What Do Patients With Gait Impairments Want?

What Can We Deliver?

Andrew G. Georgiadis, M.D.
Michael H. Schwartz, Ph.D.

Orthopedic Surgery, University of Minnesota
Gillette Children's Specialty Healthcare

What Do Patients Want?

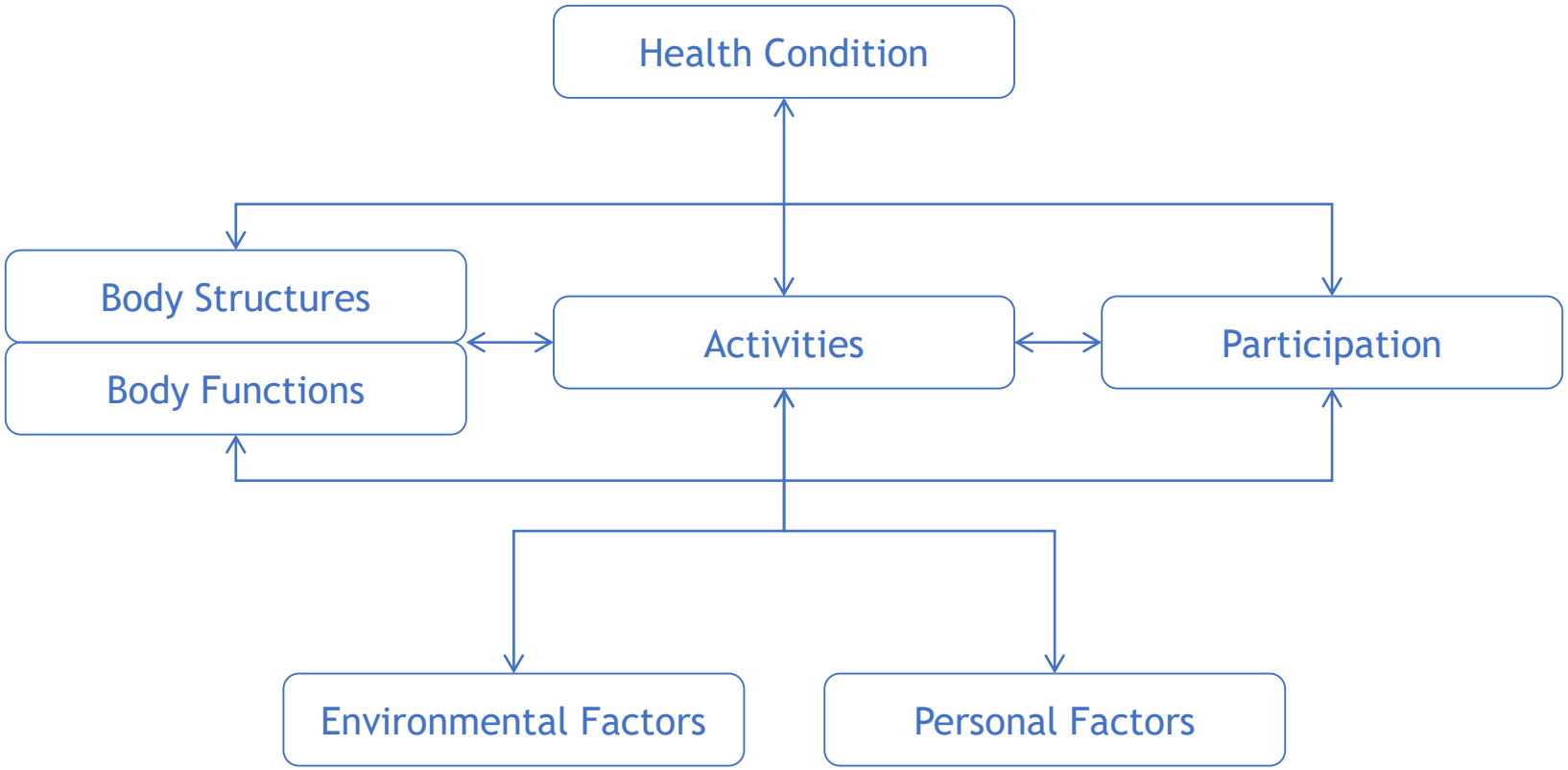
What Do Patients Want?

"Patients" are people, and therefore want the same thing all people want…

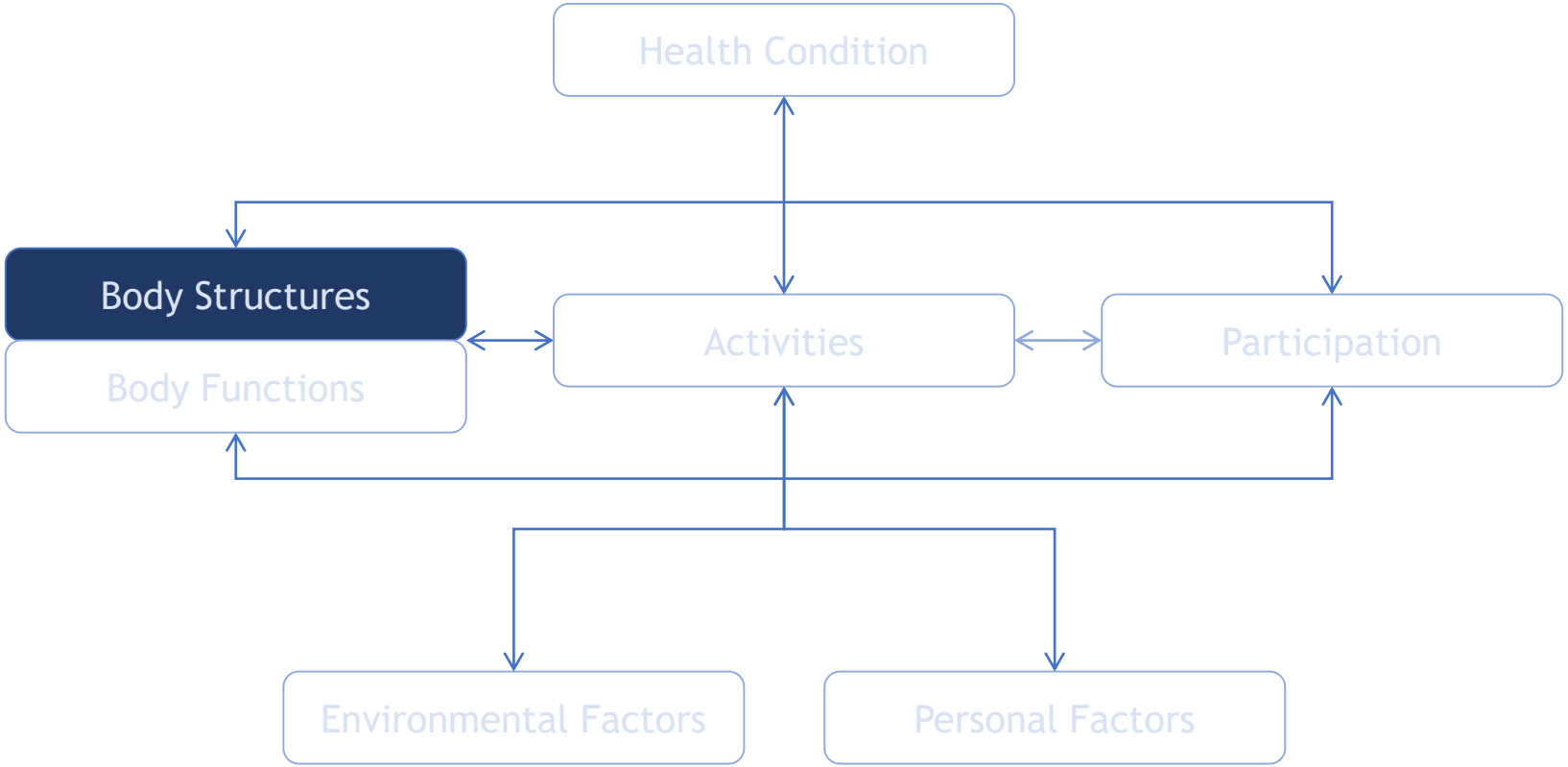
Good quality of life

- Good Health
- Rewarding Relationships
- Economic Security
- Opportunity
- Fair treatment
- …

International Classification of Functioning, Disability, and Health

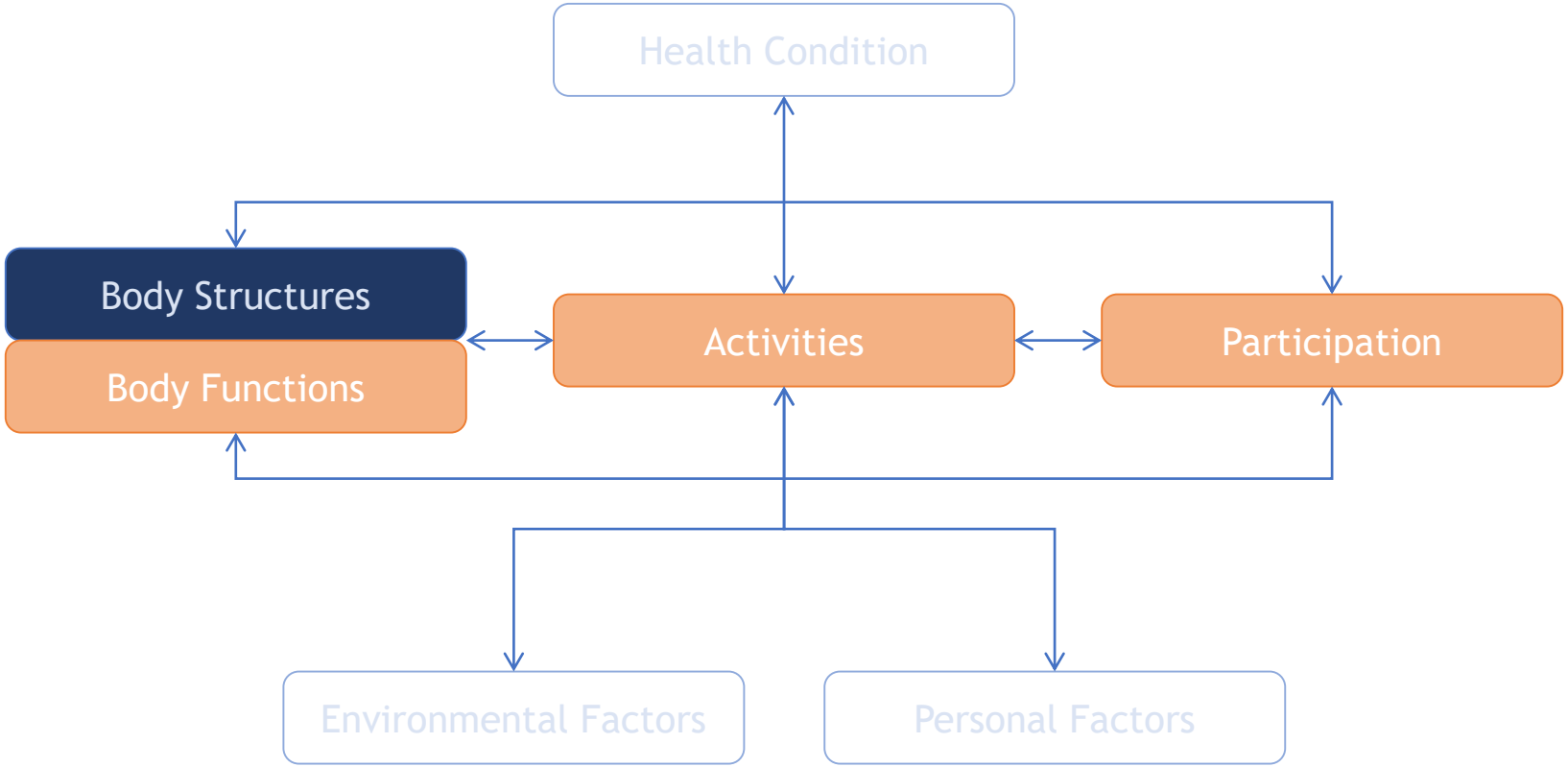


What Do We Treat?



What Do We Assume?

"Trickle-Down"



We Ask Patients

What They Can Do

What Their Goals Are

The GOAL

Gait Pattern and Appearance

- Taller
- Feet flat / straight ahead / dragging
- Tripping / Falling
- …

Gait Function and Mobility

- Getting around at home / school - indoors
- Getting up and down slopes / stairs
- Obstacles / slippery surfaces / uneven ground
- …

Activities of Daily Living and Independence

- Picking up an object
- Standing at a sink
- …

Pain, Discomfort, and Fatigue

- Feeling tired while walking
- Pain in the back, feet, legs, …
- …

Body Image and Self-Esteem

- Treated by others
- Shape/position of feet / legs
- Way you get around compared to others
- …

Activities, Sports, and Recreation

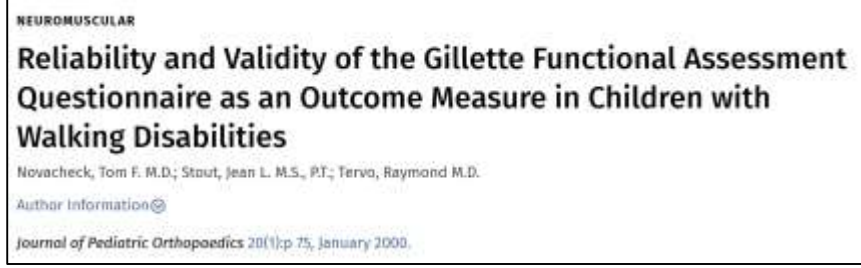
- Climbing
- Running in sport / Running as sport
- Balance
- …

Braces and Mobility

- Using a walking aid
- Using a wheelchair
- …

The FAQ and FAQt

Functional Assessment Questionnaire (and transform)


NEUROMUSCULAR

Reliability and Validity of the Gillette Functional Assessment Questionnaire as an Outcome Measure in Children with Walking Disabilities

Novacheck, Tom F. M.D.; Stout, Jean L. M.S., P.T.; Tervo, Raymond M.D.

Author Information

Journal of Pediatric Orthopaedics 20(1):p 75, January 2000.

FAQ

Overall walking scale

22 Mobility Skills

- Example: stairs, stepping off curb, riding bicycle, etc…

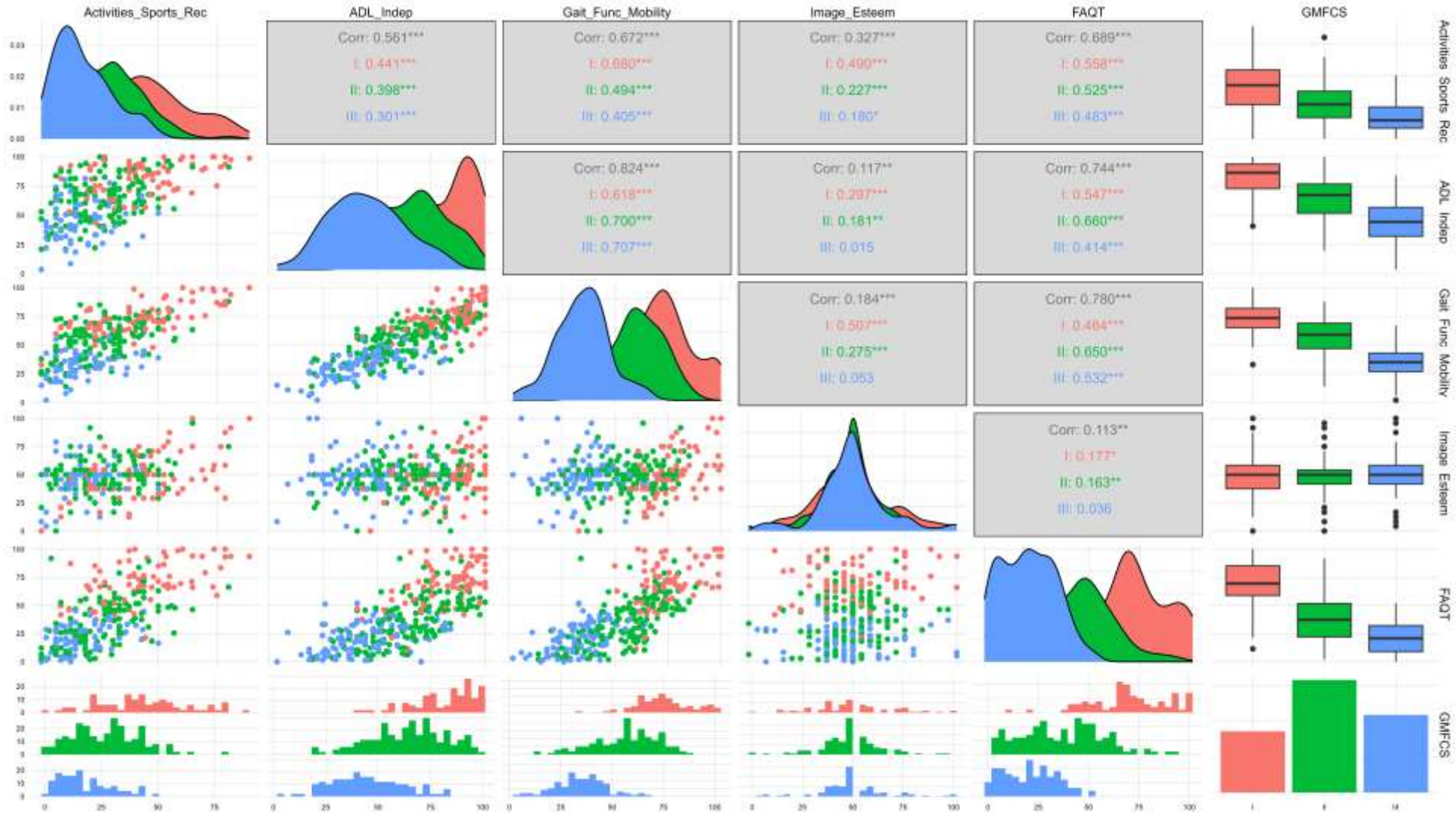
FAQt

Sum difficulty rating of all skills individual is able to perform

- Difficulty from Rasch analysis
  Gorton GE, et al. Dev Med Child Neurol. (2011) **53**(3):250-5.

Final Score on 0 – 100 point scale

GOAL - FAQt - GMFCS

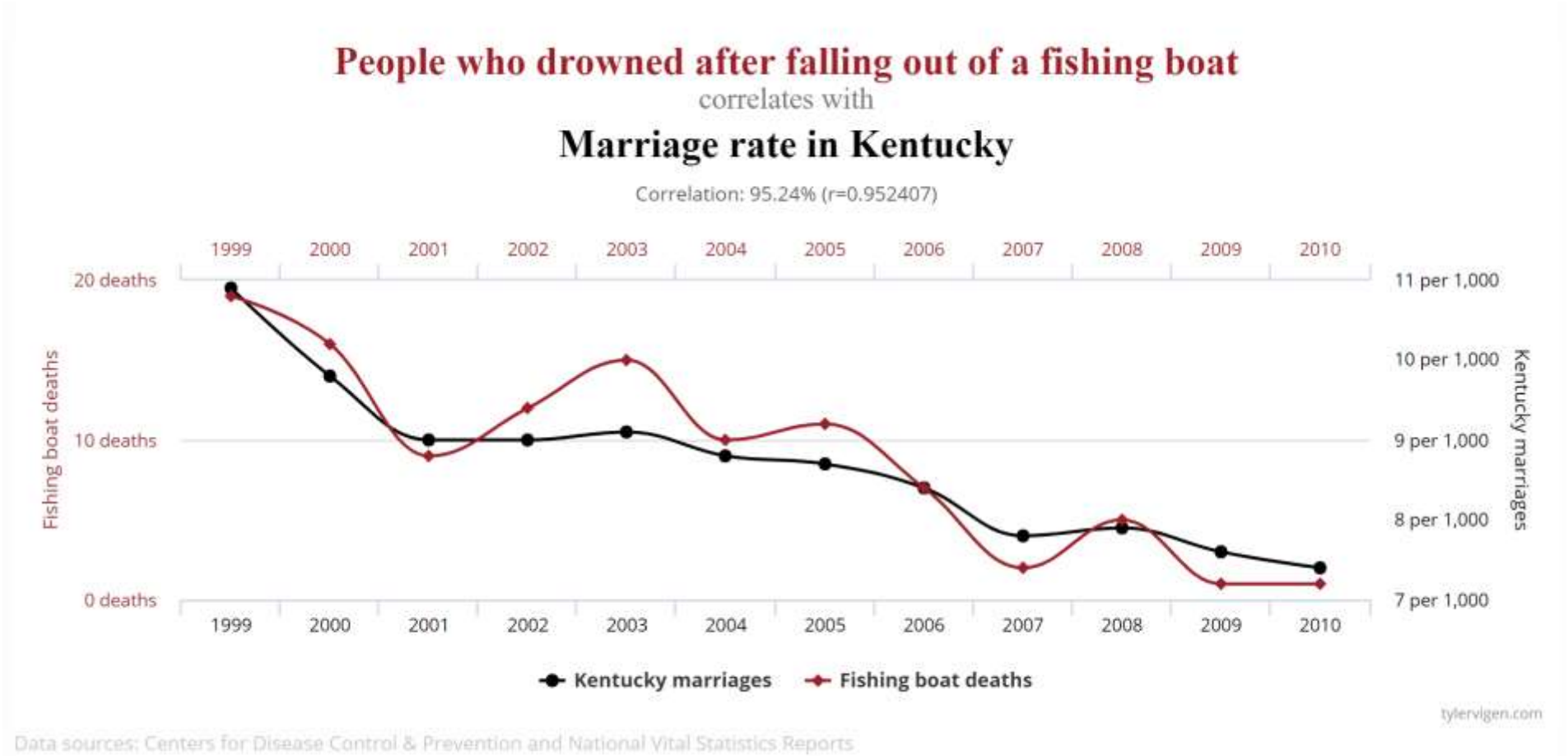


What Can We Deliver?

A Causal Analysis

The Importance of Causal Thinking and Analysis

Correlation Does Not Equal Causation



Correlation Does Not Equal Causation

This Rule Applies to Cerebral Palsy

Children with spasticity
use a lot of energy to walk

Children with excess femoral anteversion
have weak hip abductors

Children with anterior pelvic tilt
have back pain

Children with gait impairments
have diminished quality-of-life

All statements are true

That does not mean
A causes B

Formal Causal Modeling

Tools for estimating causality from observational data

Provide a scientific basis for treatment decisions

- Will treatment X improve impairment Y in patient Z?

All causal modeling methods rely on "*counterfactual*" estimates

- What would have happened to patient without treatment?

How much would crouch have improved without a patellar advancement?

> Sci Rep. 2022 May 12;12(1):7818. doi: 10.1038/s41598-022-11875-5.

Short-term causal effects of common treatments in ambulatory children and young adults with cerebral palsy: three machine learning estimates

Michael H Schwartz [1 2 3], Andrew J Ries [4], Andrew G Georgiadis [4 5]

Affiliations + expand

PMID: 35551496 PMCID: PMC9098860 DOI: 10.1038/s41598-022-11875-5

How Well Do Treatments Work?

Three Rigorous Machine Learning Methods

Matching

- Match treated (cases) and untreated (control) on key features (e.g., age, GMFCS, spasticity, …)

Virtual Twins

- Predict outcome based on key features and treatment

Bayesian Causal Forests

- Predict outcome based on treatment effect and natural history

GDI = $f(x_1, x_2, \ldots, Rx_1, Rx_2, Rx_3 \ldots)$

$GDI_{treat} = f(x_1, x_2, \ldots, Rx_1, \mathbf{Yes\text{-}Rx_3}, \ldots)$
$GDI_{cont} = f(x_1, x_2, \ldots, Rx_1, \mathbf{No\text{-}Rx_3}, \ldots)$

Effect = $GDI_{treat} - GDI_{cont}$

$$y = \mu(x, \pi_z(x)) + \tau(x)z$$

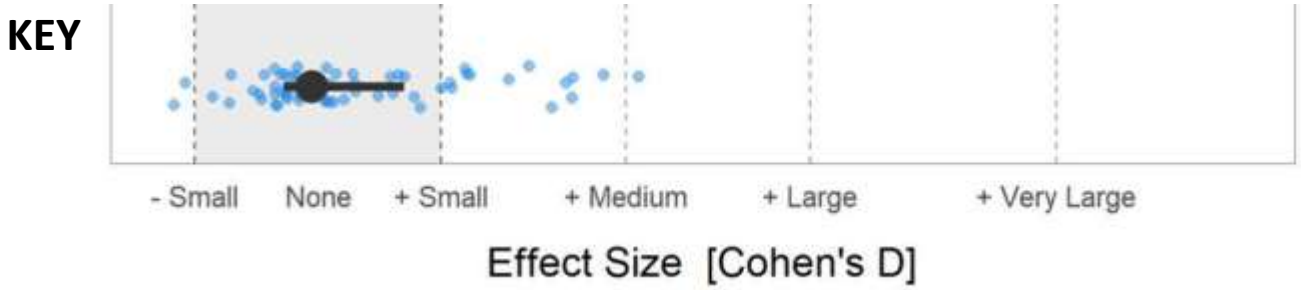
Treatment status

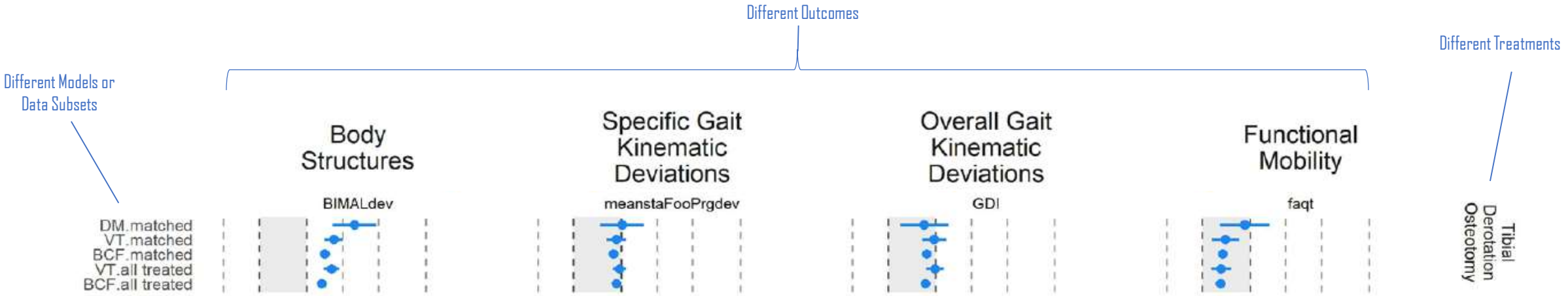
Natural History

Treatment

Results

Key to Results





Body Structure

Large+ effects

- Femoral Derotation
- Selective Dorsal Rhizotomy

Medium - Large effects

- Hamstrings Lengthening
- Patellar Advancement
- Distal Femoral Extension Osteotomy,
- Foot and Ankle Bony Surgery

Small - Medium effects

- Rectus Transfer,
- Tibial Derotation Osteotomy,
- Calf Muscle Lengthening

Focal Gait

Large+ effects

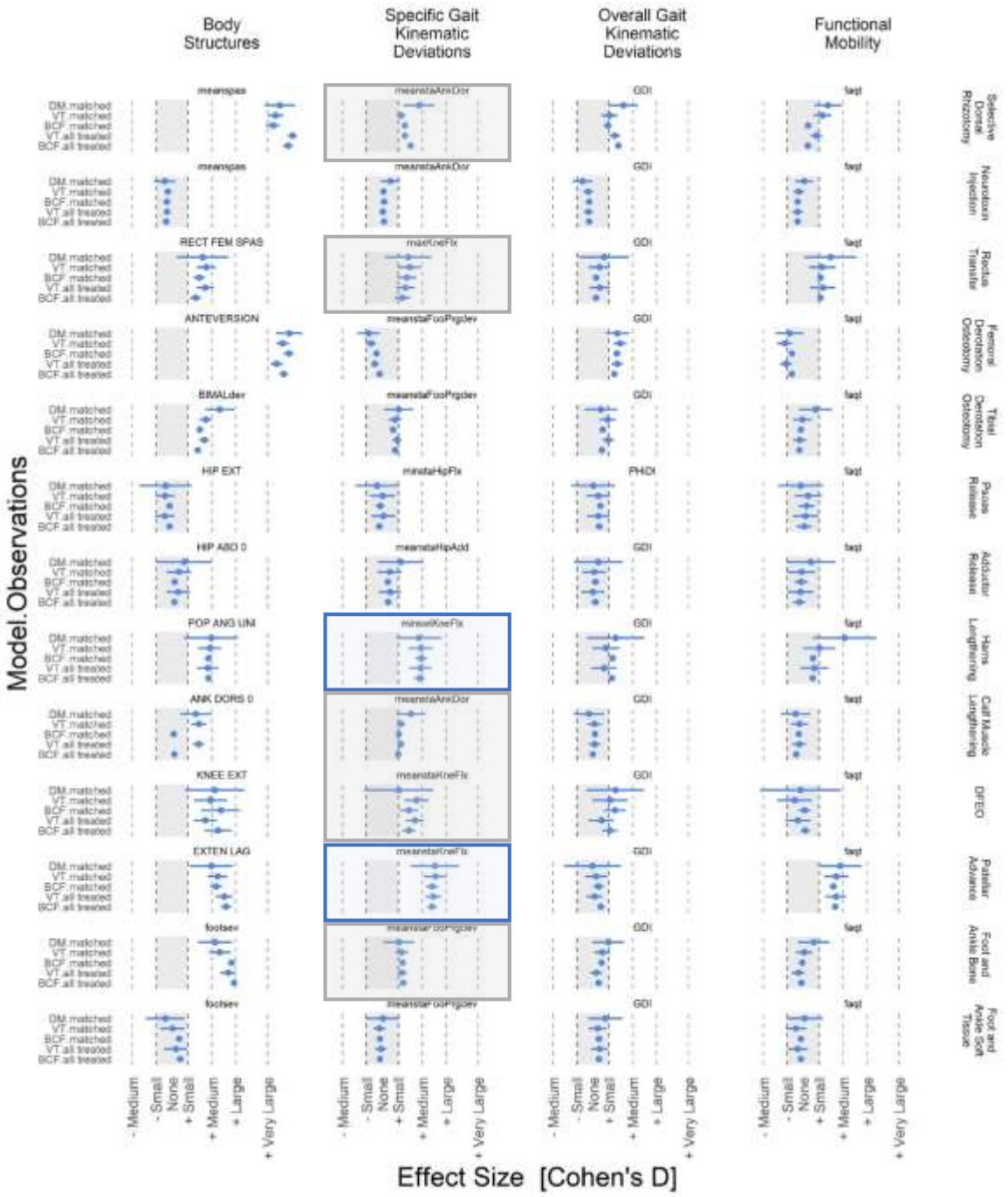
- [None]

Medium - Large effects

- Hamstrings Lengthening
- Patellar Tendon Advancement

Small - Medium effects

- Rectus Transfer
- Tibial Derotation Osteotomy
- Calf Muscle Lengthening



Overall Gait

Large+ effects

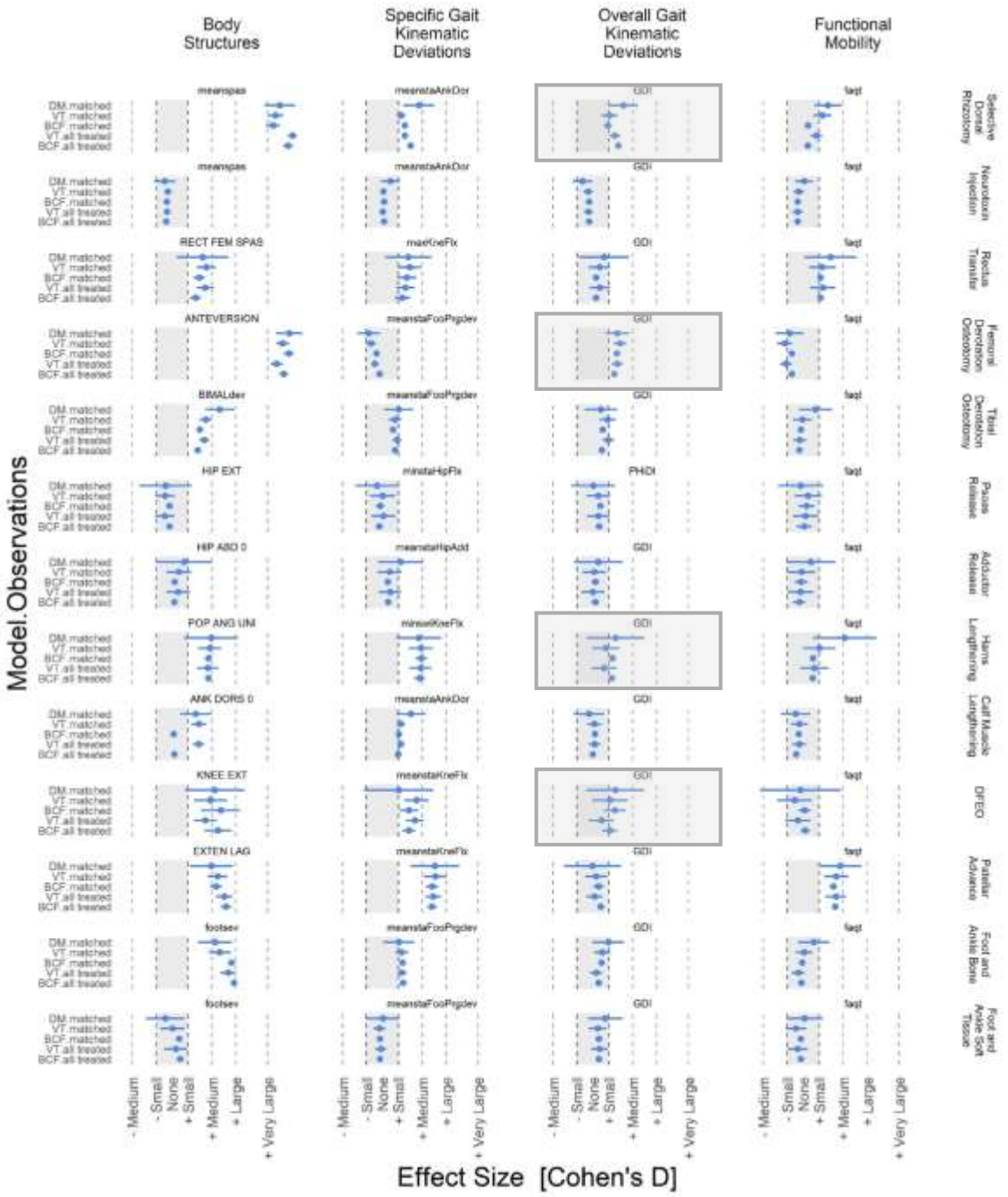
- [None]

Medium – Large effects

- [None]

Small - Medium effects

- Selective Dorsal Rhizotomy
- Femoral Derotation Osteotomy
- Hamstrings Lengthening
- Distal Femoral Extension Osteotomy



Mobility

Large+ effects

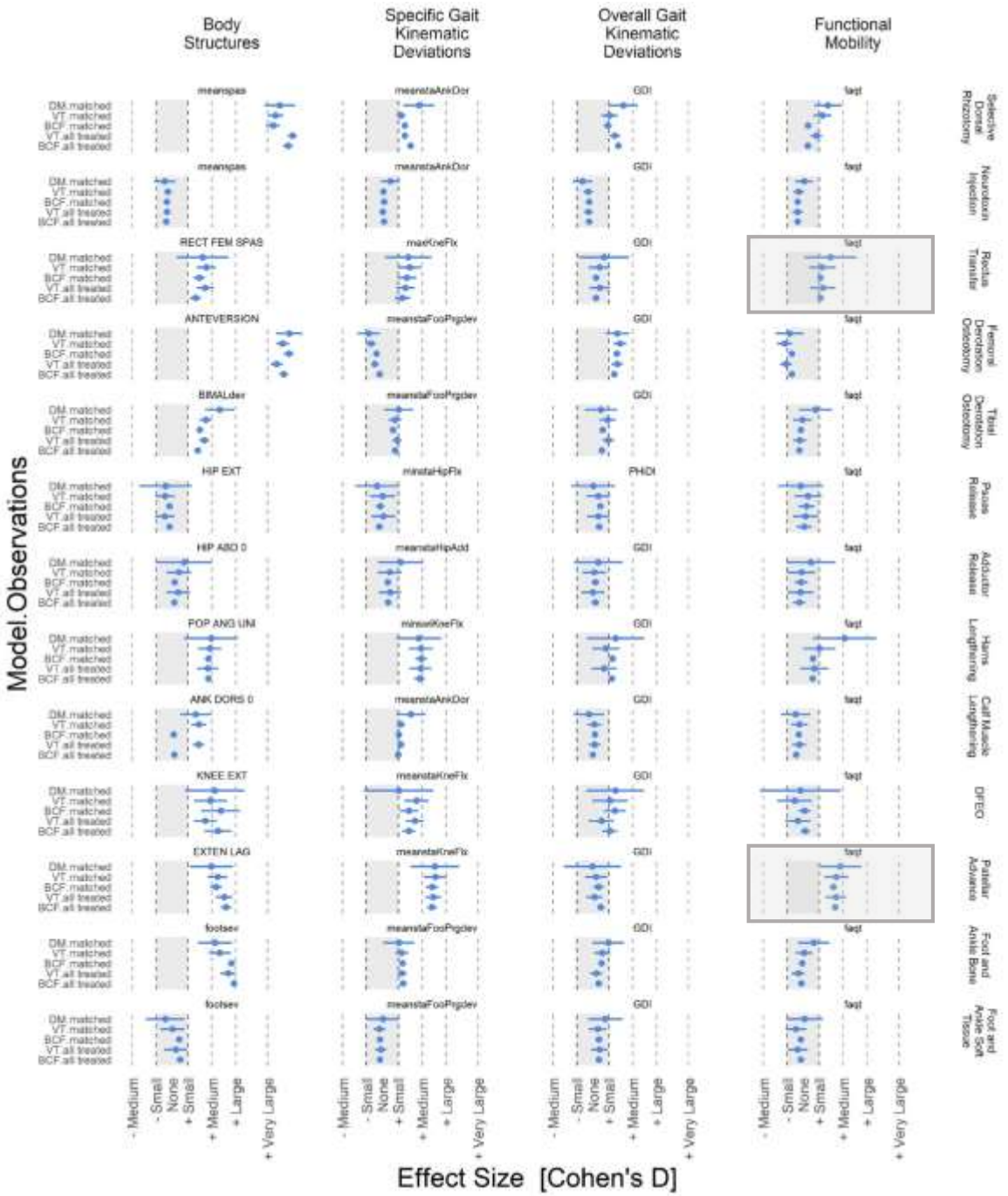
- [None]

Medium – Large

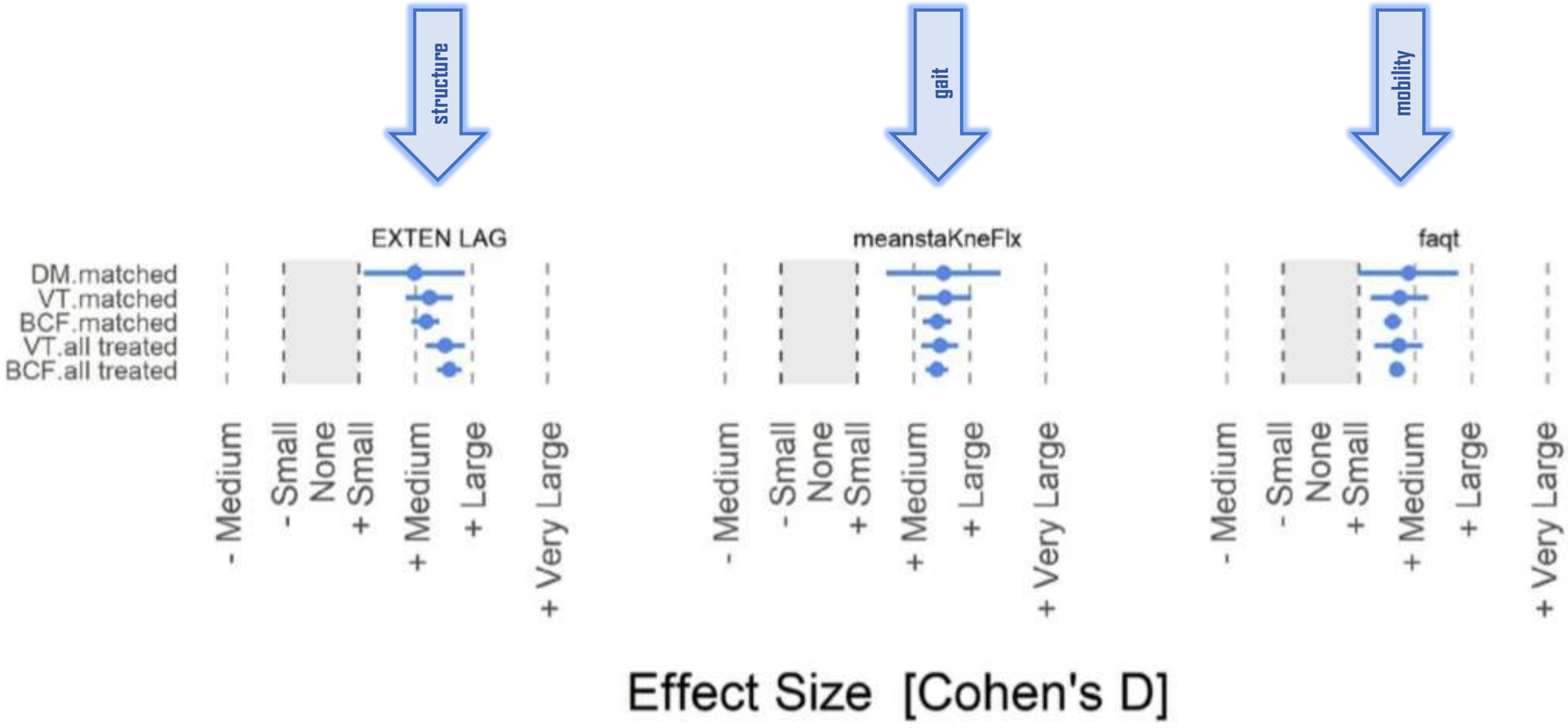
- [None]

Small - Medium effects

- Patellar Tendon Advancement
- Rectus Transfer

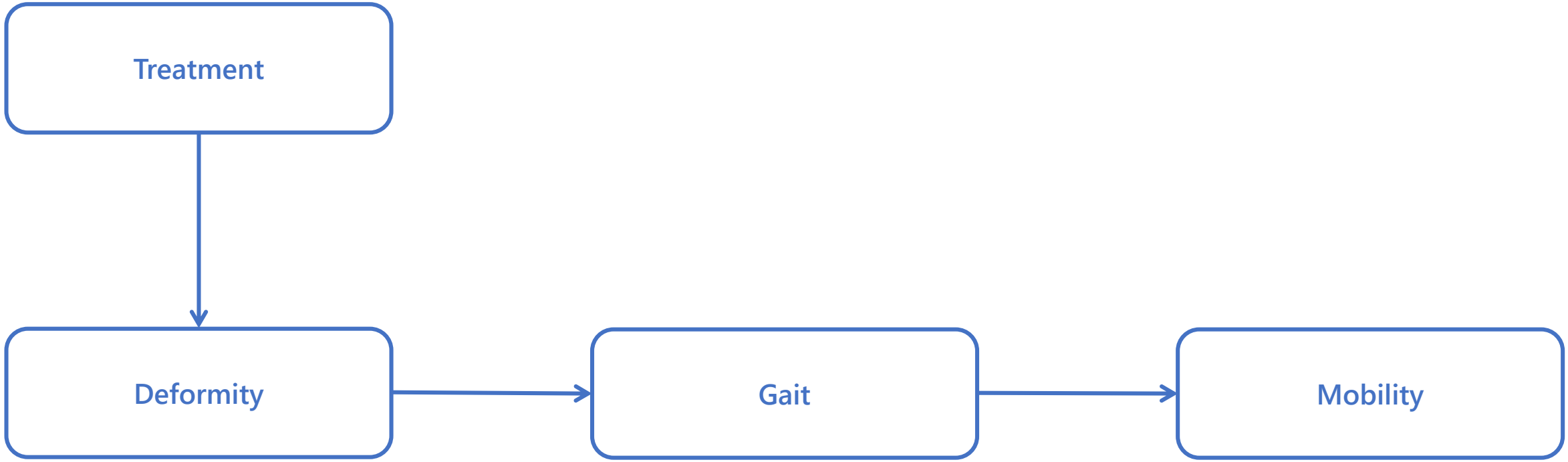


Patellar Advancement

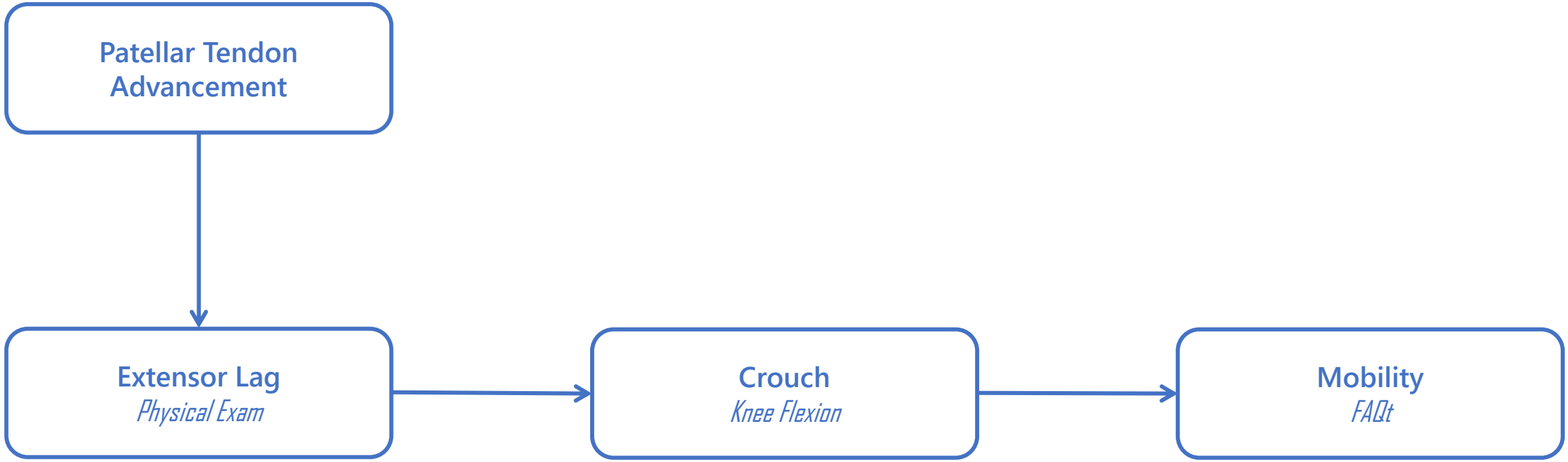


Why Do Treatments Work (or Not Work)?

To Improve Downstream Effects, Treat Underlying Cause



Causal Mechanism for PTA Affecting Mobility



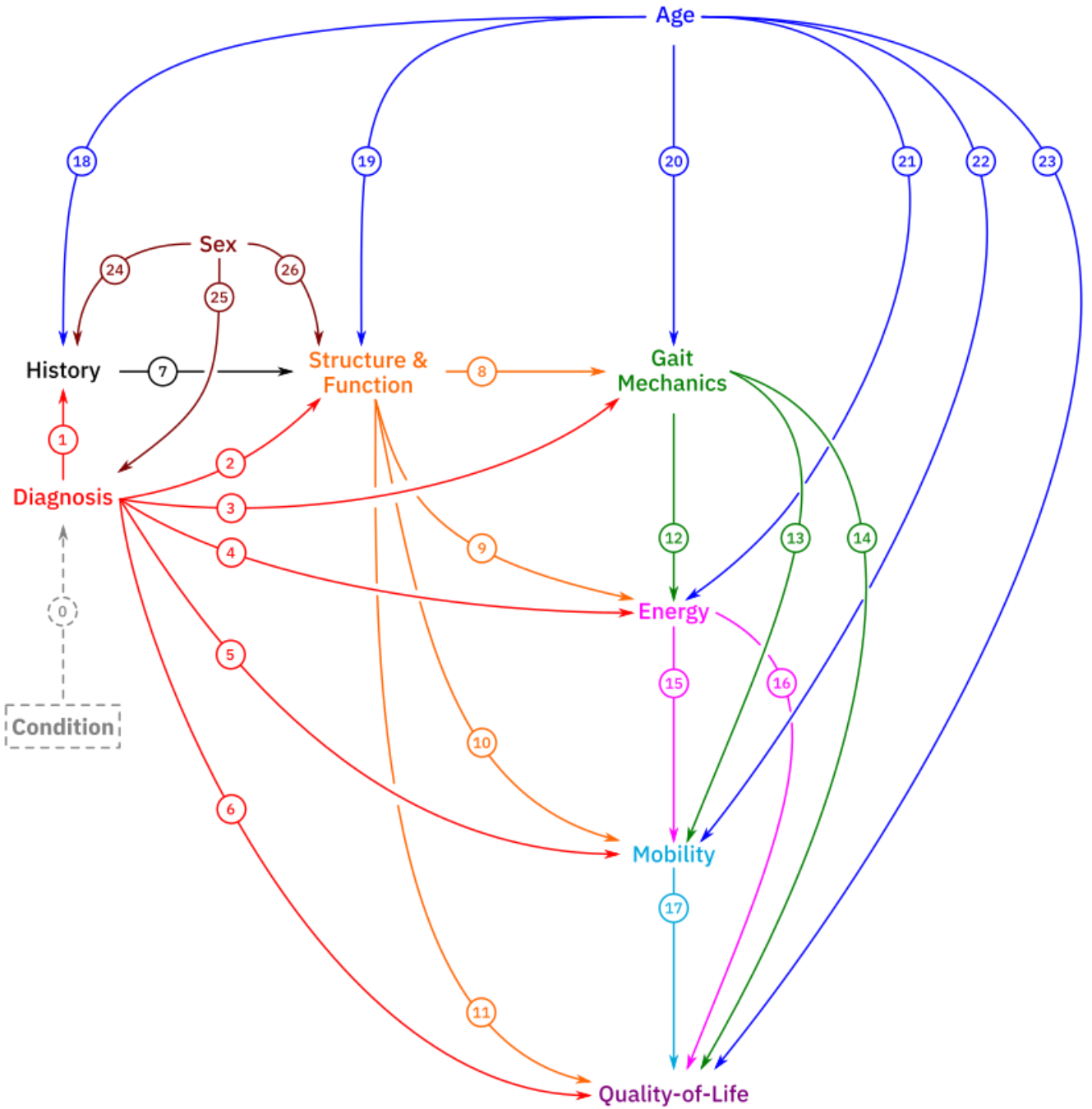
Structural Causal Model

explicit list of assumptions

- Directed acyclic graph (DAG)

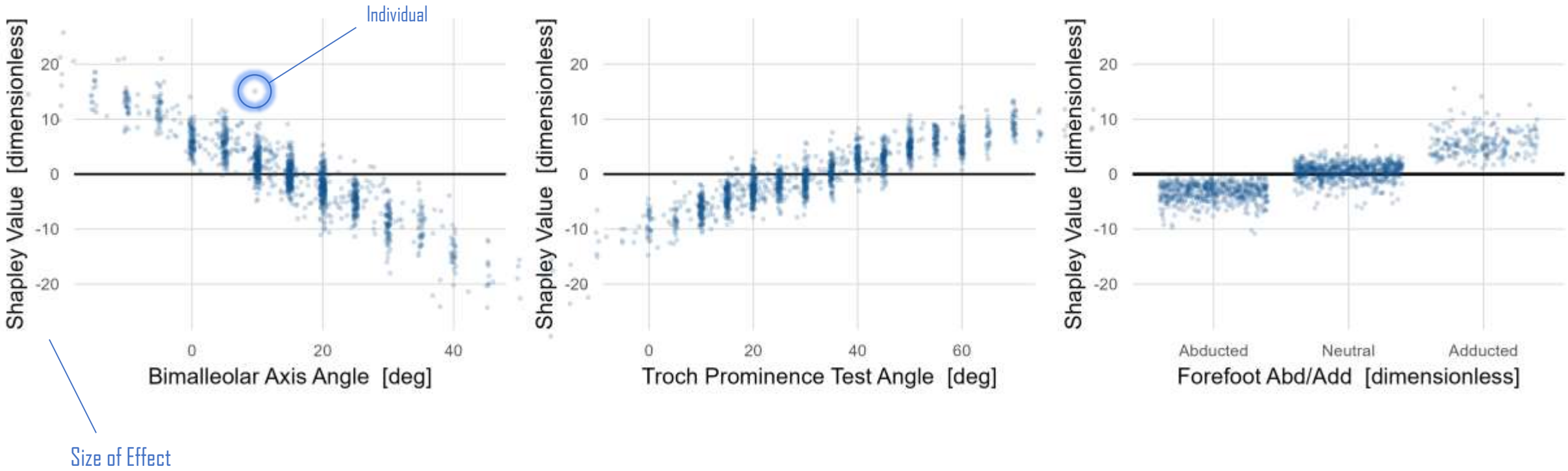
Mathematically rigorous rules identify "adjustment set"

- *"To find the causal effect of X on Y, we need to **adjust for** z1, z2, z3, ..."*

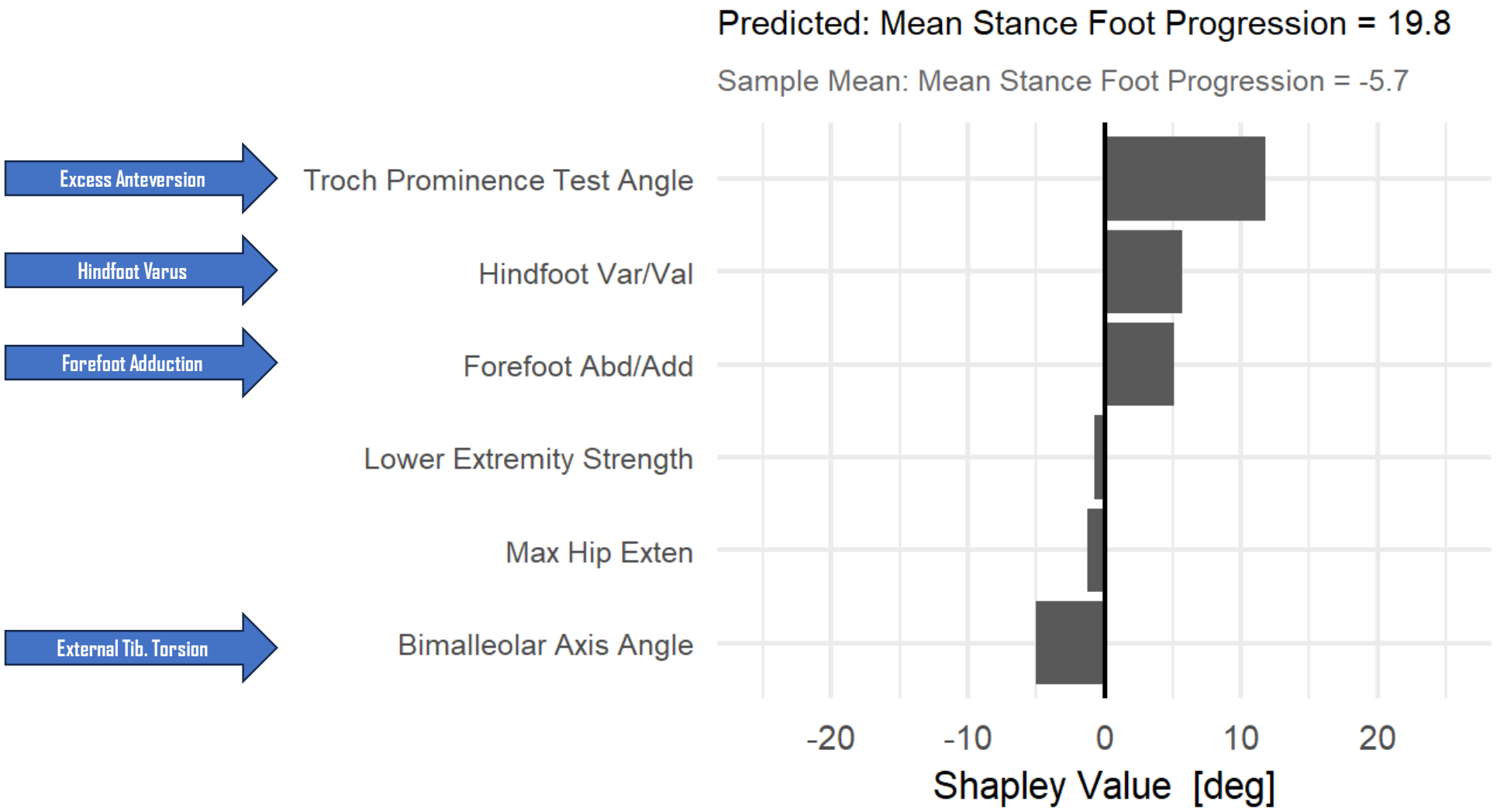


Outputs of Structural Causal Model

effects of structural deformity on foot progression

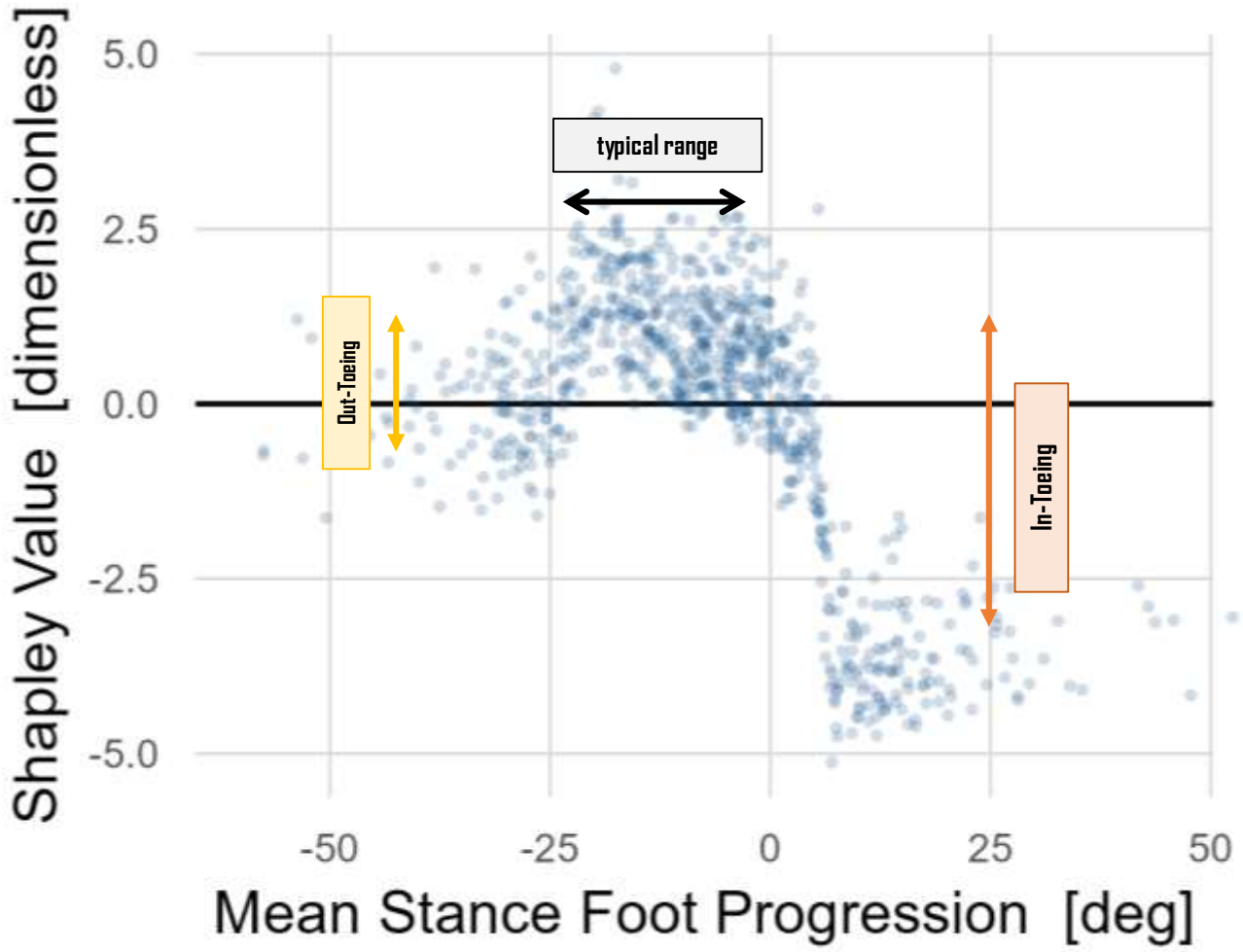


Contribution of Specific Deformities for Individual Patients



Outputs of Structural Causal Model

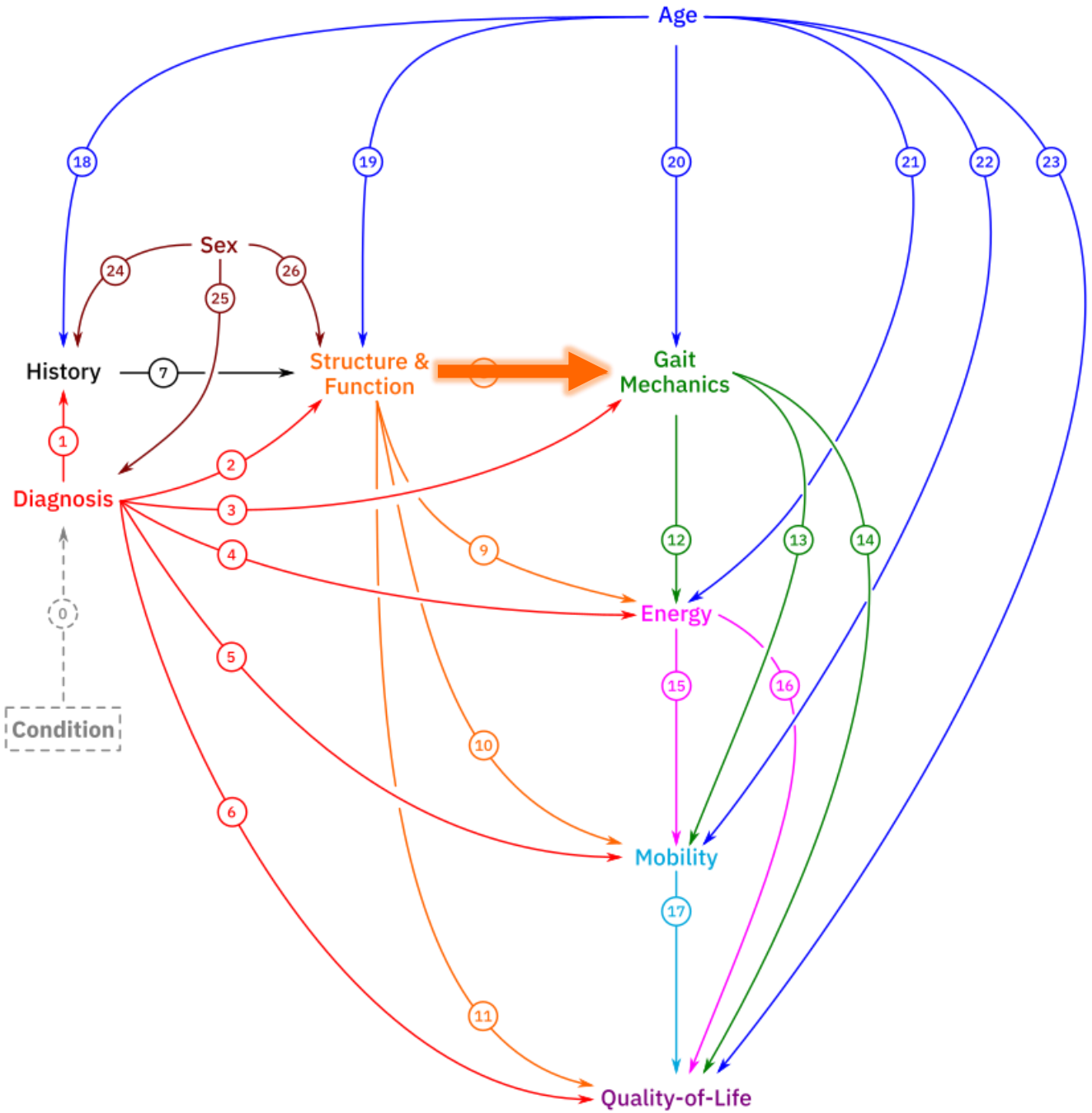
effects of foot progression on body image and self-esteem



Example

Extensor Lag → Crouch → Mobility

What **Body Structure** factors cause **Crouch**?



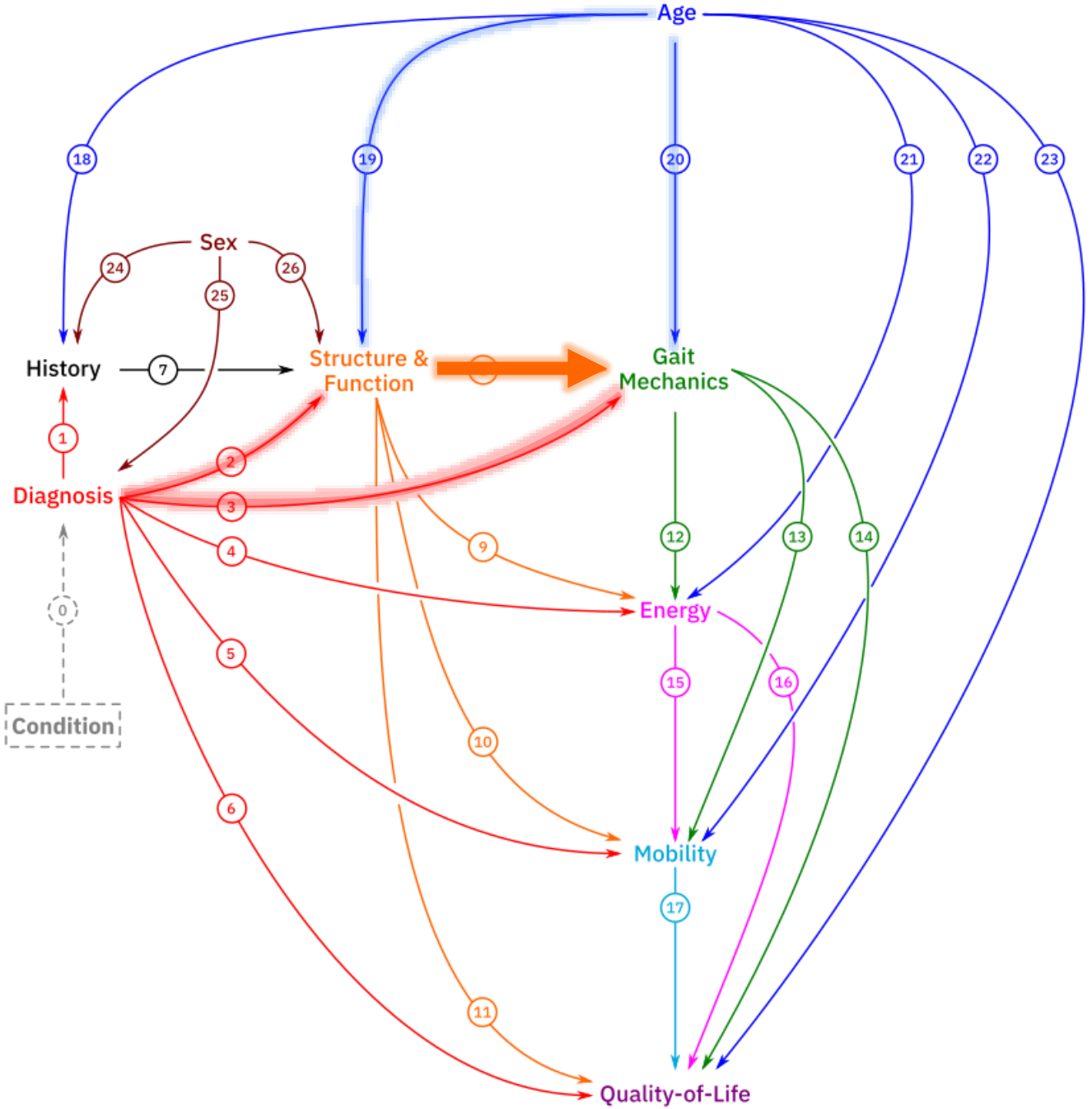
Find the adjustment set

Variable of Interest (X):
Extensor Lag

Outcome of Interest (Y):
Mean Stance Knee Flexion

Need to adjust for (z) …

- *Age*
- *Diagnosis*
- *Structure and Function*
  - *Lower Extremity Strength*
  - *Lower Extremity Static Motor Control*
  - *Lower Extremity Spasticity*
  - *Dynamic Motor Control*
  - *Max Hip Flex,*
  - *Max Hip Exten,*
  - *Max Hip Abd,*
  - *Popliteal Angle,*
  - *Max Knee Flex,*
  - *Max Knee Exten*
  - *Bimalleolar Axis Angle*
  - *Max Ankle Dorsiflex,*
  - *Max Ankle Plantarflex*
  - *Forefoot Var/Val*
  - *Forefoot Abd/Add*
  - *Hindfoot Var/Val*
  - *Midfoot Cavus/Planus*
  - *Troch Prominence Test Angle*

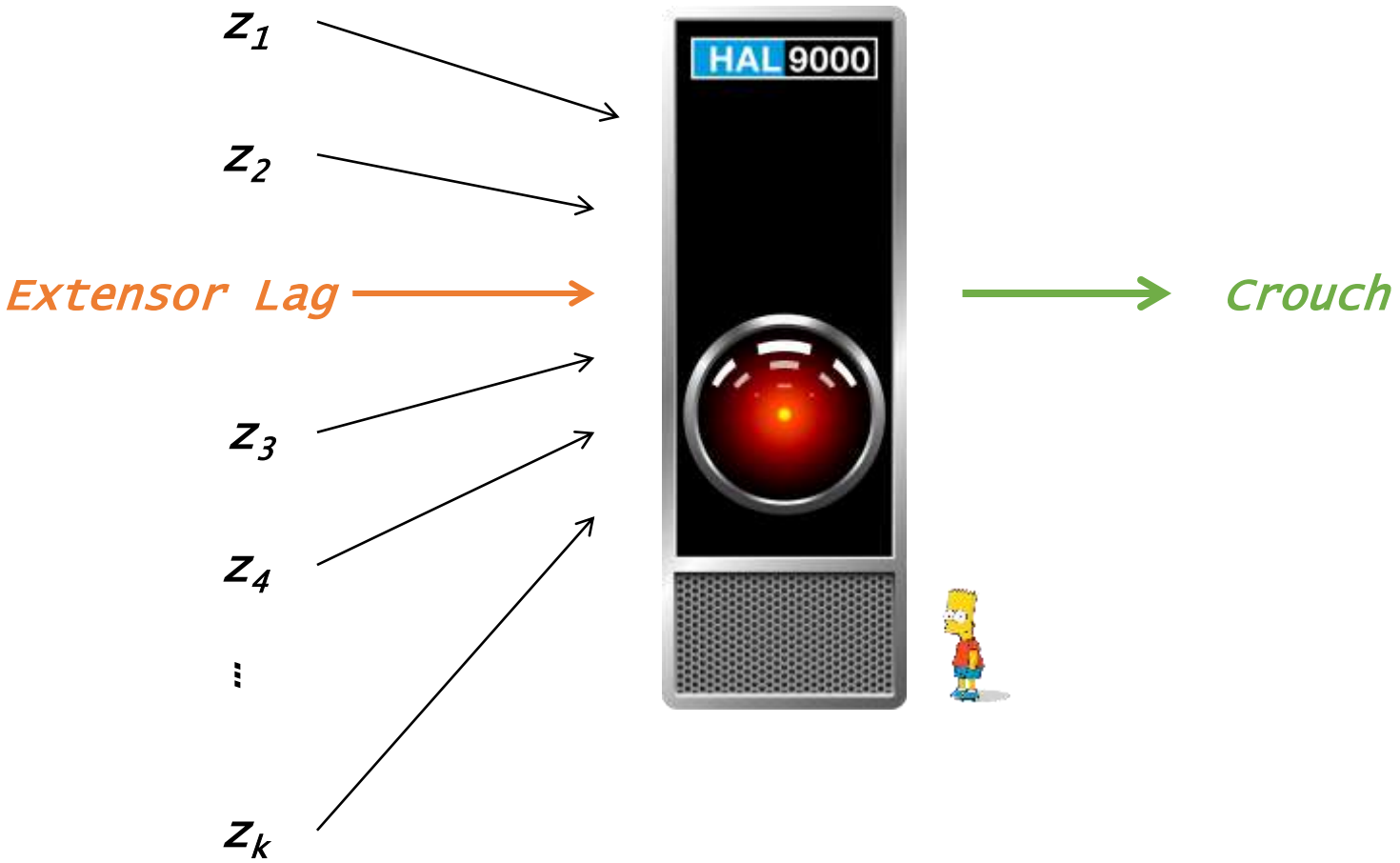


Predict Outcome

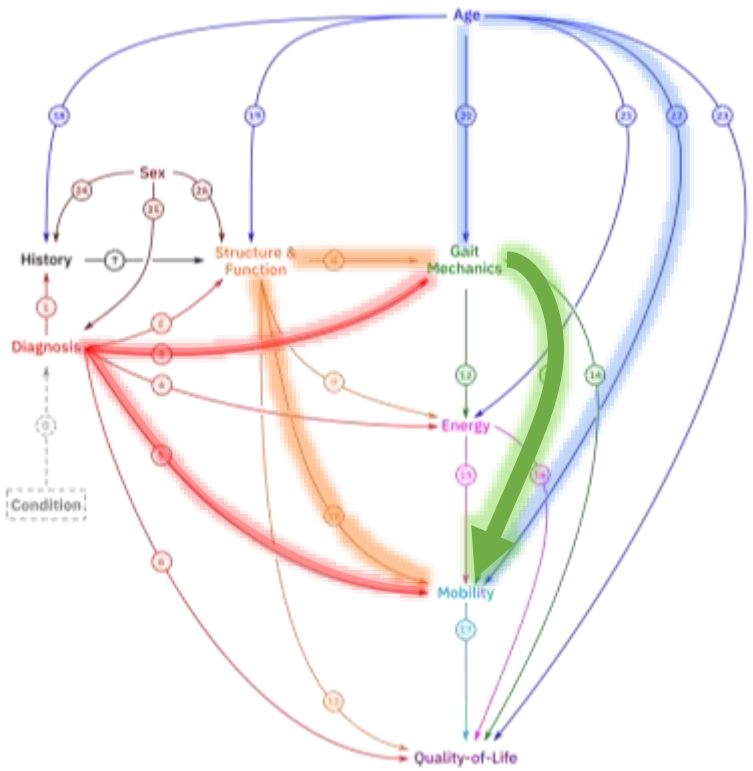
$$Crouch = f(Extensor\ Lag, z_1, z_2 \ldots z_k)$$

Build prediction model

- Bayesian Additive Regression Trees



How much does Crouch affect Mobility?



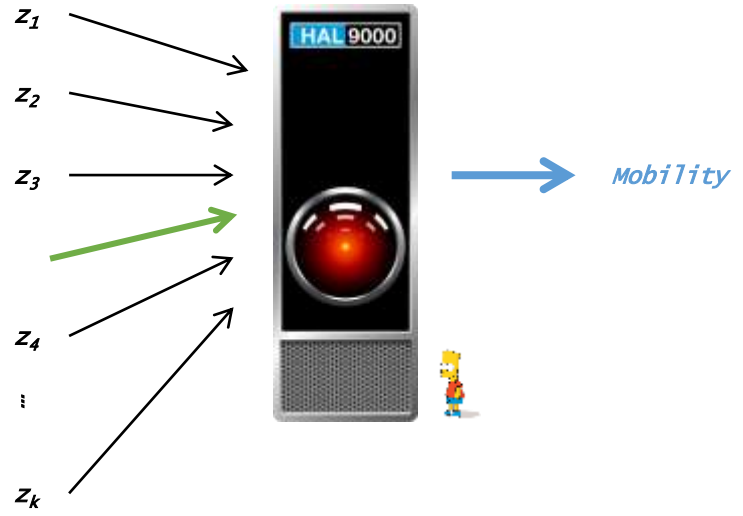
Variable of Interest (X):
Mean Stance Knee Flexion

Outcome of Interest (Y):
FAQt

Need to adjust for (z) …

- *Age*
- *Diagnosis*
- *Structure and Function*
  - *Lower Extremity Strength*
  - *Lower Extremity Static Motor Control*
  - *Lower Extremity Spasticity*
  - *Dynamic Motor Control*
  - *Max Hip Flex,*
  - *Max Hip Exten,*
  - *Max Hip Abd,*
  - *Popliteal Angle,*
  - *Max Knee Flex,*
  - *Max Knee Exten*
  - *Bimalleolar Axis Angle*
  - *Max Ankle Dorsiflex,*
  - *Max Ankle Plantarflex*
  - *Forefoot Var/Val*
  - *Forefoot Abd/Add*
  - *Hindfoot Var/Val*
  - *Midfoot Cavus/Planus*
  - *Troch Prominence Test Angle*
- *The rest of Gait Mechanics*
  - *Other kinematics at Knee*
  - *Kinematics at Pelvis, Hip, Ankle, and Foot*

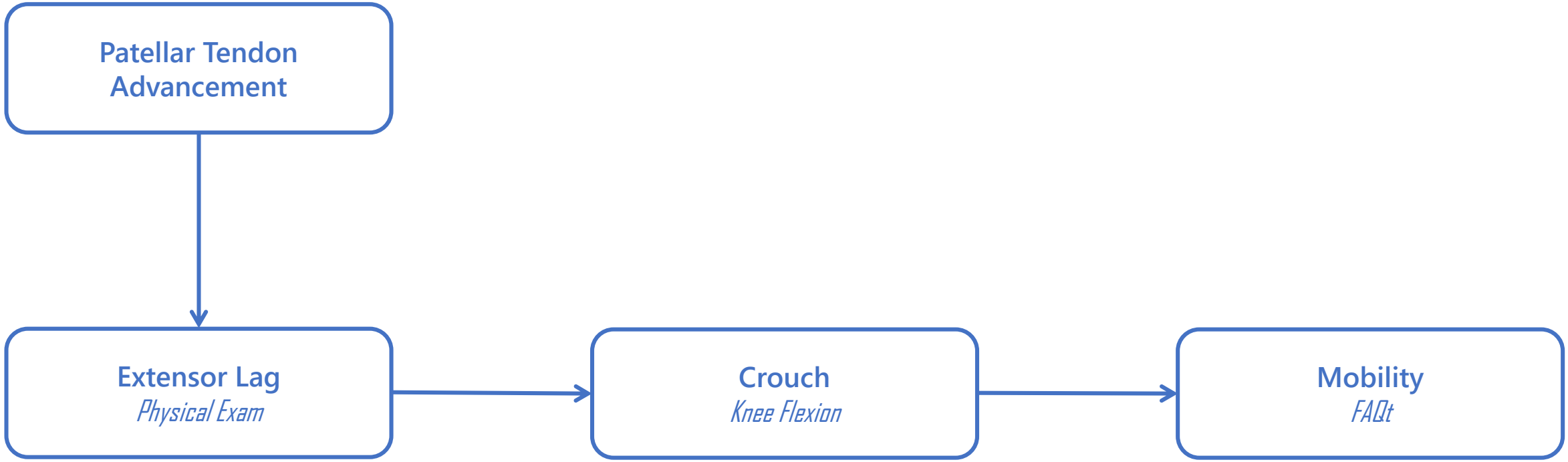
$Mobility = f(Crouch, z_1, z_2 \dots z_k)$



Example

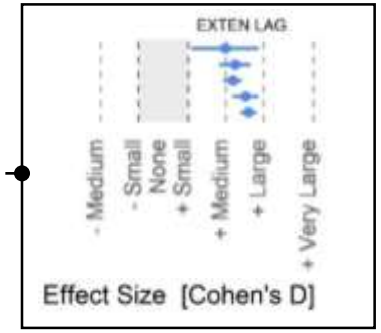
Effect of crouch on mobility

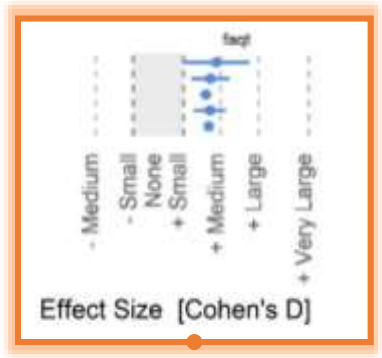
Causal Mechanism for PTA Affecting Mobility



Causal Mechanism for PTA Affecting Mobility

Patellar Tendon Advancement

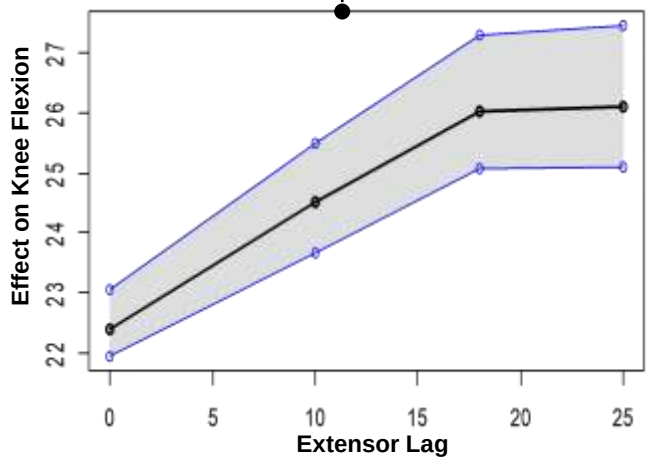


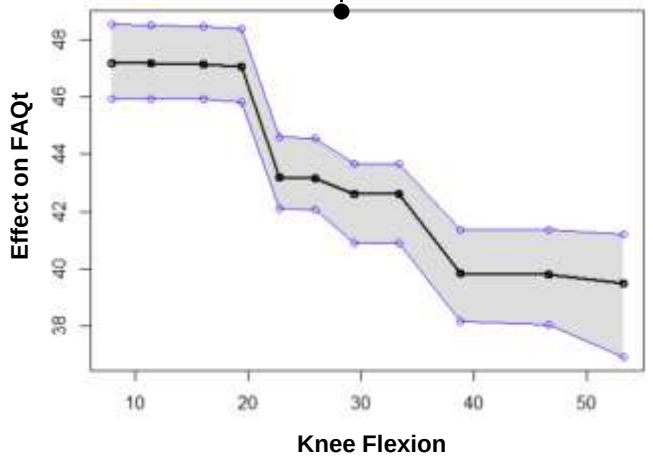


Extensor Lag
Physical Exam

Crouch
Knee Flexion

Mobility
FAQt





Case Example

11 yo, GMFCS III, Diplegia, Crouch

What is important to the child/family?

In their words (handwritten comments):

Concerns

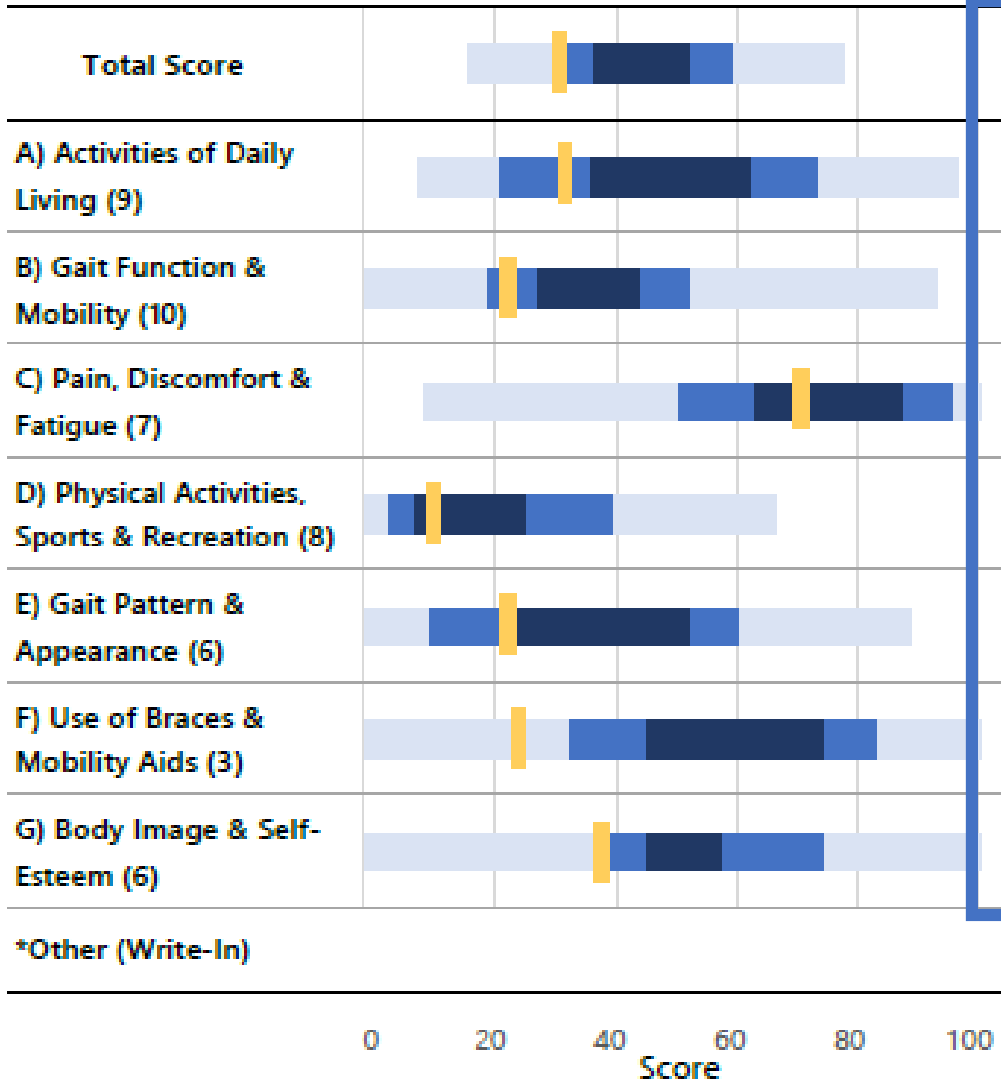
- Significant decline in walking ability over last 2-3 months

Current Goals

- Regain ability and stamina to walk with crutches
- Regain ability to stand independently
- Use AFOs less

What is important to the child/family?

How this child compares to others at GMFCS III level



	Percentile	Importance			Missing/ No Chance
		Very	Some	None	
Total Score	6	13	22	17	0/0
A) Activities of Daily Living (9)	22	2	7	1	0/0
B) Gait Function & Mobility (10)	15	6	3	1	0/0
C) Pain, Discomfort & Fatigue (7)	31	0	2	5	0/0
D) Physical Activities, Sports & Recreation (8)	28	0	3	5	0/0
E) Gait Pattern & Appearance (6)	23	3	3	1	0/0
F) Use of Braces & Mobility Aids (3)	6	0	2	1	0/0
G) Body Image & Self-Esteem (6)	18	1	2	3	0/0
*Other (Write-In)		1	0	0	

What is important to the child/family?

GOAL items

Very Important Items

Activities of Daily Living	A: Standing at a sink or counter (Extremely Difficult / Impossible)
	*A: Walking without assistive device (Extremely Difficult / Impossible)
Gait Function and Mobility	B: Walking for more than 250 meters (Very Difficult)
	B: Getting around at home (Slightly Difficult)
	B: Walking for more than 15 minutes (Extremely Difficult / Impossible)
	B: Walking faster than usual (Extremely Difficult / Impossible)
	B: Stepping around or avoiding obstacles (Very Difficult)
	B: Going up and down stairs (Very Difficult)
Gait Pattern and Appearance	E: Walking taller or more upright (Extremely Difficult / Impossible)
	E: Walking without tripping and falling (Extremely Difficult / Impossible)
	*E: Overall ease/ability (Very Difficult)
	G: The way he/she gets around compared with others (Very Unhappy)
	*Other: Regain independence in mobility

[redacted]

12-Oct-2021

B-Tethered Hinged AFOs

James R. Gage Center for Gait and Motion Analysis

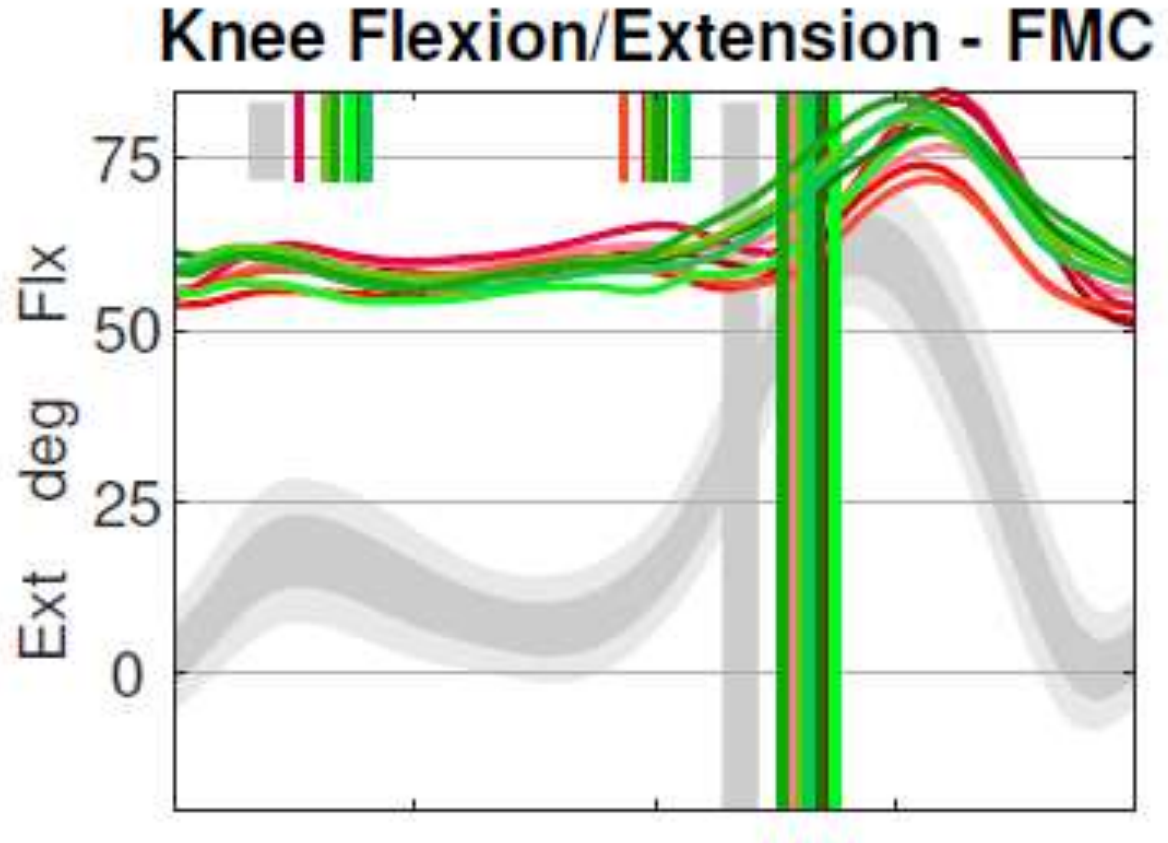
Gillette Children's Specialty Healthcare

Exam

KNEE

Extension	12	10
Flexion		
Prone	134	140
Supine	138	140
Popliteal Angle		
Unilateral	66	66
Bilateral	54	58
HS Shift	12	8
Extensor Lag	18	26
Patella Alta	Yes	Yes

Gait

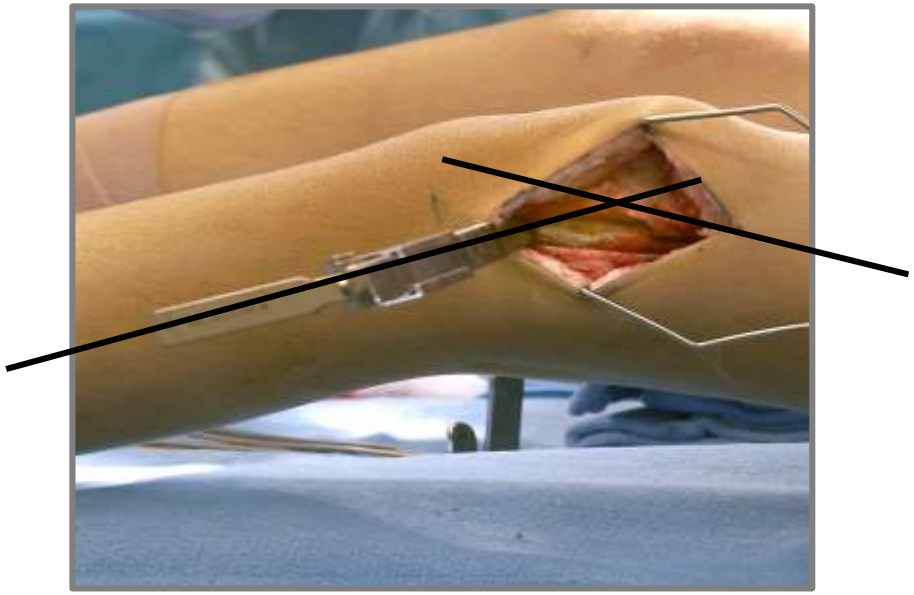


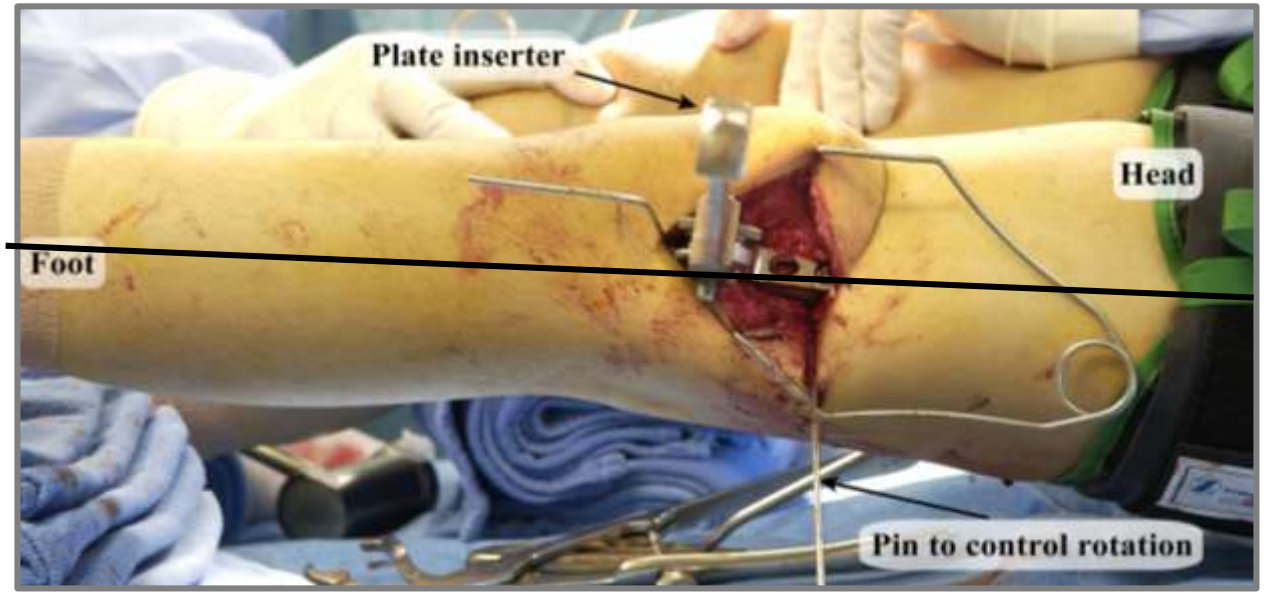
Pre-treatment

What goals can we achieve, technically?

Distal femoral extension osteotomy

Successful operation with good results in achieving knee extension in gait





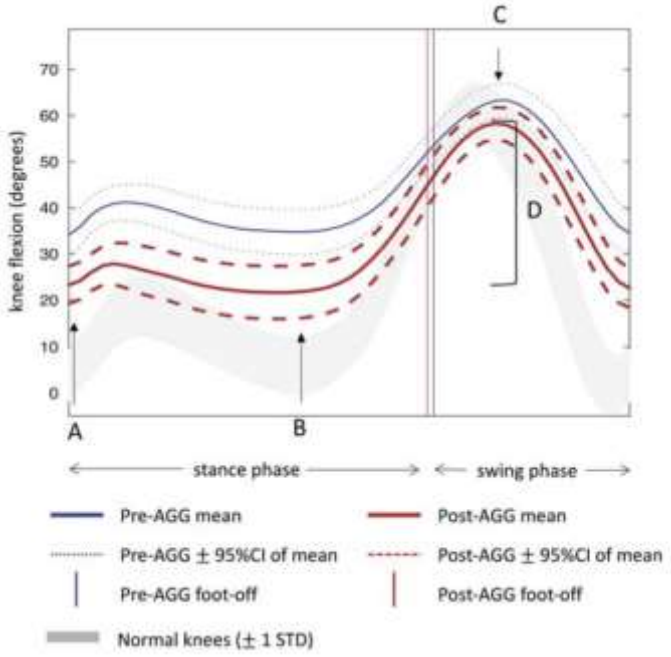
Images: Courtesy Gillette Children's Specialty Healthcare

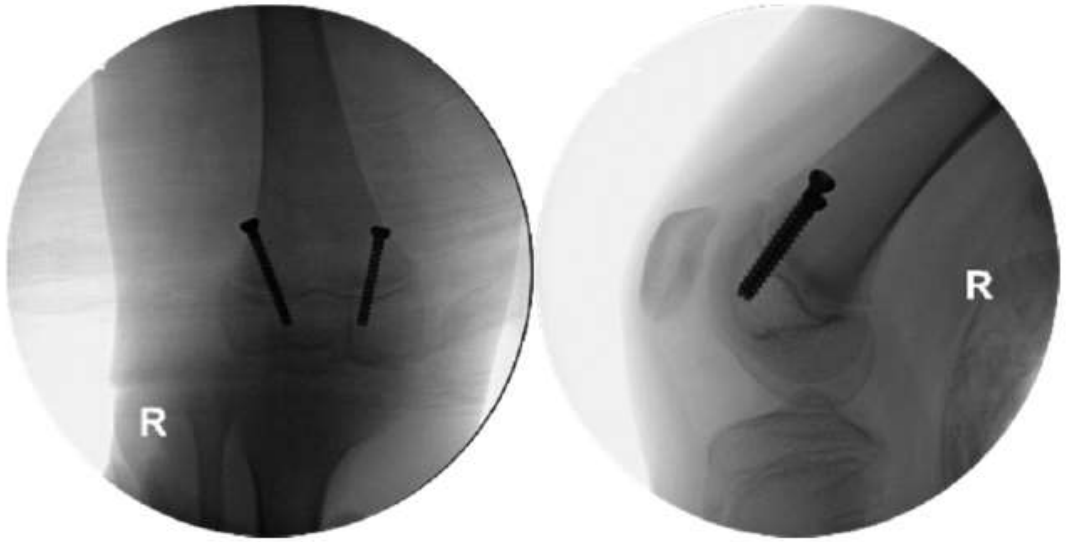
What goals can we achieve, technically?

Anterior Guided Growth of the Distal Femur for Knee Flexion Contracture: Clinical, Radiographic, and Motion Analysis Results

Kemble K. Wang, MBBS,† Tom F. Novacheck, MD,†‡§ Adam Rozumalski, PhD,‡ and Andrew G. Georgiadis, MD†‡§*

Wang et al., JPO 2018

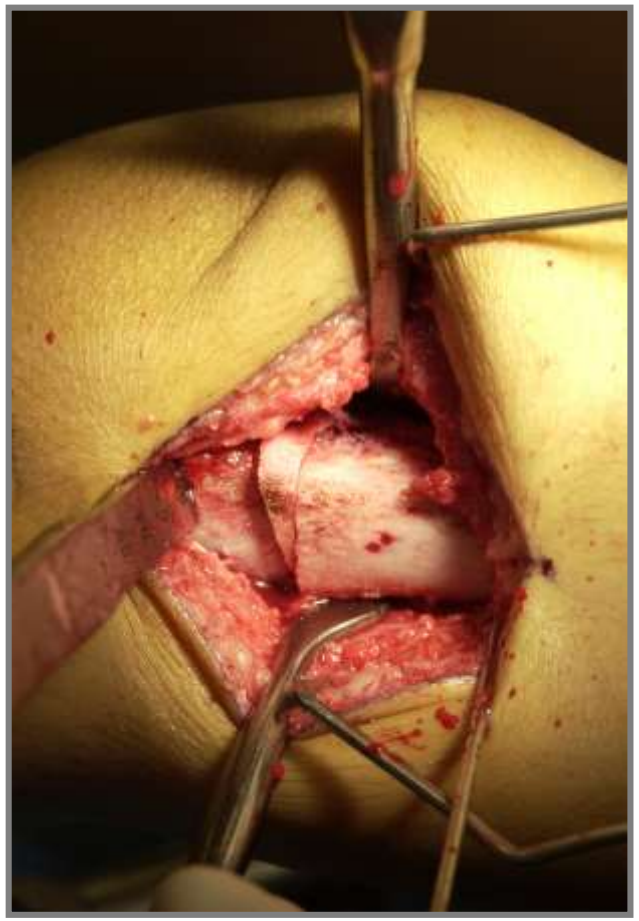




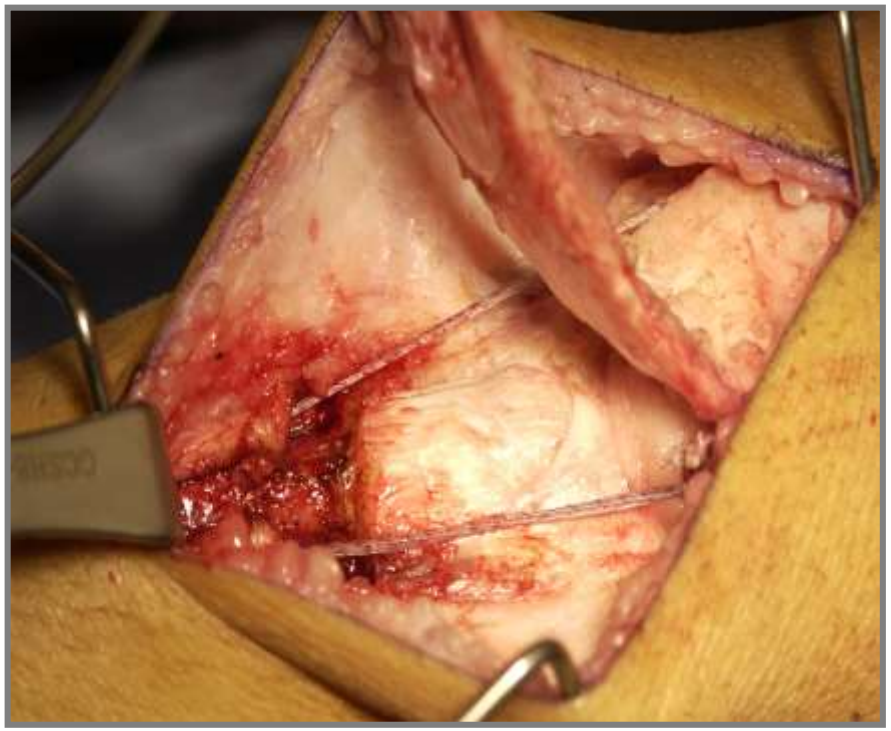
Harmer et al., JPOSNA 2022

History: DFEO & PTA at Gillette

First DFEO -- 1994



First PTA -- 1995



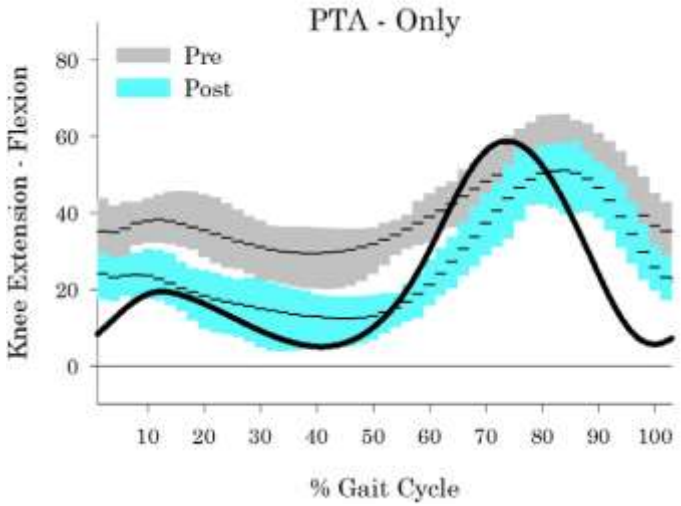
What do we know about patellar advancement?

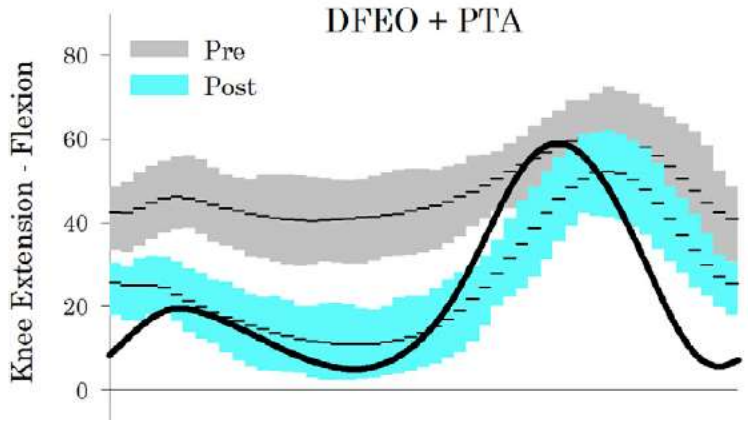
DFEO without PTA , patients will remain in crouch

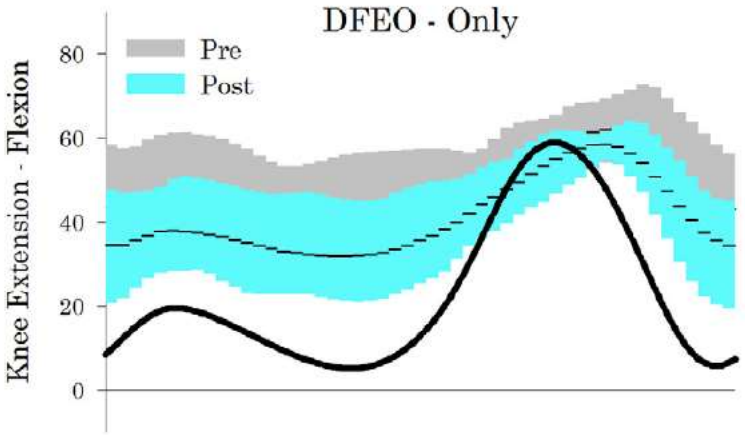
Distal Femoral Extension Osteotomy and Patellar Tendon Advancement to Treat Persistent Crouch Gait in Cerebral Palsy

By Jean L. Stout, PT, MS, James R. Gage, MD, Michael H. Schwartz, PhD, and Tom F. Novacheck, MD

Investigation performed at the Center for Gait and Motion Analysis, Gillette Children's Specialty Healthcare, St. Paul, Minnesota



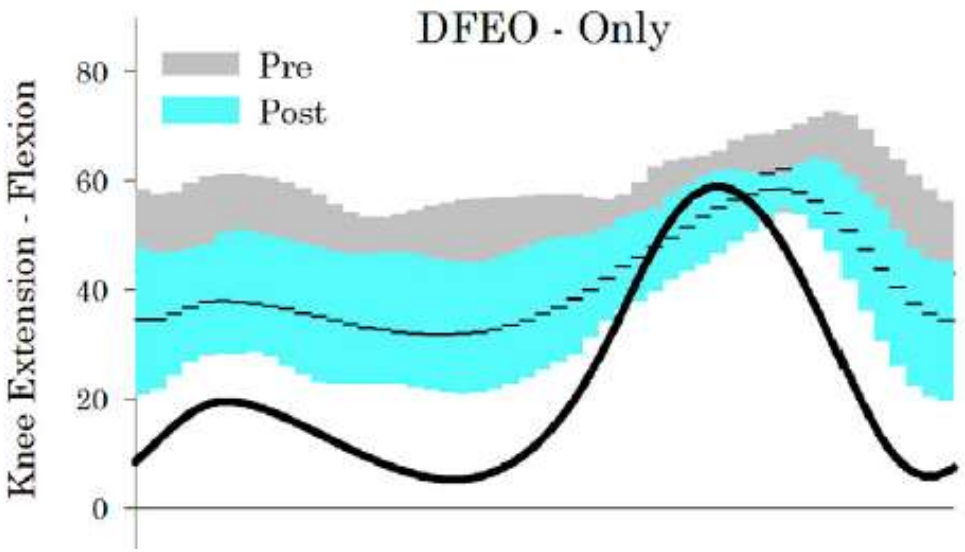


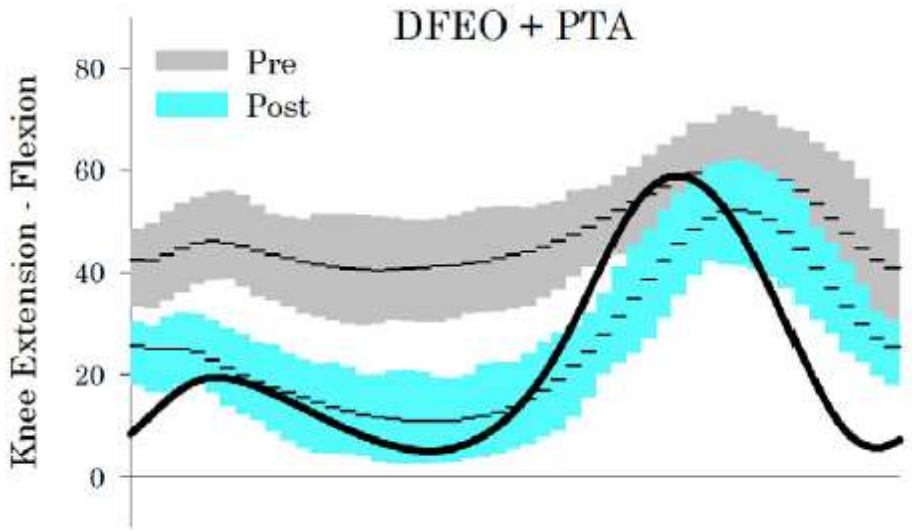


Can we meet this goal, technically?

DFEO needs patellar tendon advancement (PTA)

Else child will remain in crouch gait





Stout et al., J Bone Joint Surg 2009

Back to the patient

GOAL

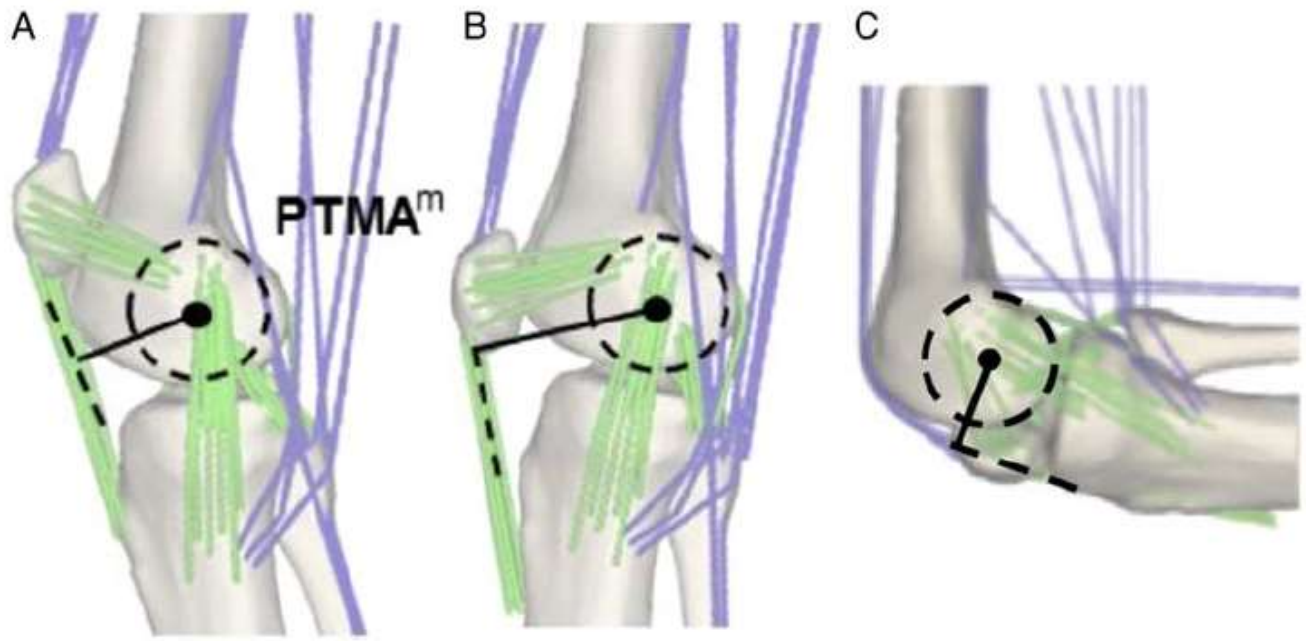
- Upright walking

BUT

- **CLINICAL HISTORY**: the patient crawls (deep knee flexion for some ADLs)
- GOAL: going up and down stairs are somewhat difficult and important to maintain

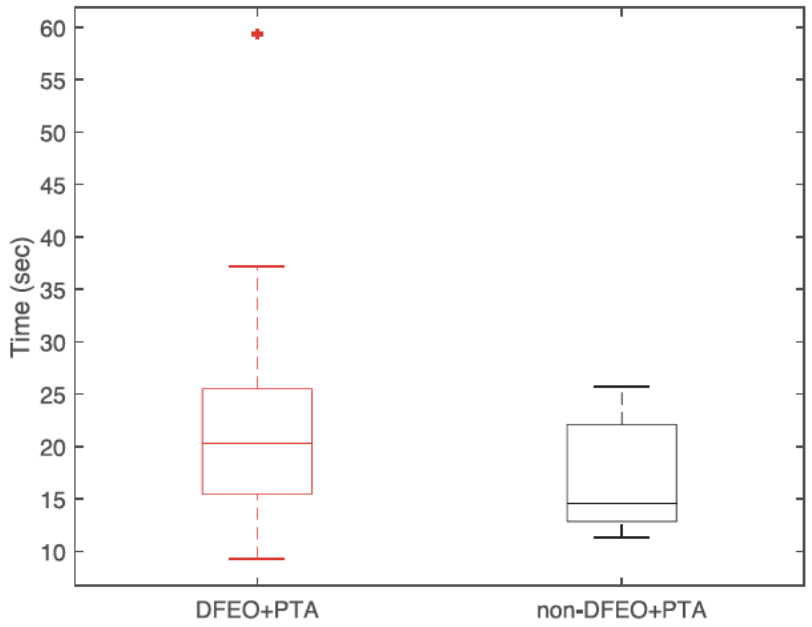
What other consequences of the procedure?

Basic science/modeling data about knee extensor moment



Bittman 2018 Gait Posture

Clinical assessment of deep knee flexion function (sit-to-stand)



Boyer 2017 Gait Posture

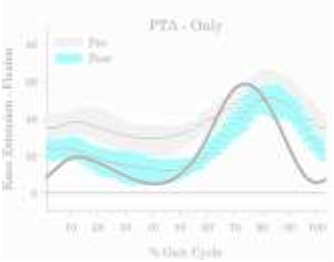
11 yo, GMFCS III, Diplegia, Crouch, 10 degree knee flexion contractures

GOALs

Walking taller, more upright
Guided growth and PTA

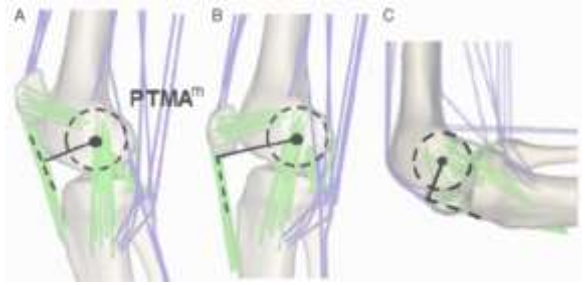
Less knee pain
Similar with and without Sx (Boyer 2018 J Bone Joint Surg Am)

Dissatisfied with AFOs
Procedure will not obviate need

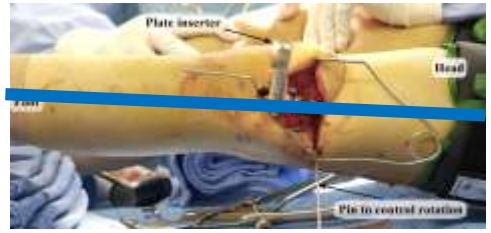


CLINICAL OUTCOMES

- Surgical Treatment (PTA)



Biomechanical data



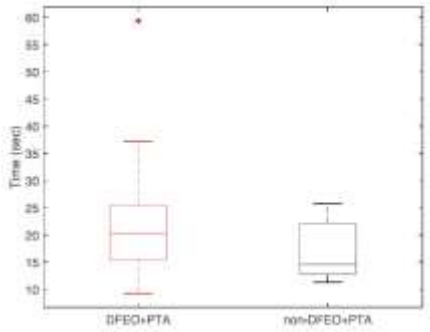
SHARED DECISION-MAKING

- Undergo procedure understanding risks, benefits, alternatives

GOALs

- upright
- maintain stairs/ADLs

Clinical study of biomechanical data



Is this patient a good surgical candidate?

She has multilevel orthopaedic “deformity”

Crouch

- Small knee flexion contractures
- Large Extensor Lags
- Hamstrings contracture

Foot deformity

- Pes Planovalgus

Do I have treatments that address these goals?

Crouch

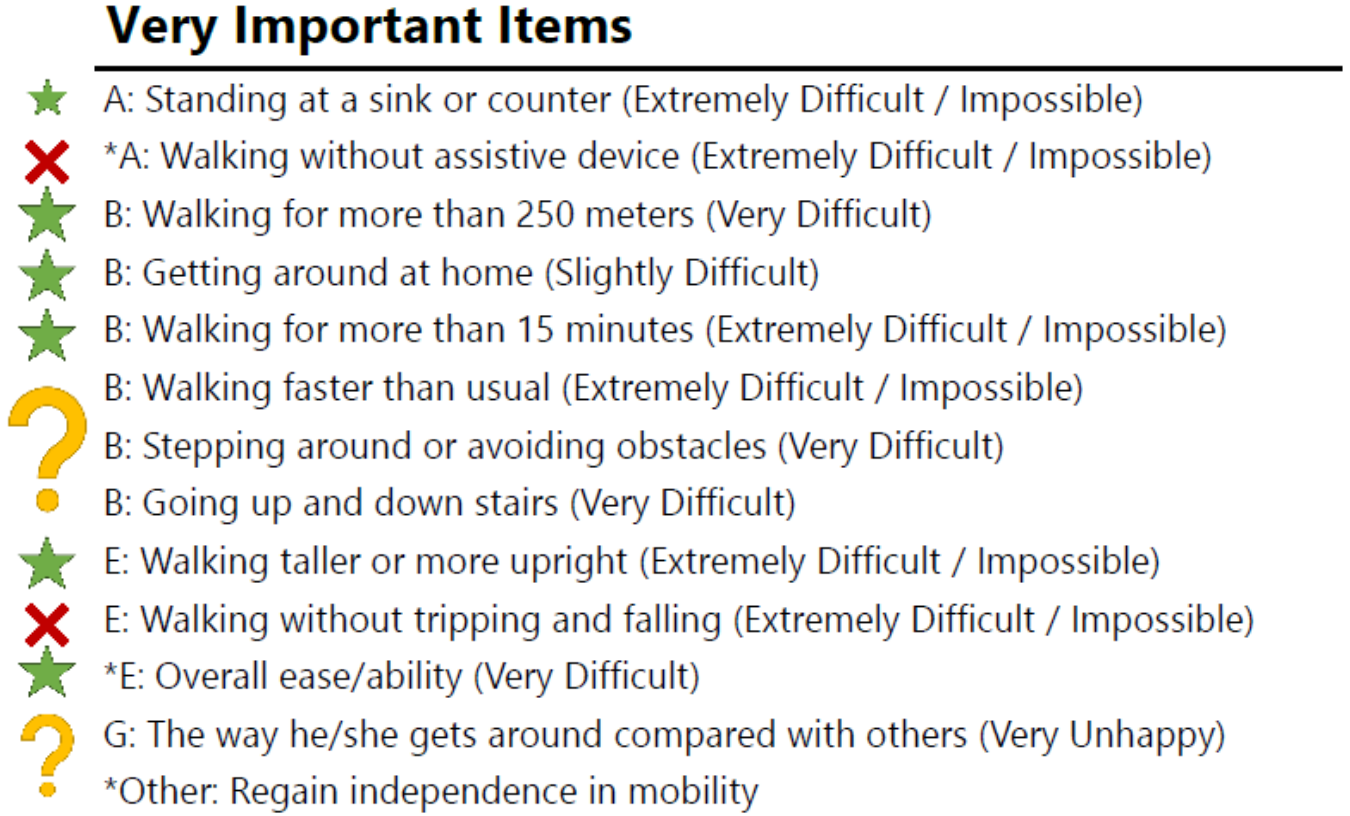
- Small KFCs
- Large Extensor Lags
- HS contracture

Foot deformity

- Pes Planovalgus

Current Goals

- Regain ability and **stamina** to walk with crutches
- Regain ability to **stand** independently
- Use **AFOs less**



Post-Treatment

Multilevel Surgery (MLS)

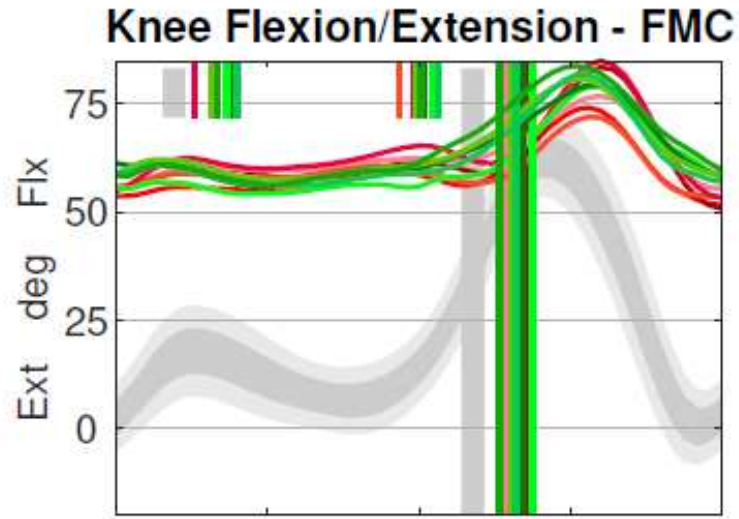
- Anterior guided growth
- Patellar advancement

[redacted]

12-Oct-2021
B-Tethered Hinged AFOs

James R. Gage Center for Gait and Motion Analysis

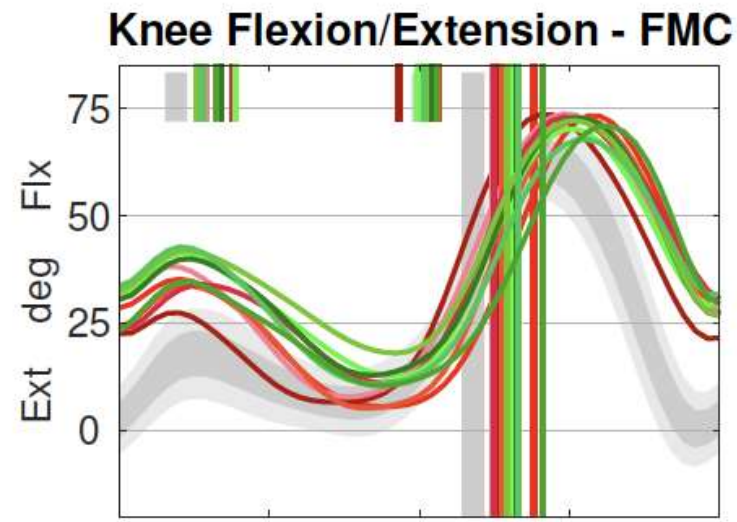
Gillette Children's Specialty Healthcare



[redacted]

14-Mar-2023
B-SAFO and Crutches

gillette CHILDREN'S
James R. Gage Center for Gait and Motion Analysis



Future of patient and family directed care

Synthesis of patient goals, available treatments, expected treatment effects, patient-specific variables, shared-decision-making

Wider application of the GOAL (not just at gait analysis)

Quantifying GOAL improvement after intervention, and correlation with changes in patient:

- Anatomy/neurology
- Gait
- Function

Summary

Patient goals are important

Patient goals can be partly ascertained through GOAL

- Probably a poor substitute for human interaction – but possibly useful for research

Treatments should be targeted at impairments that are causally related to goals

When this happens, results are more likely to meet expectations

Thank You