the long term.

(Pratt RL. Hyaluronan and the fascial frontier. International J Molecular Sci. 2021 Jun 25;22(13):6845.) ***Key resource!***

More references for these points are listed on the following slide….

 24

24

- *Al'Qteishat A, Gaffney J, Krupinski J, et al. Changes in hyaluronan production and metabolism following ischaemic stroke in man. Brain. 2006 Aug 1;129(8):2158-76.*
- *Okita M, Yoshimura T, Nakano J, Motomura M, Eguchi K. Effects of reduced joint mobility on sarcomere length, collagen fibril arrangement in the endomysium, and hyaluronan in rat soleus muscle. J Muscle Research & Cell Motility. 2004 Apr; 25:159-66.*
- *Stecco A, Cowman M, Pirri N, Raghavan P, Pirri C. Densification: Hyaluronan Aggregation in Different Human Organs. Bioengineering. 2022 Apr 5;9(4):159.*
- *Cowman MK, Schmidt TA, Raghavan P, Stecco A. Viscoelastic properties of hyaluronan in physiological conditions. F1000Research. 2015;4.*
- *Matteini P, Dei L, Carretti E, et al. 2009. Structural behavior of highly concentrated hyaluronan. Biomacromolecules 10 (6), 1516–1522.*

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Hyaluronidase

The enzyme known as hyaluronidase hydrolyzes sticky HA, thus lowering the viscosity of the extracellular matrix fluid.

Hyaluronidase has been shown to reduce muscle stiffness in stiff upper limb muscles of 18 adults at between 5 & 85 months after stroke & in 2 school-aged children with hemiplegic cerebral palsy.

(Raghavan P, Lu Y, Mirchandani M, Stecco A. Human recombinant hyaluronidase injections for upper limb muscle stiffness in individuals with cerebral injury: A case series. EBioMedicine 2016; 9: 306–13.)

 26

26

Raghavan P, Lu Y, et al state:

"The effect of treatment remained over at least three months of follow-up. These results suggest that accumulation of hyaluronan within muscles promotes the development of muscle stiffness in individuals with neurologic injury, and that intramuscular delivery of hyaluronidase is a promising direct treatment for muscle stiffness. The injections were safe and well tolerated, and without clinically significant adverse effects. Most importantly, the treatment did not pro- duce weakness, which is a common adverse effect with current treatment options for spasticity." p. 310

Raghavan P, Lu Y, Mirchandani M, Stecco A. Human recombinant hyaluronidase injections for upper limb muscle stiffness in individuals with cerebral injury: A case series. EBioMedicine 2016; 9: 306–13.

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9

Equinus Deformity Management
Strategies Using
Casts & AFOs

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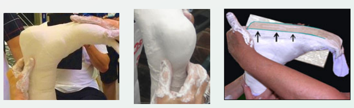
1977-1984 "Billi" Boots – Seating for the Foot

A Precursor to Tuning AFOs and Shoes



In March of 1977, Joan Mohr, PT, NDT Instructor, taught us to make casts for children with CP.

Wow! Feet Matter!!

 2

2

…And the crowd went WILD!!!!!

 3

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Marina
5 year-old girl
Diplegic CP - Level III/IV

 4

4

Serial casting & tuned AFO-FC objectives*
do NOT** include **STRETCHING
the targeted muscles & soft tissues!

In fact, the targeted triceps surae
are relieved of excess tension in the cast.

**AFO-FC: Ankle Foot Orthosis-Footwear Combination*

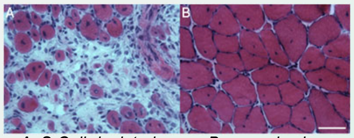
 5

5

Stretching Can Promote Scarring

Hypertonic muscle in children with CP is fibrotic (contains scar tissue) with reduced satellite cell (S-Cell) content.

When **maximally stretched by cast immobilization for 14 days,** mouse soleus muscles with decreased S-Cell content did not add a normal complement of sarcomeres – as did the normal mouse soleus – & developed significant fibrosis.



A: S-Cell-depleted soleus muscle tissue   *B: normal soleus*

(Kinney MC, Dayanidhi S 2017)

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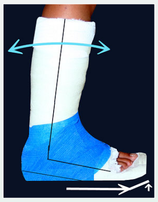
Ankle DFROM Increases with Tissue Tension Reduced



Since 1977, in my experience,
ankle DFROM INCREASES
after setting the ankle
in progressively smaller degrees
of PLANTARFLEXION
& FULLY LOADING THE HEELS
with posting that fill the space
under them and under the toes.

 7

7

Specialized Casts Beginning in Ankle PF → DFROM Gains

13 children (24 feet) averaged age 3.4 yrs & were casted using "Cusick's technique."

No neurovascular complications or pressure sores occurred.

Serial casting corrected all 24 equinus contractures; mean ROM gain of 26º
& mean of 3.8 casts

The last cast used in each series was revised into a night splint, and AFOs were prescribed for daytime use.

At 8 months follow-up, no contractures had recurred.

(Donovan E 1990)

 8

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Hypotheses about the physiology:

The workload on shortened TS muscles & fascia is reduced when the heels are fully loaded → they can relax.

Fascia needs water for filaments to glide. Reducing tension on the shortened, dehydrated muscle & fascia allows them to hydrate.

https://www.youtube.com/watch?v=uzy8-wQzQMY

Recently identified fasciocytes regulate hyaluronan production & density in adaptation to routine muscle use. Hyaluronan acts as a water reservoir & lubricant, influencing fascial fiber & slab gliding with movement.

(Stecco C, Fede C, Macchi V 2018)

 9

9

Can Casts Alone Manage Equinus Deformity?

Features of the
Below-Knee Serial Casting Program
Ann & Robert Lurie Children's Hospital
Chicago, Illinois

https://www.luriechildrens.org/en/specialties-conditions/serial-casting/

 10

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Recent Publication about the Lurie Children's Hospital BKSCP

https://issuu.com/americanoandp/docs/march_2022_final …pages 19-25.

 11

11

The Below-Knee Serial Casting Program (BKSCP)
at Lurie Children's Hospital in Chicago

For children with CP, ITW & Talipes Equinovarus

Note the BIG "Baby" Foot

The foot & ankle are 1st aligned & molded with plaster.

The elongated fiberglass toe restrains anterior COM displacement.

Posting brings the tibia as close to vertical as is possible for function & posterior knee joint protection.

Images courtesy of Mary Weck, PT

 12

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The 4 Elements of the Lurie's BKSCP

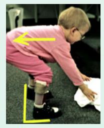
1. Repeat casting
at AA of R1A DFROM-KE until R1A = +15º.



Images courtesy of Mary Weck PT & Kaitlyn's Mom

2. Daily home exercise program

In casts: play in sports-stance posture, weight-line back activities, weight-shifts & practice walking with foot advancing first x 45 minutes.

Between & after casting: ankle muscle strengthening x 100 reps.

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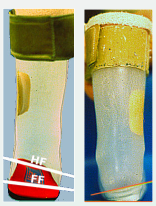
3. Specialized AFOs - Worn All Day

For COG-Back Training:



Solid
AA: 0ºPF
HF Varus: ~16º
FF varus: ~8º

Toe end stiffened.

4. **Sleeping AFOs – AA = ≥10º**
- until skeletal growth ends.

Brigid makes the night splints.

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Research on Retention of Lurie's BKSCP Outcomes

53 families of former participants agreed to a telephone interview regarding outcomes for 2 →14 years after casting.

Conclusions: *Commitment to the 4 elements of the BKSCP → retention of ankle DFROM & gait improvements for → 14 yrs (mean 5.6 years).*

(Brazg G, Johnstone K 2012, poster)

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Research on Retention of BKSCP Outcomes, continued…

- *100% of families who reported compliance with **all aspects** of the post-casting program – night bracing, practice walking, strengthening exercises, & AFO use until criteria for stopping are met - reported full retention of the goal outcomes.*
- *52% of families who reported noncompliance with any of the 4 program elements lost correction.*

(Brazg G, Johnstone K 2012, poster)

…So, no, casts & AFOs alone cannot correct EQD & researchers should evaluate the whole program.

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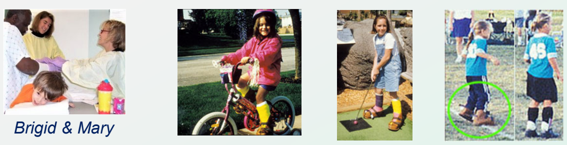

Brigid & Mary

Photos courtesy of Mary Weck, PT, who passed 2019 & is deeply missed.

https://www.luriechildrens.org/en/specialties-conditions/pediatric-orthotics/casting/

Brigid Driscoll, PT, CO will take questions:
BDriscol@luriechildrens.org

Remember, when she says she uses R1 end range DFROM, she means R1A (the harder 2nd catch).
I confirmed that distinction with Mary Weck in 2018.

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Children with Unilateral CP get Bilateral Casts & AFOs

Children with unilateral CP have 2 different sensory information streams.

Bilateral casting & AFOs deliver a similar sensory experience to both lower limbs.

Goal: Prolonged retention of DFROM gains & better whole-body integration.

 18

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For children with bilateral CNS dysfunction…

- No data supports the practice of limiting PF to 0º to reduce or prevent EQD.
- *Serial casting data* shows that setting the ankles in PF in solid devices with tuned soles *decreases EQD.*

(Ackman JD, Russman BS 2005; Glanzman AM, Kim H 2004; Brouwer B, Davidson LK 2000; Brouwer B, Wheeldon RK 1998; Donovan EM, Aronson DD 1990)

Classic Cusick Cast

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If a Casting Course is Abbreviated

Becker Camber Axis hinge joint

Keep the successful effects of casting going.

In cases where you expect to change the PF'd AA & heel height over time, consider using an adjustable joint to lock the AA &, maybe much later, to introduce a few degrees of ankle motion as the child gains control.

Consider the child's functional level & strength & the Motion control joint durability.

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Relevant Questions → Relevant Solutions

What do you expect from the ankle-foot orthoses (AFOs) for your clients with CP & ITW?...

Are you sure your expectations are realistic?

Are you generally satisfied with these outcomes?

- Wearer wants/likes to wear them.
- Foot joint alignment is optimized.
- Standing balance improves significantly.
- Gait pattern improves visibly.

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DL Sackett on evidence:

“Good doctors use both individual clinical expertise and the best available external evidence, and neither alone is enough.”

“By best available external clinical evidence we mean clinically relevant research, often from the basic sciences of medicine” [as well as patient centered clinical research].

DL Sackett. Evidence based medicine: what it is and what it isn't. Brit Med J. 1996:312: 71-72.

Until stronger data accumulates,
we must rely on science & clinical expertise.

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What sciences do we bring to orthotic design?

- Postural control acquisition & maintenance
- Somatosensory contributions to balance & movement
- The role of massed practice in motor learning
- Kinesiology – joint alignment & muscle use in function
- Muscle physiology & pathophysiology
- Biomechanics –forces, leverage, available motions
- Gait development – kinematics & kinetics

All of these factors are interdependent.

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Customizing Solid-Ankle Orthoses

Enclosure: partial or total contact distributes corrective forces over a large surface area.

Posting (shimming): Adjusting the plantar contact surface to fill spaces between the foot segments in improved alignment & the ground to optimize load-bearing alignment, sensory input, & function.

Degrees of Available Motion: Manipulating the number of distal operating joints & movements to simplify a motor learning task more proximally.

Specialized cast boots & comparable AFO-FCs
apply all 3 functions.

 24

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Somatosensory cortical activity is related to the mobility & strength impairments in children with CP.

The magnitude of somatosensory cortical activity in response to input from the feet in children with CP had a strong positive relationship with ankle muscle strength, step length, & walking speed.

(Kurz MJ, Heinrichs-Graham E 2015)

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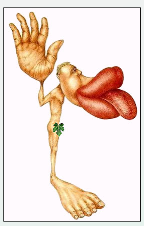
Enhancing Somatosensory Input to the Foot & Ankle



Our feet have hundreds of thousands of sensory receptors:
– extero-, proprio–, load-, & tactile.

No stimulus, no sensory reception.

Optimize contact with - & loading on – the feet, especially the heels.

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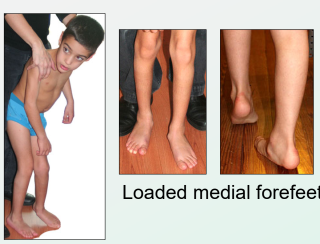
What is Francesco learning?



Loaded medial forefeet.

Sensory receptors must be stimulated in order to inform.

(Wright WG, Ivanenko YP 2012; af Klint R et al 2010; Blackburn J et al 2006; Kavounoudias A 1998;

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Sagittal-Plane Posting for EQD

Like “shimming”, the shoe or orthosis is adapted to accommodate an existing ankle DFROM-KE deficit (i.e. permitting ankle PF), providing loading input to the heels & protecting loaded foot & knee joints from excessive strains Imposed by EQD.

Heel lifts

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Principles & practices of tuning AFO-FCs apply only to gait.

Candidates for successful AFO tuning for gait must be ambulatory without devices.

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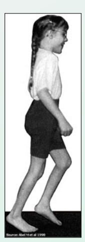
Owen Focuses on the “Shank”

2 issues in gait:

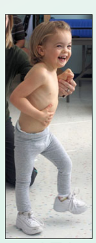
1. Excessive tibial (shank) inclination (ETI)

2. Inadequate tibial (shank) inclination (ITI)

(Cusick’s abbreviations)



E T I



I T I

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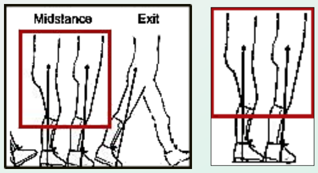
The goal of Owen's "Tuned AFO-FCs": Optimize the Mst SVA

The AFO ankle must be solid.



(Owen E 2010)

Swing limb knee extension & step length are products of postural control & stance-side hip & knee stability.

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Factors Limiting Successful AFO & Shoe Tuning for Gait

- Flexion contractures at hip (>15°) &/or knee (HLT* >45°) *(add TheraTogs?)*
- Markedly increased body COG velocity (begin with serial casting…?)
- Excessive FPA* (intoeing or out-toeing)
- GN contracture with high stiffness >10° - wedges become too large - usually not accepted *(serial cast first…?)*

(Jagadamma KC, Coutts FJ 2015; Butler PB, Farmer SE 2007)

*HLT: hamstring length test *FPA: Foot progression angle

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AFO Tuning - Step 1:

Choose the Ankle Angle (AA)

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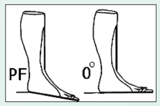
Goal: Accommodate the available extensibility of a stiff & shortened gastrocnemius muscle.

"Spasticity" (MAS, MTS) is not considered.

Owen's evaluation of ankle DFROM lacks standardization, is undertaken in supine lying, elevates the lower limb, stretching the sciatic nerve & overlooks the catches.



From here on, as Owen & I differ in assessment procedures & goal-setting. I refer you to her courses for her methods & strategies.

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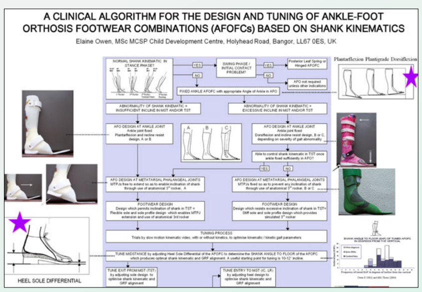
Owen's Tuning Algorithm

...No photos show AA in PF.



(Owen E 2005)

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Tuned AFO-FC Research on 0º-PFd AFOs

5 children with CP, ages 7-11 yrs; 4 bilateral, 1 unilateral, all Level II.

Gait kinematics: barefoot, non-tuned & tuned AFO-FC.

All ankles were set at 0º AA in AFOs???

Conclusions: Tuning the AFO-FC of children with CP can improve hip function, pelvic function, stance-phase knee extension & swing phase knee flexion.

The 2 children with best results showed stance-phase knee hyperextension.

(Eddison N, Chockalingam N et al 2020)

Mid-swing?

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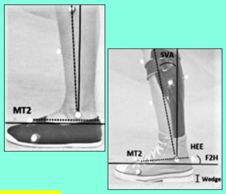
More Tuned AFO-FC Research on 0º-PFd AFOs

18 children with CP, mean age 10.8 ± 3 years, GMFCS Levels I & II.

No DFROM measures.

2 gait types: knee extended & knee flexed
3D gait analysis on a treadmill.

0º-PF AFOs w/ heels inclined incrementally with wedges.



Results: Increasing heel height → increased knee flexion, more inclined SVA, & increased knee extension moments overall – an improvement only for some with EXT-type gait.

...Why?

(Oudenhoven LM, Kerkum YL et al 2021)

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Billi's Guidelines for Choosing the Ankle Angle
(Subject to Further "Tuning" with Implementation)

Hypothesis: R1A DFROM-KE with congruent foot is unforced, so the child should be comfortable in an AFO AA set at R1A.

- If R1 → R2 DFROM-KE reveals an **R1A,** set the AA at/near **R1A**.
- If **R1A** in an ambulatory client is **>-5º,** use tuned serial casting first. If casting is not possible, begin tuning program with standing only to gain DFROM for 2-4 weeks, then reduce AA & post for walking.
- If R1A in a nonambulatory client is **>-10** & casting is not possible, **set AA at R1A with fibula vertical for standing only.**

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AFO Tuning – After setting the AA, Step 2:

Modify the sole as needed
to set the shaft inclination angle
at midstance/midswing in gait.

(Cusick B 1990, Owen E 2010)

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Candidates for Tuned AFOs Have Different Skills & Requirements

Owen's primary candidates for tuned AFO-FC are ambulatory without devices – Levels I & II.

As with specialized cast boots, many children with CP who function at GMFCS levels III & IV can benefit from tuning modifications used to improve heel-loaded standing stability & lateral weight shifting skills.

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Preliminary casting can prepare the child to continue to work on upright balance in tuned AFO-FCs of similar design.

Sam

Casts + big boots – standing & weight shifts only.

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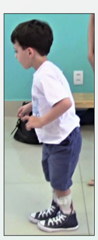
Function-Based Candidates for Tuned AFOs

1. PRE-AMBULATORY: POOR STANDING BALANCE



Bernardo, age 5 yrs, diplegic CP GMFCS Level III

Articulated AFOs with flat shoes.
Leg is inclined 13° at the fibula; AA = 13°DF.

R_1A DFROM-KE = 0°

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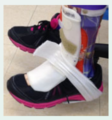
Anterior Shell Reduces Degrees of Freedom

Form an anterior shell with Aquaplast-T or any low-temperature splinting material with a strip of firm foam on the underside for corrugation.

Accelerate setting by stroking it with a cloth soaked in iced water.



Attach the anterior shell with an elastic strap that runs from the anterior dorsal ankle over the posterior edge of the shoe heel.

The AFO AA = 0º after stabilizing it against DF.

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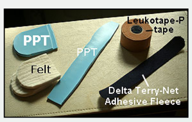
Typical Supplies for Clinical Posting Trials



Adhesive-backed, wedged posting strips

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Bernardo - Age 5.5 Years
Diplegic CP
GMFCS Level III

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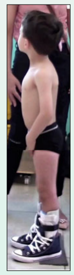
Bernardo in Modified AFOs, Shoes, & PF Wedge

We added a 4º heel wedge
to tilt the AFO shaft forward
for standing & side-stepping only.



Now he must practice!

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Ideally, the AFO AA is Adjustable

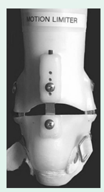
Dual Axis & Motion Control Joints

SVA is too high

PhoenixHabTech New Prototype Static Adjustable

Integrated Double-Action Joint - OTS

A strong joint will fail if the plastic is weak.



Becker Motion Control Limiter #655

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Function-Based Candidates for Tuned AFOs, continued.

2. DEVICE-DEPENDENT – Level III - R1A DFROM-KE $\geq$ -10º

Children who require walkers – particularly with hand-loading & chest-loading - show little effect of tuned AFO-FC interventions on gait.

This functional group typically shows deficits in standing & sitting balance & sitting posture.

Build preambulatory skills. Remediate A-G EXT, sitting & standing balance. Tune AFO-FCs for standing practice. Proceed to cruising when able.

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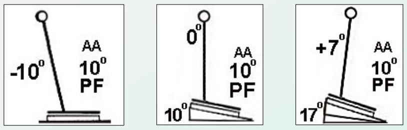
AFO "Tuning" for Walking if R1A = -10°

Leg axis is standard vs. SVA



Heel wedging for walking requires the addition of ~5-7° (standard) to incline the leg at midstance

→ **wedge must = 17°.**

Not feasible for walking.

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Function-Based Candidates for Tuned AFOs, continued.

3. AMBULATORY – Levels I & II - R1A DFROM-KE = 0° +/-5.

These children are optimum candidates for tuned AFO-FCs.

(Eddison N, Chockalingam N et al 2020; Eddison N 2018; Jagadamma KC, Coutts FJ 2015)

These children should devote 60 minutes/day to:

- Practicing keeping body COG back in standing & walking.
- Practicing walking with swing knee extension & heel strike.
- Strengthening all ankle muscles in closed-chain conditions.

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Tuning the Footwear
to Complement the AFO

Reduce COG Acceleration
& Excess Tibial Inclination

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High Heel → Shorter Foot → Weight Forward
Hi Yi YI!!!
Try bigger shoes.
Restore or enhance functioning foot length with a stiff long toe on both the AFO & the shoe.
Preview by sticking a crepe wedge to the toe end of the shoe sole, wide end in front. Later, insert it under the sole.
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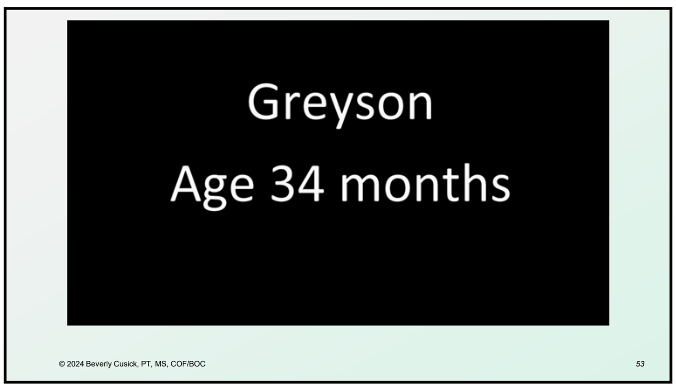
Greyson
Age 34 months
© 2024 Beverly Cusick, PT, MS, COF/BOC
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Preview Tuning Effects in Clinical Trials
Articulated, Free-DF AFOs - 0° PF stop.
Rigid Sole
RIGID-SOLED post-op (cast) shoes applied over posted orthoses or orthoses & shoes.
Solid AFOs in 10°PF with rigid cast shoes + wedges + duct tape.
© 2024 Beverly Cusick, PT, MS, COF/BOC
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Footwear to Reduce Speed & ETI

Shop for stiff-soled shoes with a deep, sturdy heel box, a late toe rocker, & a stiff toe.




MEMO

PIEDRO

NIKE AirForce 1 line for children

www.memo-shoes.com

www.piedro-therapy.com/stability

https://www.nike.com/t/force-1- (toddlers)

www.nike.com/t/air-force-1-high-big-kids - children

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Tuning the Footwear to Complement the AFO

Knee Hyperextension:
Increase the Magnitude
& Speed of Tibial Inclination

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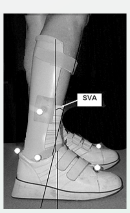
Tuning Shoe Sole For ITI – Positive Heel




A positive heel & flexible or rounded toe rocker

(Jagadamma KC et al 2010)

Johnnie Morris, CPO
Western Slope Orthotics
westernslope02@gmail.com

 57

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Chloe. age 4 years
S/P lumbar perfusion deficit
during cardiac surgery
at age 2 years

 58

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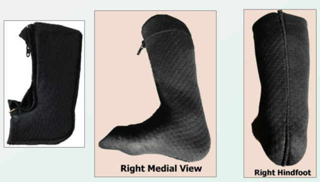
Early EQD Prevention

PADROM-KE shows a catch before age 30 months, start preventative night splinting in $\geq 10^\circ$ DF



Turtlebrace™ ankle; Toe end pulled hard to support toes.

Aquaplast-T

**AFS: Ankle-Foot Splints*

 59

59

In EQD, how can we enhance function?

- Optimize load-bearing joint & body alignment to
- Optimize weight distribution to optimize sensory input to
- Optimize postural responses, muscle use & strength?
- Deliver adequate practice reps in improved alignment & sensory input to
- Optimize cortical mapping of more successful sensorimotor experiences to
- Optimize daily functional abilities undertaken while standing & walking?

 60

60

Summary

- Loading the heels is an essential element of postural control & calf muscle contracture prevention & management.
- Setting an ankle in PF to accommodate a PF contracture facilitates heel loading, postural control, & DFROM gain only if the weight line falls through the heel > metatarsal heads.
- Orthoses should be designed to provide a normal sensory experience of weight loading & help with managing degrees of freedom.

 61

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Summary

- In the presence of excessive tibial inclination, ankle DF control is more important than PF control.
- The common use of an articulated AFO for children with EQD & tibial inclination is misguided.
- Shoe features matter, particularly the stiffness of the sole at the toe box.

 62

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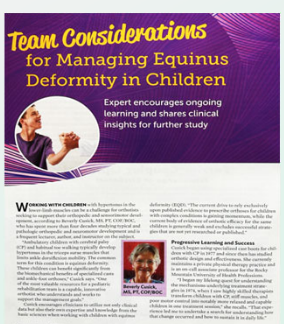
Recent Interview for O&P Almanac March, 2022



https://issuu.com/americanoandp/docs/march_2022_final
…pages 26-31.

 63

63

10

After Casting

Using AFOs
& Shoe Modifications
to Support
Neuromotor Re-Education

#

1

Managing Postural-Control Acquisition

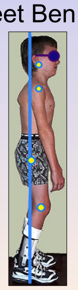
by manipulating distal joint motion constraints

1. Solid ankle – maximum limit on motions
2. Ankle motion-limits – stop, check strap
   – Limit both PF & DF
   – Limit PF OR DF
3. Free ankle / No ankle

#

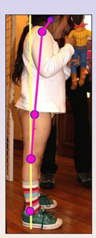
2

Meet Ben and Ana…



DFROM-KE:
R1: -15º •
R1A: -8º
++++ →
R2: +4º
SIMILAR ON
BOTH SIDES:

Ben - Age 9 yrs, pronates



DFROM-KE:
R1: -15º
++++
→ R2: +5º
SIMILAR ON
BOTH SIDES:

Ana - Age 6 yrs, supinates

#

3

Casting → DFROM-KE Results

Ben will achieve these casting results:

R1A: 0°	→ Set the AFO ankle angle at ~0° with posting as needed to align the foot & incline the MDST leg.

Ana will achieve these casting results:

R1A: -5°	→ Set the AFO AA at ~5° PF'd. Add a total of ~12° of heel lift, by combining the shoe heel with wedging, for walking with optimum MDST leg inclination.

 #

4

Checklist: Serial Casts in PF w/ Long Toe

Device	Could it support these goals?	Y	N	Maybe
	Improve foot joint alignment	☆		
	Increase plantar heel loading / input	☆		
	Improve knee joint alignment	☆		
	Improve hip & pelvic alignment	☆		☆
	Improve standing stability	☆		
	Improve stance phase stability in gait	☆		
	Increase propulsion power		☆	
	Improve swing-limb clearance	☆		
	Increase step length	☆		
	Prepare the foot for weight assumption	☆		
	Increase energy efficiency	☆		
	Facilitate learning a new gait pattern	☆		

 #

5

Solid AFOs

 #

6

Checklist: Solid AFO in PF + Heel Lift

Device	Could it support these goals?	Y	N	Maybe
Solid AFO at 0 to 5PF + Heel Lift + shoe	Improve foot joint alignment			
	Increase plantar heel loading / input			
	Improve knee joint alignment			
	Improve hip & pelvic alignment			
	Improve standing stability			
	Improve stance phase stability in gait			
	Increase propulsion power			
	Improve swing-limb clearance			
	Increase step length			
	Prepare the foot for weight assumption			
	Increase energy efficiency			
	Facilitate learning a new gait pattern			

7

Checklist: Solid AFO in PF + Heel Lift - BEN

Device	Could it support these goals?	Y	N	Maybe
Solid AFO at 0 to 5PF + Heel Lift + shoe	Improve foot joint alignment	☆		
	Increase plantar heel loading / input	☆		
	Improve knee joint alignment	☆		
	Improve hip & pelvic alignment			☆
	Improve standing stability	☆		
	Improve stance phase stability in gait	☆		
	Increase propulsion power		☆	
	Improve swing-limb clearance	☆		
	Increase step length	☆		
	Prepare the foot for weight assumption	☆		
	Increase energy efficiency	☆		
	Facilitate learning a new gait pattern	☆		

8

Checklist: Solid AFO in PF + Heel Lift - ANA

Device	Could it support these goals?	Y	N	Maybe
Solid AFO at 0 to 5PF + Heel Lift + shoe	Improve foot joint alignment			
	Increase plantar heel loading / input			
	Improve knee joint alignment			
	Improve hip & pelvic alignment			
	Improve standing stability			
	Improve stance phase stability in gait			
	Increase propulsion power			
	Improve swing-limb clearance			
	Increase step length			
	Prepare the foot for weight assumption			
	Increase energy efficiency			
	Facilitate learning a new gait pattern			

9

Checklist: Solid AFO in PF + Heel Lift - ANA

Device	Could it support these goals?	Y	N	Maybe
Solid AFO at 0 to 5PF + Heel Lift + shoe	Improve foot joint alignment	☆		
	Increase plantar heel loading / input	☆		
	Improve knee joint alignment	☆		
	Improve hip & pelvic alignment	☆		
	Improve standing stability	☆		
	Improve stance phase stability in gait	☆		
	Increase propulsion power		☆	
	Improve swing-limb clearance	☆		
	Increase step length	☆		
	Prepare the foot for weight assumption	☆		
	Increase energy efficiency	☆		
	Facilitate learning a new gait pattern	☆		

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10

Solid AFO with Adjustable Ankle Angle


Benefit:
AA & heel posting can be changed as settings permit.

This one was made by Lorelei Orthotics & Prosthetics.

Becker Motion Limiter #655 with 3 Ankle Angle settings

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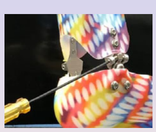
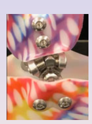
11

Dual Axis & Motion Control Joints



Becker Camber Axis Hinge

https://beckerorthopedic.com/Product/AnkleComponents/ThermoplasticAnkleJoints/750

Flexion Control Ankle Joint

Lower Extremity Technology Inc.

http://fc2ankle.com/product

A strong joint will fail if the plastic is weak.

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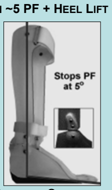
Articulated (Hinged) AFOs

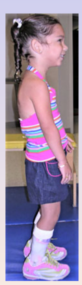
13

Checklist: HAFO in PF w/ PF Stop + Heel Lift - BEN

Device	Could it support these goals?	Y	N	Maybe
HAFO WITH PF STOP IN ~5 PF + HEEL LIFT	Improve foot joint alignment			☆
	Increase plantar heel loading / input			☆
	Improve knee joint alignment		☆	
	Improve hip & pelvic alignment		☆	
	Improve standing stability		☆	
	Improve stance phase stability in gait		☆	
	Increase propulsion power		☆	
	Improve swing-limb clearance		☆	
	Increase step length		☆	
CASCADE ORTHOTICS IN CALGARY	Prepare the foot for weight assumption		☆	
	Increase energy efficiency		☆	
	Facilitate learning a new gait pattern		☆	

14

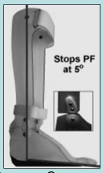
The most common error
in orthotic Rx
for children with
excess tibial inclination
& weak LE extensors
is the articulated AFO
with free DF.



Free DF, hinged AFOs

15

Checklist: HAFO in PF w/ PF Stop + Heel Lift - ANA

Device in gait	Could it support these goals?	Y	N	Maybe
HAFO WITH PF STOP IN ~5 PF + HEEL LIFT	Improve foot joint alignment	☆		
	Increase plantar heel loading / input	☆		
	Improve knee joint alignment	☆		
	Improve hip & pelvic alignment	☆		
	Improve standing stability	☆		
	Improve stance phase stability in gait			☆
	Increase propulsion power		☆	
	Improve swing-limb clearance	☆		
	Increase step length	☆		
CASCADE ORTHOTICS IN CALGARY	Prepare the foot for weight assumption	☆		
	Increase energy efficiency	☆		
	Facilitate learning a new gait pattern	☆		

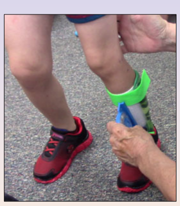
16

AFO Designs for EQD & Optimizing Tibial Inclination

Would You Approve?
Yay or Nay

17

What do you think of this AFO that was issued to a child with left hemiplegic CP…



Solid Ankle Angle: 10° DF
Shoe heel to forefoot drop: 4°
Anterior SVA: 18°
Fibular inclination: 14°

___Shaft length?
___Tibial control?

18

What do you think of these features…

___Shaft length?
___Tibial control?
___Foot packaging?
___Posting?
___Strapping?
___Comfort?

 #

19

What do you think of these features…

___Shaft length?
___Tibial control?
___Foot packaging?
___Posting?
___Strapping?
___Comfort?

 #

20

What do you think of these features – DF-assist joint(s)…

___Shaft length?
___Tibial control?
___Foot packaging?
___Strapping?
___Comfort?

 #

21

What do you think of these features…

___Shaft length?
___Tibial control?
___Foot packaging?
___Posting?
___Strapping?
___Comfort?

#

22

What do you think of these features…

___Shaft length?
___Tibial control?
___Foot packaging?
___Posting?
___Strapping?
___Comfort?

#

23

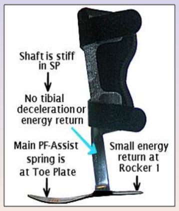
What do you think of these features…

___Shaft length?
___Tibial control?
___Foot packaging?
___Strapping?
___Posting?
___Comfort?

#

24

What do you think of these features…



- ___Shaft length?
- ___Tibial control?
- ___Foot packaging?
- ___Posting?
- ___Strapping?
- ___Comfort?

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Kiddiegait(TM)
AFO
Critique

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Checklist: Ankle-Height FO + Heel Lift - CP

Device	Could it support these goals?	Y	N	Maybe
ANKLE-HEIGHT FO (SUPRAMALLEOLAR ORTHOSIS) WITH HEEL LIFT 	Improve foot joint alignment	☆		
	Increase plantar heel loading / input	☆		
	Improve knee joint alignment			☆
	Improve hip & pelvic alignment			☆
	Improve standing stability	☆		
	Improve stance phase stability in gait			☆
	Increase propulsion power			☆
	Improve swing-limb clearance		☆	
	Increase step length			☆
	Prepare the foot for weight assumption		☆	
	Increase energy efficiency		☆	
	Facilitate learning a new gait pattern			☆

(c) #

27

Allow <u>Adequate Time</u> to Practice & Learn

Unlike orthopedic problems with intact neuromuscular systems, **people with movement disorders** & a history of use in the context of postural control deficit, sensory input & processing deficit, pathokinesiology & pathomechanics **<u>require more practice</u>** in the improved functioning context to try to overrule existing cortical maps & other physiologic adaptations.

Think in terms of years.

#

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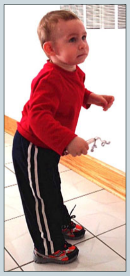
Let's Push Some Barriers Down!

#

29



11

Greyson
Diplegic CP
Level II

 1

1

Greyson - Age 37 months

Resting Postures

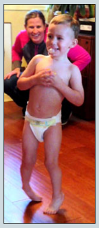
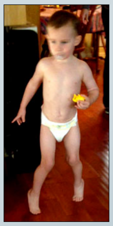
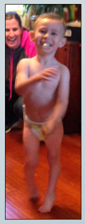
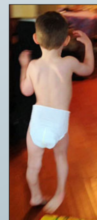
 2

2

Greyson
Age 3 years
Diplegic CP

 3

3

 4

4

First Assessment Findings

TEST	LEFT	RIGHT	Age IDEAL
Ankle DFKE – R1 /R1A	**-22/-12**	**-18/-7**	+15 /+30
Ankle DFROM - KF	-10/NT	-8/NT	25/35

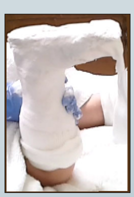
Feet pronate when he lowers his heels to the ground, requiring that he hyperextend or flex his knees.

 5

5

Applied 2 Casts: Plaster & SoftCast

- Molded casts with Greyson lying prone & knee flexed ~90º.
- Ankle Angle in casts ~10º PF.
- Posted casts to BC's (fibular) leg inclination of ~7º.




Posted inner boot

 6

6

Greyson
The next day
at the library…

 7

7

Second Set of Casts

Adding TheraTogs Abdominal, Hip EXT & LE Rotation Strapping

 8

8

DFROM Gains over 3 Casts

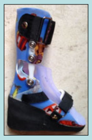
	Session 1		Session 2		Session 3	
	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
R1	-22	-18	-13	-10	-6	-5
R1A	-12	-7	+3	+5	0	+4

- Active PF in prone lying is still very strong.
- Davin Amara, CO casted his feet for AFOs.
- Posting plan: Set AA at -5º + leg inclination angle at 7º inclined.

 9

9

Orthotic Design Selected

Device	Could it support these goals?	Y	N	Maybe
SOLID, PF'D, TOTAL-CONTACT AFO	Improve foot joint alignment	√		
	Increase plantar heel loading / input	√		
	Improve knee joint alignment	√		
	Improve hip and pelvic alignment	√		
	Postural response acquisition	√		
	Improve stance phase stability	√		
	Improve propulsion power		√	
	Improve swing-limb clearance	√		
	Increase step length			√
GCO Phoenixhabtech.com	Prepare foot for weight assumption	√		
AA 5º PF	Increase energy efficiency	√		
Heel wedge 12º SVA 7º	Help learning a new gait pattern	√		

 10

10

Ongoing Assessments & Interventions

	Precast 1		Precast 3		10 days After Cast 3	3 weeks later	
	LEFT	RIGHT	LEFT	RIGHT	DFROM NT Began using GCOs that needed revising to lengthen the forefeet.	LEFT	RIGHT
R1	-22	-18	-6	-5		-6	0
R1A	-12	-7	0	+4		+4	+10

Orthotist obtained latest findings.
We agreed to leave AA at 5ºPF thru summer.

 11

11

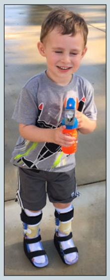
Greyson

Gait Control Orthoses

 12

12

Revised GCOs & Night Splints





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13

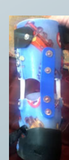
Starting in the Fall of the same year, things fell apart…

Greyson was growing very fast & calling the plays….

 14

14

- He had not worn the Tank Top & abdominal posture straps since late summer →
- The thoracic & pelvic cups were not stacked.
- He had not used the night splints for 6 months.
- His AFOs broke & needed reinforcing. →
- He was losing foot alignment in them → skin sores → padded.

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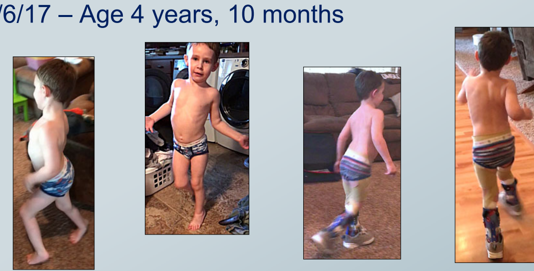
3/6/17 – Age 4 years, 10 months



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 17

17

Repeat Assessment Findings

TEST	LEFT	RIGHT	Age 4 IDEAL
Ankle DFKER1/R1A	**-20 / -12**	**-22 / -10**	+10/+25
11 months ago	-22/-12	-18/+7	No R1A

 18

18

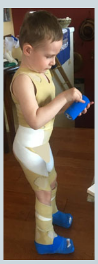
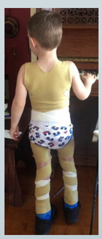
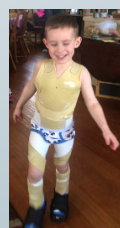
Repeat Casting ROM Record – 3 weeks

TEST	Date: 3/31/17 Time: 11:00 Am	Date: 4/14/17 Time: 3:46 P	Date: 4/17/17 Time:	Date: 4/21/17 Time:
ANKLE DF KNEE EXTENDED (prone)	**Right** R1 -20 (16?) R1A -10 R2 +10	**Right** R1 -10 R1A 0 R2 +15	**Right** R1 -10 R1A -5 ? R2 +20	**Right** R1 -4 R1A +2 active R2 +20
	Left R1 -20 R1A -12 R2 -6	**Left** R1 -14 R1A -5 R2 +8	**Left** R1 -10 R1A -4 R2 +20	**Left** R1 -5 R1A 0 R2 +20 «eff 24

4/21: Went home in casts for 10 more days….

19

Repeat Casting, Full Eval, & Resumed Togging

He cannot stack those cups.

20

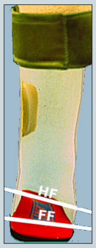
Night splinting reinstituted, weight-back training with a PT, wearing new AFOs…

June 1..

DFROM-KE Findings:			
LEFT		RIGHT	
R1: -10°	**R1A: +15°**	R1: -7°	**R1A: +10°**

21

Requested Post-Cast Orthotic Specifications



Solid
AA: 0ºPF
HF Varus: ~16º
FF varus: ~8º #1-5
for COM-back training.

Toe end stiffened on the shoes.

His orthotist had a better idea….

 22

22

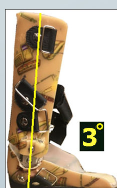
Motion Control – Locked at Optimum Ankle Angle

16º Varus Heel

8º Varus Forefoot

Varus-posted insole
XPE - UCO International

AA: ~3º DF



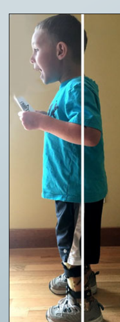
Ottobock Dual Action
Joints - Locked

Made by John Held, CPO – Great Steps O&P, Sartell, MN 56377
jheld@greatstepsop.com

 23

23

Alright! Yay Greyson!



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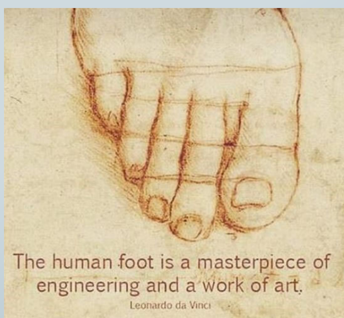
Questions?

Discussion..?



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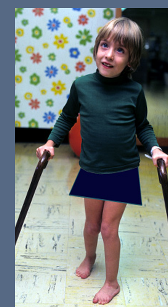
12

Considerations & Ideas for Researchers

1

Children with CP present some common - but many uniquely personal - constellations of obstacles, e.g.:

- Sensorimotor experience
- Brain & neuromotor mapping
- Sensory deficits
- Postural control deficits
- Compensatory muscle recruitment strategies
- Weakness
- Modulus of muscle stiffness
- Joint & bone deformities
- Selective motor control
- Ligament status



2

Complexity Impedes Rehabilitation Research

1. Researchers like cause-effect relationships between single variables.
2. Children with a history of compensatory postural control & movements show personal constellations of modeling errors.
3. Data about the relationships between use history & modeling errors is scarce *(see # 1 above).*
4. Gait analysis routinely dismisses COM projection over BOS as a factor.

Horn SD, DeJong G, et al 2005

3

Efficacy Studies

Randomized Controlled Trials (RCTs) - "Level I" of Sackett's 5 levels of evidence - evaluate ONE effect of ONE variable, such as a drug, on ONE factor.

Does this grading of the value of research apply to the management of children & adults with CNS dysfunction?

(Sacket DL 1993 & 1986)

4

Effectiveness Studies

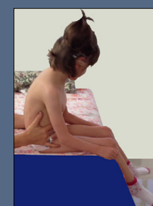
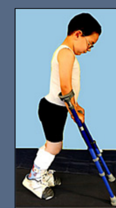
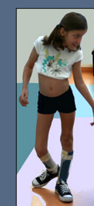
Example: Clinical Practice Improvement studies (CPIs) identify & consider many coexisting variables.

CPIs are more relevant than efficacy studies for researching these populations, & don't get funded as readily.

Haynes RB. Clinical Epidemiology: How to Do Clinical Practice Research. Lippincott Williams & Wilkins; 2012.

5

Effectiveness studies strive to understand the effects of existing factors on function, on intervention outcomes, & on what happens sequentially in actual practice.

A well-designed case study can teach us a lot about the potential effectiveness of an intervention for a comparable subject.

6

Researching the Effectiveness of a Neuromotor Re-Ed Program

Sensory-motor learning & relearning require thousands of hours & perhaps millions of repetitions of purposeful, successful occurrences.

Physiologic adaptation of bone, muscle, & soft tissues occurs after a prolonged & routine use history.

Specifics of required use histories for adaptation to occur are not clear outside of strengthening exercises & serial casting regimens.

7

Researching the Effectiveness of a Neuromotor Re-Ed Program

8 weeks of data collection - a standard for research projects to show an effect – are *NOT adequate* to assess the effectiveness of a complex course of neuromotor re-education for children with years of mapping & physiologic bone & tissue adaptation to overcome.

8

Any intervention's potential for effectiveness for a selected population depends upon:

- The context & similarities among subjects.
  The GMFCS groups subjects by ability but takes no account of coexisting biomechanical factors.
- The intervention's mechanical & sensory properties.
- The potential of the intervention to deliver – & of the researcher to record - massed practice.

9

The Scientific Method

- A published study method must be replicable PRECISELY by the reader who challenges the results, or the value of the study is diminished.
- This level of scientific replicability is a rare event.
- Money (keep my job) & status (fame begets glory) can drive many researchers to publish.
- Competition for attention & profits might drive many decisions by journals to publish.

10

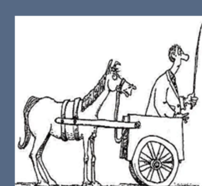
A Resource Accuracy Shortfall

"Citation and quotation errors are common in the pediatric orthopaedic literature. Reference accuracy continues to be a substantial problem in the biomedical literature." p. 1155

Davids JR, Weigl DM, et al 2010. Reference accuracy in peer-reviewed pediatric orthopaedic literature. J Bone Joint Surg Am. 92(5):1155-61. [

11

The clinical practice guidelines cart is in front of the horse...



- Few studies used as "evidence" are replicable.
- Most clinicians are not adequately trained to conduct clinical research.
- Most clinicians are overworked & are not paid to conduct clinical research.
- Most clinicians lack PhDs needed to seek adequate funding for research.

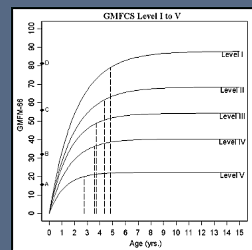
12

Clinical practice guidelines?

- Questions asked by resourced researchers are often irrelevant.
- Developmental & neuromotor disabilities are life-long & ever-changing conditions.
- Rehabilitation strategies are ongoing, variable, & multifactorial.
- Short-term effects of isolated interventions prevail in the literature.

13

The Stability of the Motor Growth Curves



Rosenbaum PL et al *(2002)* evaluated GMFM status on >600 children with CP in the Toronto area → these achievement curves.

Conclusion: Each GMFCS level can be expected to exhibit a predictable plateau.

TheraTogs & AFO tuning strategies were introduced in 2002, so none of these children wore live-in functioning alignment systems & optimized AFOs.

14

Relevance of Motor Growth Curves

Alriksson-Schmidt A (2017) supported the stability of GMFCS levels over time.

Some propose that this data is evidence of the inevitability of failure to advance GMFCS levels.

I take it as a challenge to change the management paradigm.

Growth curves can be ***used in lieu of a control group*** to investigate change in function after of introducing rehab-supporting interventions. Effectiveness = the child advances a level.

15

GMFM-66 Reference Percentiles

- Cross-sectional reference percentiles have been developed for the GMFM-66 within levels of the GMFCS.
- Reference percentiles extend the clinical utility of the GMFM-66 & GMFCS by providing for appropriate normative interpretation of GMFM-66 scores within GMFCS levels.

(Duran I, Stark C, Martakis K, et al 2019; Hanna SE, Bartlett DJ, Rivard LM, Russell DJ 2008)

16

GMFM-66 Reference Percentiles

- A gain in function within a higher level can be quantified as a % of the new level.
- Establish GMFCS level with percentiles & then introduce a new management strategy for a minimum of 6 months → reassess.

(Duran I, Stark C, Martakis K, et al 2019; Hanna SE, Bartlett DJ, Rivard LM, Russell DJ 2008)

17

Is scientific merit "evidence?"

18

DL Sackett on "Evidence"

"Good doctors use both individual clinical expertise and the best available external evidence, and neither alone is enough. Without clinical expertise, practice risks becoming tyrannized by evidence, for even excellent external evidence may be inapplicable to or inappropriate for an individual patient." p. 72

(Sacket DL 1996)

19

"Evidence based medicine is not "cookbook" medicine. Because it requires a bottom up approach that integrates the best external evidence with individual clinical expertise and patients' choice, it cannot result in slavish, cookbook approaches to individual patient care." p.72

(Sacket DL 1996)

20

20

"External clinical evidence can inform, but can never replace, individual clinical expertise, and it is this expertise that decides whether the external evidence applies to the individual patient at all and, if so, how it should be integrated into a clinical decision." p. 72

(Sacket DL 1996)

21

21

What do we need to know more about to prevent & reduce equinus deformity without harming anybody?

22

Normative Studies

23

Typical Development?

"Typical" development seems to mean that there are no known diagnoses or brain dysfunction.

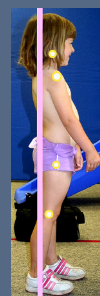
However, "typical" development embraces a wide range of differences in morphologic characteristics & in muscle recruitment & gait strategies.

24

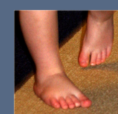
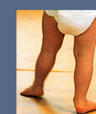
Suggested Exclusion Criteria for Normative Studies Pertaining to Ankle & Foot Development & Function

25

If the following issues are present in a TD group, assign them to groups to compare data with those without these issues:



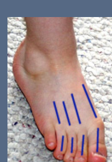
- Anterior COG carriage in standing & gait
- Intoeing >5º - established from ≥12 barefoot prints (6 strides) via pedobarograph or computerized pressure sensing mat e.g. Protokinetics™ walkway.
- Out-toeing ≥10º.

26

Exclude those with excess standing foot pronation showing ≥4 of these 8 criteria (age ≥ 3 years):

1) Medial weight load on the heels & forefeet
2) Everted heels
3) Knee joints in medial rotation
5) Skin crease on dorso-lateral junction of the foot with the leg
6) Static toe flexion
7) Static lateral toe deviation
7) Visible & palpable medial talar head.




27

Exclude those with excess standing foot supination showing ≥4 of these 5 criteria:


1) Lateral weight load on the heel & forefoot
2) Inverted calcaneus
3) Knee joint in lateral rotation
4) Forefoot medially deviated on the hindfoot.
5) Visible & palpable lateral talar head at the sinus tarsi.

28

28

Cusick's Suggestions for Researchers of Live-In Orthotic Interventions

- For ambulatory children, optimize feet first – alignment & load distribution.
- Gather data pre/post addressing feet.
- Compare effects of tuning to no-tuning orthoses.
- THEN add to the optimized foot & leg the more proximal functioning alignment aid, such as taping, an elasticized garment & strapping system, a different strapping application, a TLSO, etc.

29

Interested in Researching TheraTogs Effectiveness?

Formulate your question(s) & hypothesis & check in to verify that your question fits this system's properties & purposes.

Contact: Beverly Cusick, PT, MS, CMO
Email: bcusick@theratogs.com
Phone: 970-239-0103

TheraTogs, Inc. will help you as much as possible within the bounds of ethical research protocol.

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Keep Reading

Clinical scientists are finally exploring some relevant questions, e.g. the relationship between postural control & motor function, the physiology of neuro-musculo-skeletal adaptation to routine function, & the role of the sensory system in rehabilitation.

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