IPRC
International
Pediatric Rehabilitation
Collaborative

Dosing Rehabilitation Interventions for Children with Cerebral Palsy

Linking Structural and Functional Changes

In the musculoskeletal system

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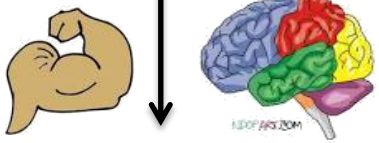
Learning Objectives

- **Identify the dosing parameters for different types of interventions for the musculoskeletal system;**

- **Identify the inconsistencies in published evidence concerning changes at the level of body structures and function, activity, and participation;**

- **Using a systems model, develop interventions program designed to promote structural and behavioral change for children with different levels of severity and for different ages.**

Health Condition



Body Structures & Function

Activity

Participation

Interventions

Environmental Factors

Personal Factors

Contextual Factors

Adapted from:
World Health Organization, 2002.

“Personal Bias” or “Disclaimer”

Dosing **MUSCULOSKELETAL SYSTEM**

for **HEALTH & FUNCTION**

- Promote Changes in Muscle and Bone architecture that are sustainable over time and result in improved function….

- Promote ***HEALTH AND HAPPINESS*** throughout the lifespan.

What's really important, anyways?

- Feel "Good" about yourself
  (Werner & Smith 1989, 1992)

- Be Happy 
  (Diener 2000, Csikszentmihalyi 2008)

- Be Healthy
  - Know there are complex inter-relationship between these phenomena, direct and indirect relationships

  (Agner et al. J Happiness Studies 2012)

Follow Up Study: Walking Abilities

Good orthopedic care works!

Motion Analysis Results		
Gillette Gait Index	350 (209, 76 -767)	350 (269, 50 -913)
Improved or Maintained=22	**343 (208, 76 -767)**	**271 (193, 50 -715)**
Declined N=4	388 (247, 170-741)	762 (182, 515- 913)
Gait Velocity (cm/sec)	79 (33, 28-143)	83 (37, 13-142)
Kinematics		
Hip Flexion Range	43 (22, 13-136)	40 (9, 22-59)
Knee Flexion at Initial Contact	30 (16, 0-73)	28 (14, 8-59)
Knee Flexion Maximum as % Swing	.80 (.07, .67- .96)	.78 (.07, .64- .93)
Knee Flexion Range in Swing	22 (12, .3-42)	26 (12, 5-51)
Maximum Dorsiflexion in Stance¶	**13 (8, -8-27)**	**20 (9, 4-42)**

¶*p<.002*

Gannotti et al. 2013 Disability & Health

Follow Up Study: Participation

- Despite Bachelor's degrees and Master's degrees, and training in vocations, only a few worked, mostly part-time
- Only 1 full time professional (in power chair)
- Only 1 part-time professional married with a child
- ***These two people were also the two who declined the most in walking abilities***
- ***The person with the greatest functional improvements was living alone, unemployed, and did no volunteer activities, and was dissatisfied with participation.***

Gannotti et al. 2013 Disability & Health

Factors Promoting Success?

- Common pattern of:
  - Reports of “Excellent Orthopedic Care”
  - Participation in Fitness Activities 2-3x a week
  - Personality “accept me for who I am”
  - Supports: family, friends, care attendants

  - *small sample, but unique in linking structural and functional long term outcomes*

Gannotti et al. 2013 Disability & Health

Self Concept of Adults with Cerebral Palsy

Level of severity- GMFCS level or the Functional Independence measure not directly associated with self concept….

	level I n=36	level II n=12	level III n=32	level IV n=13	level V n=9
Physical	53T	52T	51T	52T	54T
Moral	51T	51T	51T	52T	54T
Personal	48T	48T	48T	49T	49T
Family	47T	45T	44T	49T	53T
Social	50T	50T	50T	51T	49T
Academic/Work	44T	45T	41T	44T	35T

Gannotti et al 2011 Dis Rehab

Not a direct relationship with life satisfaction either…….but indirect…..

Gannotti et al 2012 AACPDM abstract

Happiness: Adults with Cerebral Palsy

- Similarities between physical therapists and adults with CP in "meanings" of Happiness
  (Gannotti et al 2014 Ped PT, abstract)

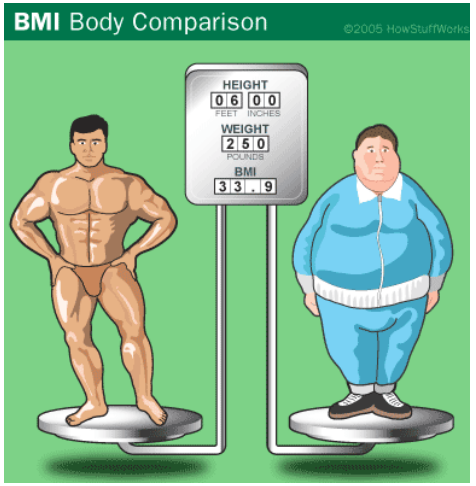
- Participation in society, meaningful activities are important
  (Law et al. Arch Phys Med Rehabil 2007; Keogh et al. Am J Ment Retardation 2006)

  - Satisfaction with participation in society may mediate the influence of functional limitations on life satisfaction.

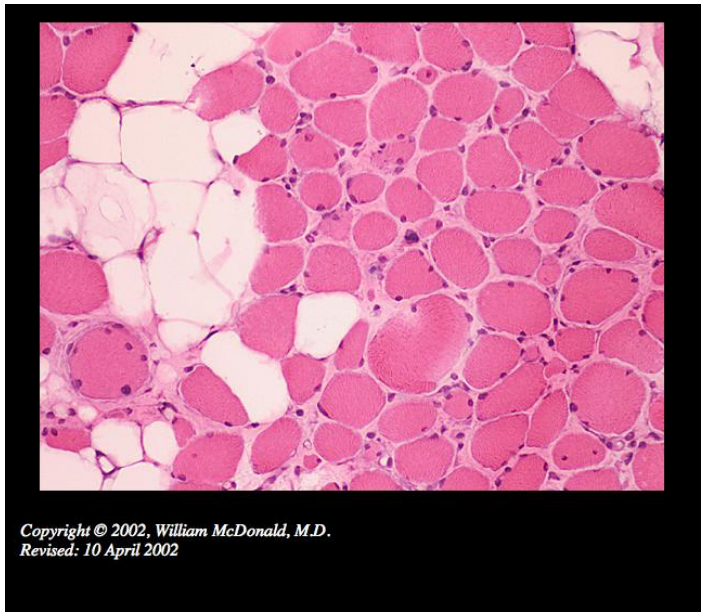
- Although disability paradox is well documented…….
  (Albrecht & Devlieger Soc Sci Med 1999)

- High Risk for Health Problems
  - Secondary conditions
  - Early onset sarcopenia and metabolic disease
    (Peterson et al 2013 Obes Rev)

Adults with Cerebral Palsy: Muscle Health



- **Decreased Muscle Mass**
  (Lange et al. Brain Dev 2006)
- **Sarcopenia**
  (Shortland Devel Med Child Neurol 2009)
- **Vitality/Subjective Fatigue**
  (Peterson et al. Obes Rev 2013)
- **Obesity/Adiposity**
  - Increased BMI
  - Increased Fat to Muscle Ratio
  - Ectopic Adiposity
    (Peterson et al. Obes Rev 2013)
  - Abnormal glucose and lipids in adolescence and early adulthood



Adults with CP: Bone Health

- **Spinal Deformity**

  (Koop Devel Med Child Neurol 2009; Horstmasnn et al. Devel Med Child Neurol 2009)

- **Limb Deformity**

  (Murphy Devel Med Child Neurol 2009, Sheridan Devel Med Child Neurol 2009; Carter & Tse Devel Med Child Neurol 2009)

- **Joint Pain**

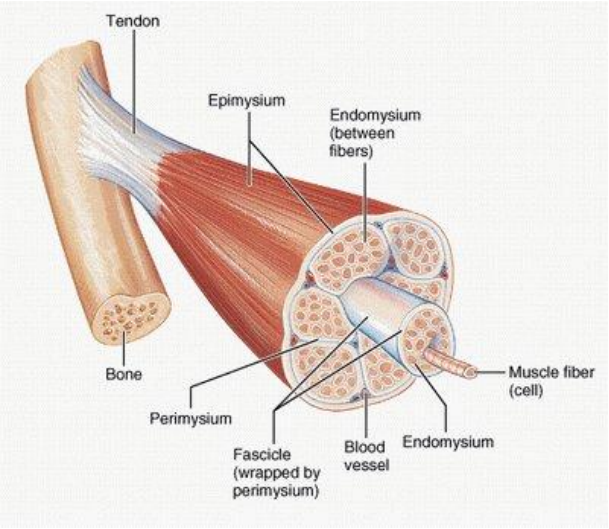
  (Vogtle Devel Med Child Neurol 2009)

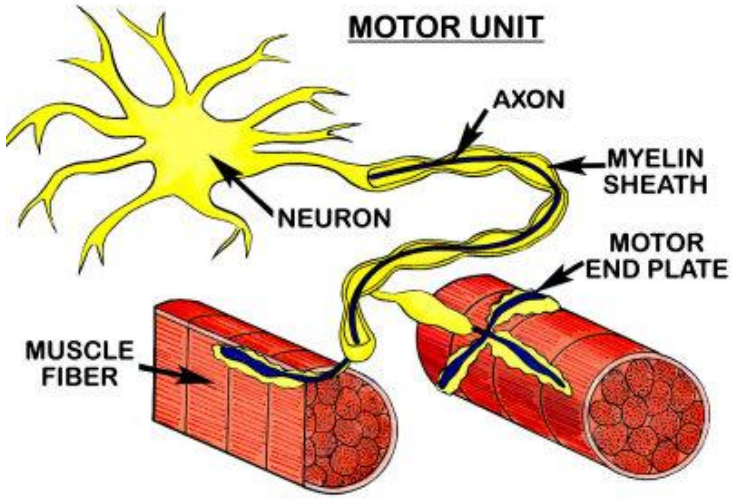
- **Neuralgia**

  (Turk Devel Med Child Neurol 2009)

Muscle Development

- Critical Periods for Muscle Development (ages 0-6 years)
  - Differentiation of Type I and Type II fibers
  - Motor unit formation
  - Sarcomere length, tendon pennation, and fat to fiber ratios (Navarrette & Vrbova 1993; Lexell et al. 1994)





Youth Resistance Training: Updated Position Statement Paper From the National Strength and Conditioning Association

Avery D. Faigenbaum,[1] William J. Kraemer,[2] Cameron J. R. Blimkie,[3] Ian Jeffreys,[4] Lyle J. Micheli,[5] Mike Nitka,[6] and Thomas W. Rowland[7]

Journal of Strength and Conditioning Research; Aug 2009; 23, 5; ProQuest

Table 2. Recommendations for progression during resistance training for strength.*

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exercise choice	SJ and MJ	SJ and MJ	SJ and MJ
Intensity	50–70% 1RM	60–80% 1RM	70–85% 1RM
Volume	1–2 sets × 10–15 reps	2–3 sets × 8–12 reps	≥3 sets × 6–10 reps
Rest intervals (min)	1	1–2	2–3
Velocity	Moderate	Moderate	Moderate
Frequency ($d \cdot wk^{-1}$)	2–3	2–3	3–4

*ECC = eccentric; CON = concentric; SJ = single joint; MJ = multi-joint; 1RM = 1 repetition maximum; rep = repetition.

As early as age 7 (5) years, resistance training indicated to maximize muscle STRENGTH

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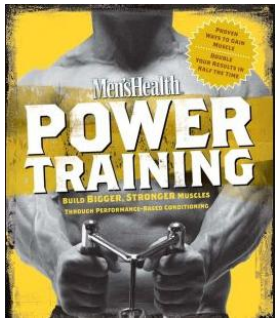
Table 3. Recommendations for progression during resistance training for power.*

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exercise choice	MJ	MJ	MJ
Intensity	30–60% 1RM VEL	30–60% 1RM VEL 60–70% 1RM STR	30–60% 1RM VEL 70 to ≥80% 1RM STR
Volume	1–2 sets × 3–6 reps	2–3 sets × 3–6 reps	≥3 sets × 1–6 reps
Rest intervals (min)	1	1–2	2–3
Velocity	Moderate/fast	Fast	Fast
Frequency ($d \cdot wk^{-1}$)	2	2–3	2–3

*ECC = eccentric; CON = concentric; MJ = multi-joint; 1RM = 1 repetition maximum; VEL = velocity; STR = strength; rep = repetition.



As early as age 7 (5) years, resistance training indicated to maximize muscle POWER

Dosing for Muscle Length

- With typically developing children
  - 2-4 times/5-10 min a week for durations of 6-9 months

Sanjona Medina 2007 J Sports Med Phys Fitness

Stretching not recommended prior to strengthening exercises as increased muscle length inhibits force production

Faigenbaum 2009 J Strength Cond

Warm up exercises recommended to increase blood flow and “prepare” muscles for performance

What do we see in muscles of children with cerebral palsy?

- **Highly endurant muscles**
  - More Type I fibers

    (Ito et al Brain Dev 1993)
- **Low force production**

  (Stackhouse 2005 Muscle & Nerve)
- **Reduced rate of force development or power**

  (Moreau et al 2013 Neural Rehabil Repair)
- **Low muscle mass, Adipose infiltration**

  (Johnson et al 2009 J Pediatr, Ohata et al 2009 DMCN)

What do we see in muscles of adults with cerebral palsy?

- Decreased muscle strength & power (sprint power test) by 53 to 69% – active adults with CP! (de Groot, 2012; *J Rehab Med*)
- Muscles less fatigable (i.e., more endurant) (Moreau, 2008; *APMR*)
- Aerobic capacity (VO2 peak) not different from healthy adults (de Groot et al, 2012)

- i.e., same issues as kids with CP!!

Take Home

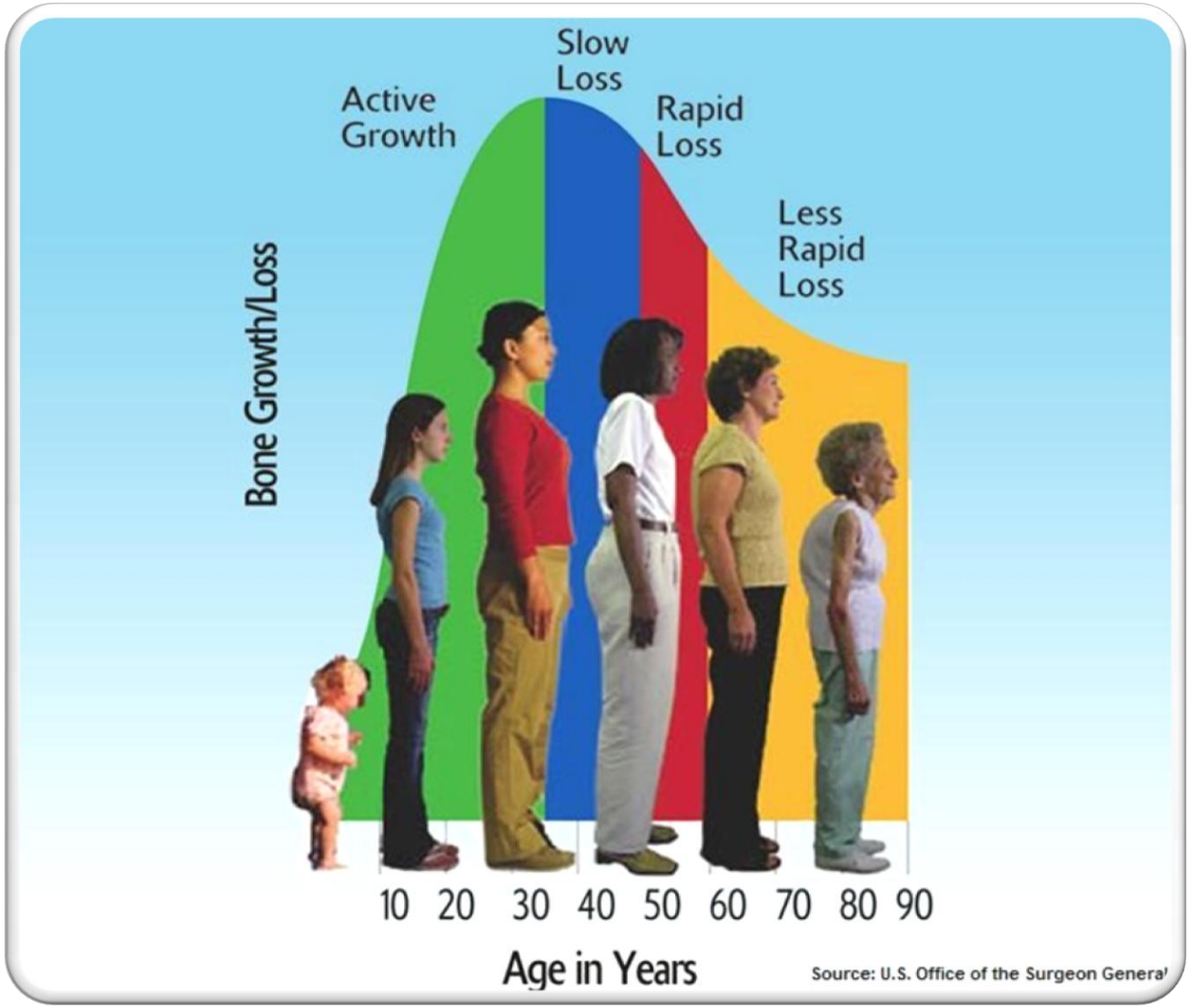
- **Increase the overall force generating capacity and rate of force development to increase muscular reserve and reduce relative effort**
- **Maintain muscular reserve and muscle mass with aging!**

Bone development

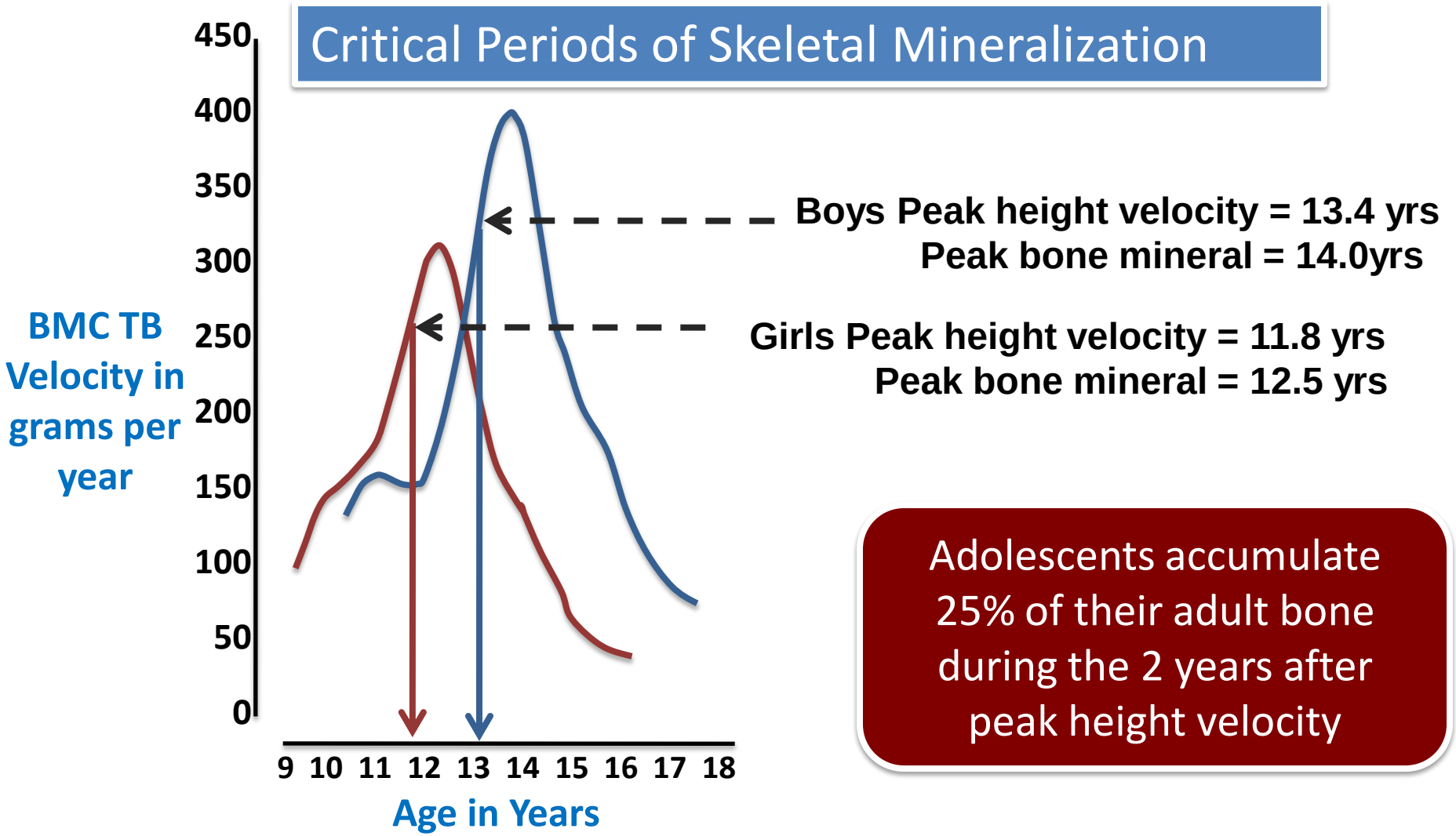
- Critical periods for Bone Development
  - Majority of Bone Mineral Density accrued prior to puberty; peak at 18 (f) 20 (m) years

(McKay et al.1998)

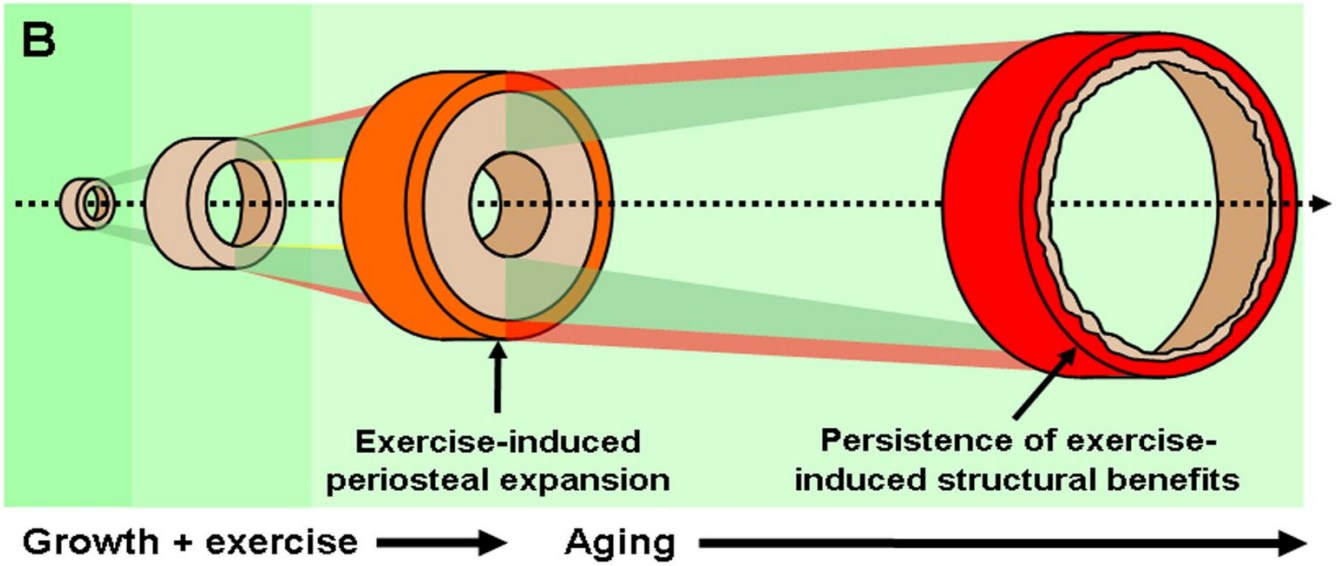
Bone health across the lifespan



Timing of bone modeling during growth



Important changes in bone structure during growth and aging



Exercise and other anabolic agents optimizes skeletal structure to ↑ bone strength without overtly ↑ overall weight of the skeleton

Hierarchy of osteogenic activities

Highly Osteogenic

- squash, tennis, soccer, ice-hockey, badminton, volleyball and weight-lifting

Moderately Osteogenic

- long distance running, stair stepping, rowing machines

Least Osteogenic

- walking, swimming, cycling, yoga, pilates

Effective Interventions for Bone

Study	Sample	Frequency	Duration	Ground Reaction Force Produced	Activity
Fuchs et al. 2001	89 boys/girls Mean age 7.5 yr 26 controls Mean age 7.6 yr	3x weekly	7 months	8 x body weight Measured at beginning and end of intervention	61 cm jumps 100 x's

Fuchs & Snow *J Pediatr* 2002;141:357-362.

Gunter et al. J Bone Min Resear. 2008; 23(7):986-93.

BONE responds to NOVEL MULTIDIRECTIONAL FORCES
NEEDS about 10 minutes of stimulation, NEEDS rest to respond

Osteogenic Potential of An Activity (OP_a)

Turner & Robling, 2003 *Exercis Sci*

OP_a= intensity * ln [frequency +1]

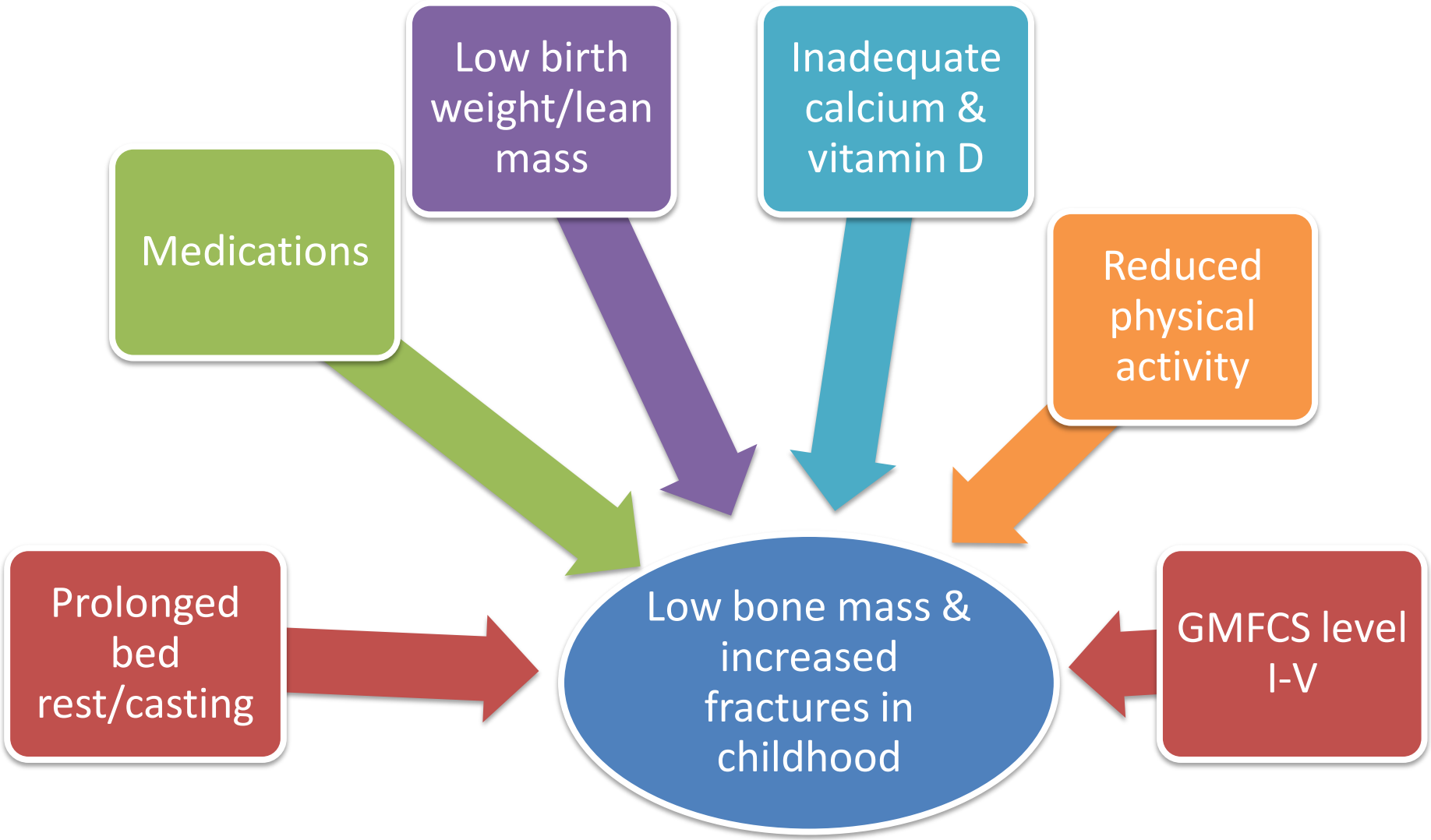
So….if we calculated the OP_a, we could calculate a dose for a modified activity for children who cannot jump.

Dosing for Bone Health

- Age of intervention
  - Pre-puberty (growth hormones)
- Intensity of intervention
  - How much skeletal loading is occurring and what bony sites are being loaded (eg, GRF)
- Cycles of loading per session
- Frequency and duration
- BONE NEEDS TO REST minimum of 24-48 hours between loading

Turner & Robling 2003 Exerc Sport Sci

Children with CP Risk for Low Bone



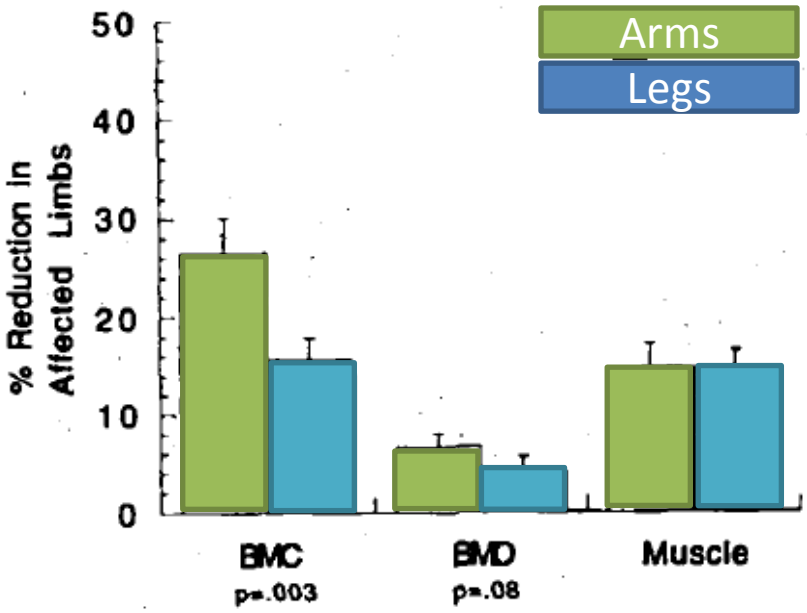
Risks for pediatric fractures

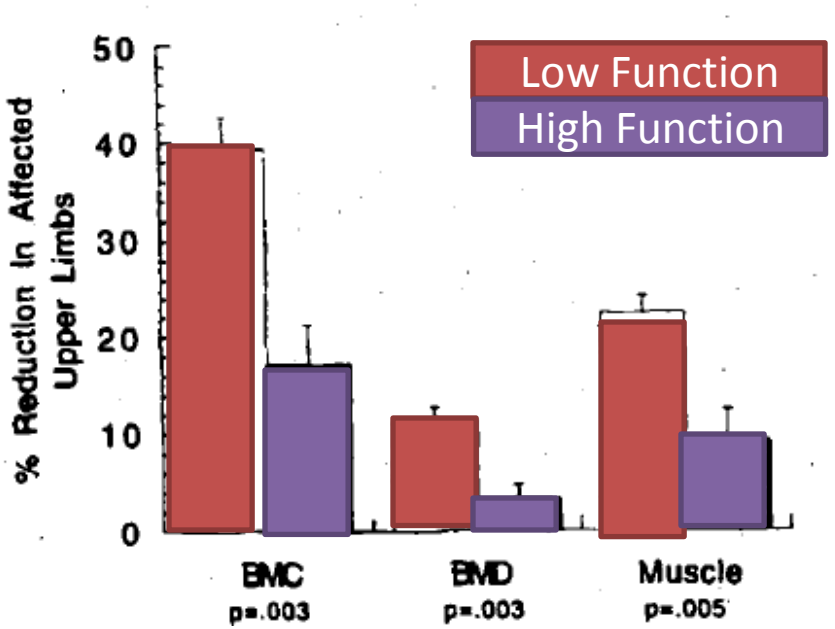
- Fractures in children with cerebral palsy
  - Epidemiological study of 536 children
    - GMFCS levels I-III and GMFCS levels IV-V
    - Data collected over a period of 9 years
  - **KEY FINDINGS**
    - Risk of fx similar for children with CP GMFCS levels I-III compared to typically developing children
    - Increased risk of fx without trauma for GMFCS levels IV-V using antiepileptic drug therapy, stunted growth and did not use standing devices
    - 4 fold reduction in fx without trauma for GMFCS levels IV-V using standing frames.

Wort et al., Dev Medicine and Child Neurology, 2013

Bone health in children with CP

- Compromised bone health across tanner stages and all GMFCS levels

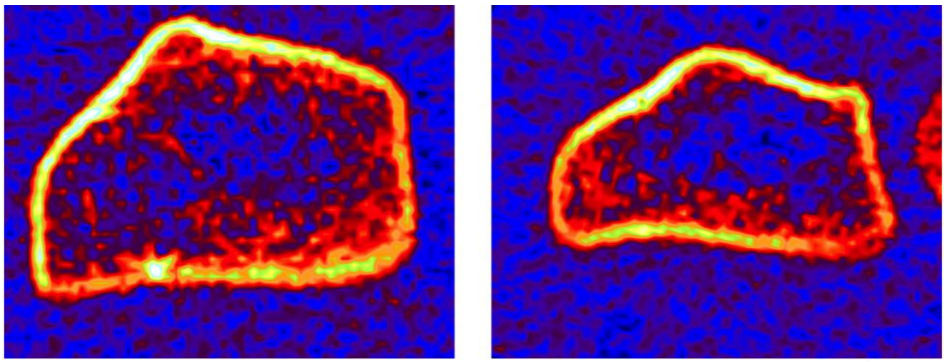




Deficits in mineral and muscle mass are not telling us the whole story for why kids with CP have a higher incidence of fractures

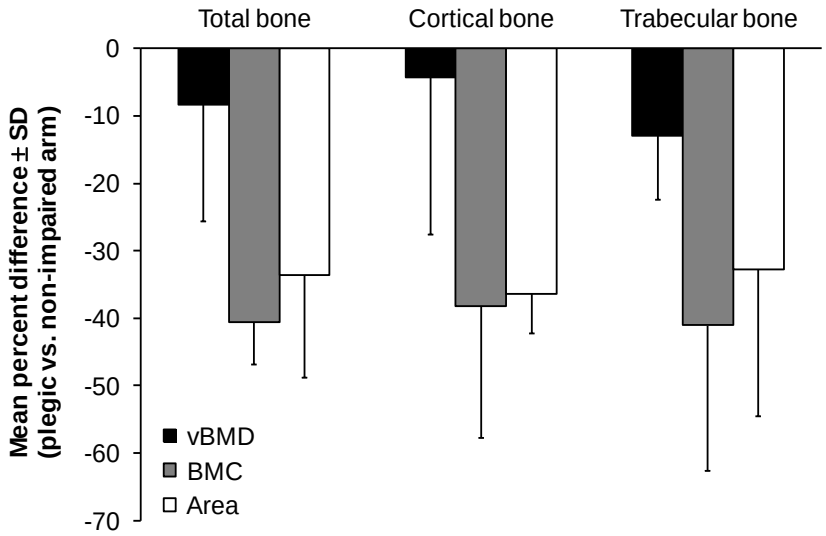
Bone structure in children with CP

A)



Non-paretic Paretic

B)

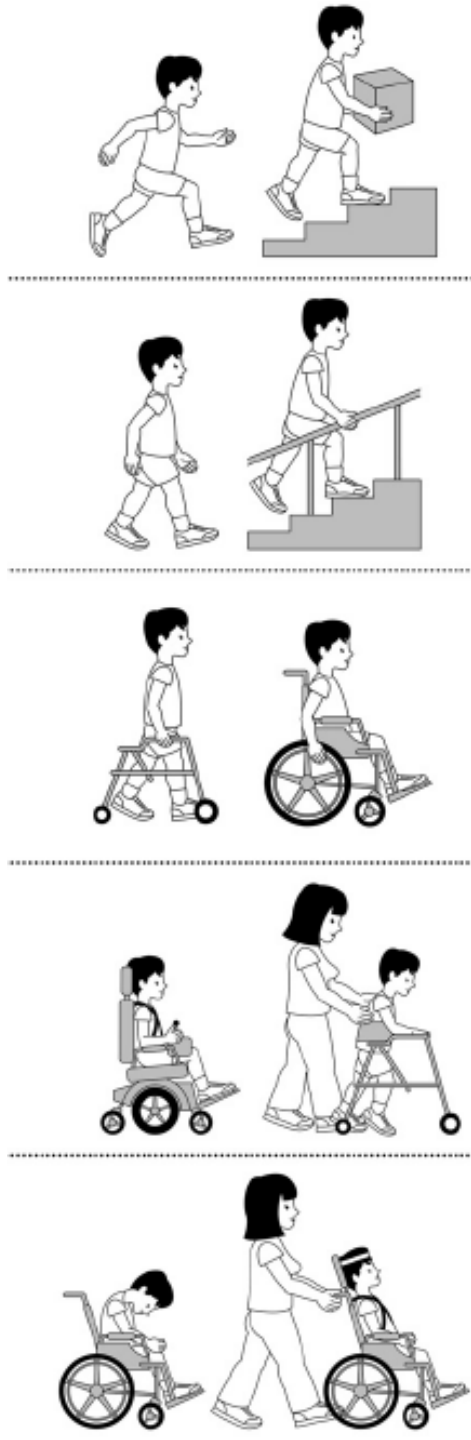


A) Peripheral quantitative computed tomography images of the distal radius in the nonparetic and paretic upper extremities of a 15-year-old girl with hemiplegic CP due to a perinatal stroke. Note the much smaller cross-sectional area on the paretic side. **B)** Mean percent differences in peripheral quantitative computed tomography measures of the distal radius in adolescents with hemiplegic CP.

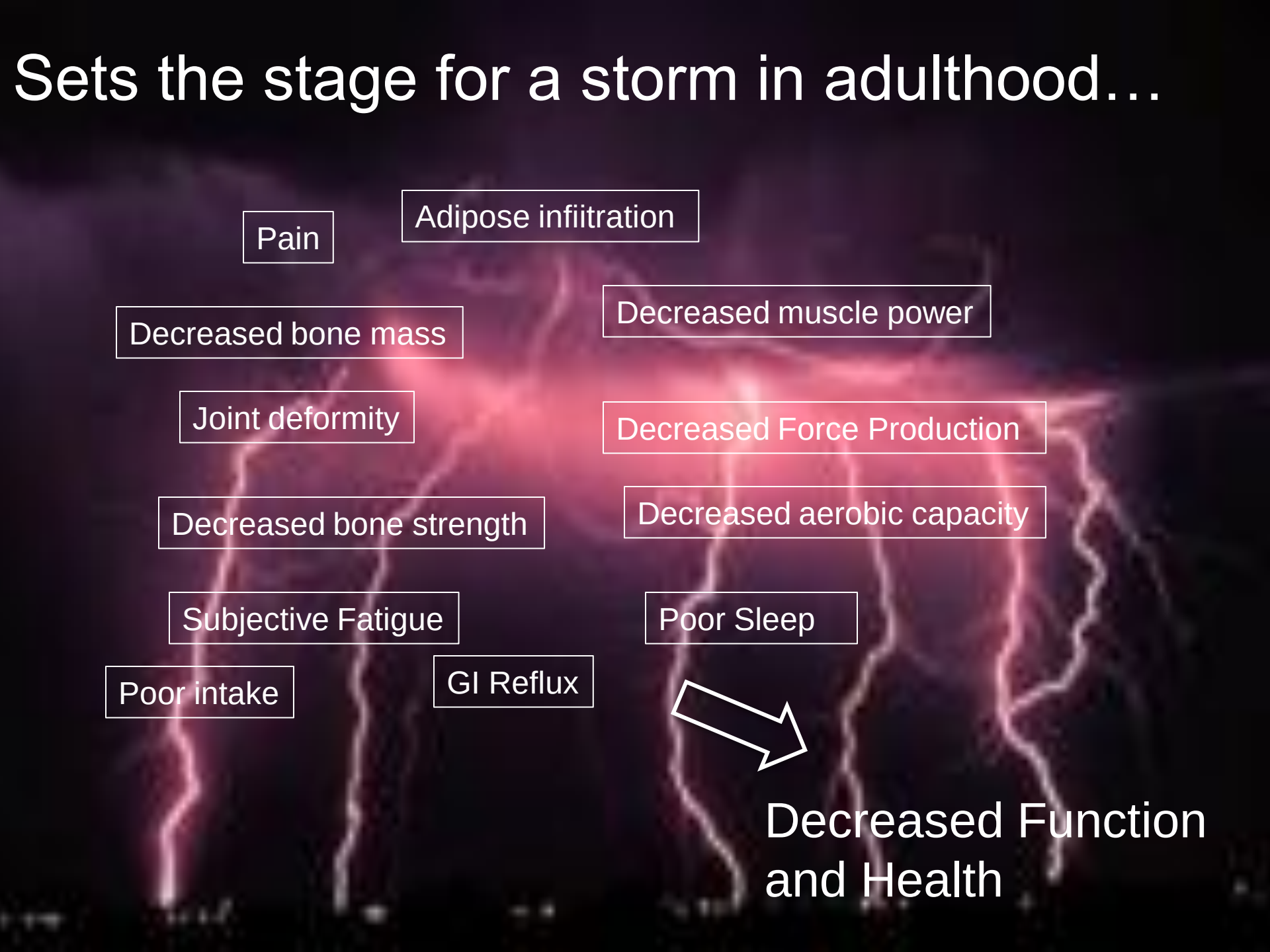
Take Home Message

- **Lack of activity in critical periods in childhood results in**
  - Muscles that are cannot generate adequate force
  - Muscles that lack power, or do not generate force quickly
  - Reduced Muscle Mass
  - Reduced bone strength
  - Reduced bone mass

for children across all levels of severity



Sets the stage for a storm in adulthood…



What does the literature report about effectiveness of interventions at both the structural and functional level?

Increasing Range of Motion

- Which type is effective?
  - Passive range of motion

Wairt et al 2008 Pediatr Phys Ther

  - Splinting
  - Positioning

} 3-5x's week

  - Robotic assisted active range of motion

- Can we link changes in range of motion to changes in function?

Increasing Range of Motion

- Losses in ROM impact function overtime

- Combined Passive Movement with Active Assistive Motion in antagonist direction
  - Increased range of motion
  - Decreased spasticity
  - Increased function
  - Elongation of muscle fascicles, reduced pennation angle, reduced fascicular stiffness, decreased tendon length, increased Achilles tendon stiffness

Wu et al 2011 Neural Repair Rehabil

Zhoa et al 2011 J Appl Physiol

Increasing Strength

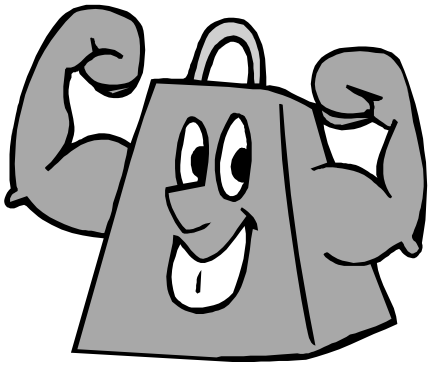
- Which types have been shown to increase strength?
  - Progressive resistive exercise-open chain
  - FES assisted progressive resistive exercise
  - Loaded sit to stand or functional training
  - Isokinetic training or power training

Dodd et al Arch Phys Med 2002

Mockford et al Pediatr Phys Ther 2008

Strength Training and Activity

- Despite moderate increases in strength, there is no higher level evidence that resistance training improves walking speed or other measures of functional walking capacity (Scianni et al, *AJPT*, 2009; Verschuren et al, *PTJ,* 2011)
- Small but clinically insignificant effects on GMFM (Scianni et al, *AJPT*, 2009)
- Dosing Issues:
  - Inadequate **Intensity**
  - Inadequate **Duration**
  - **Train POWER**



Velocity Training vs. Strength Training: RCT

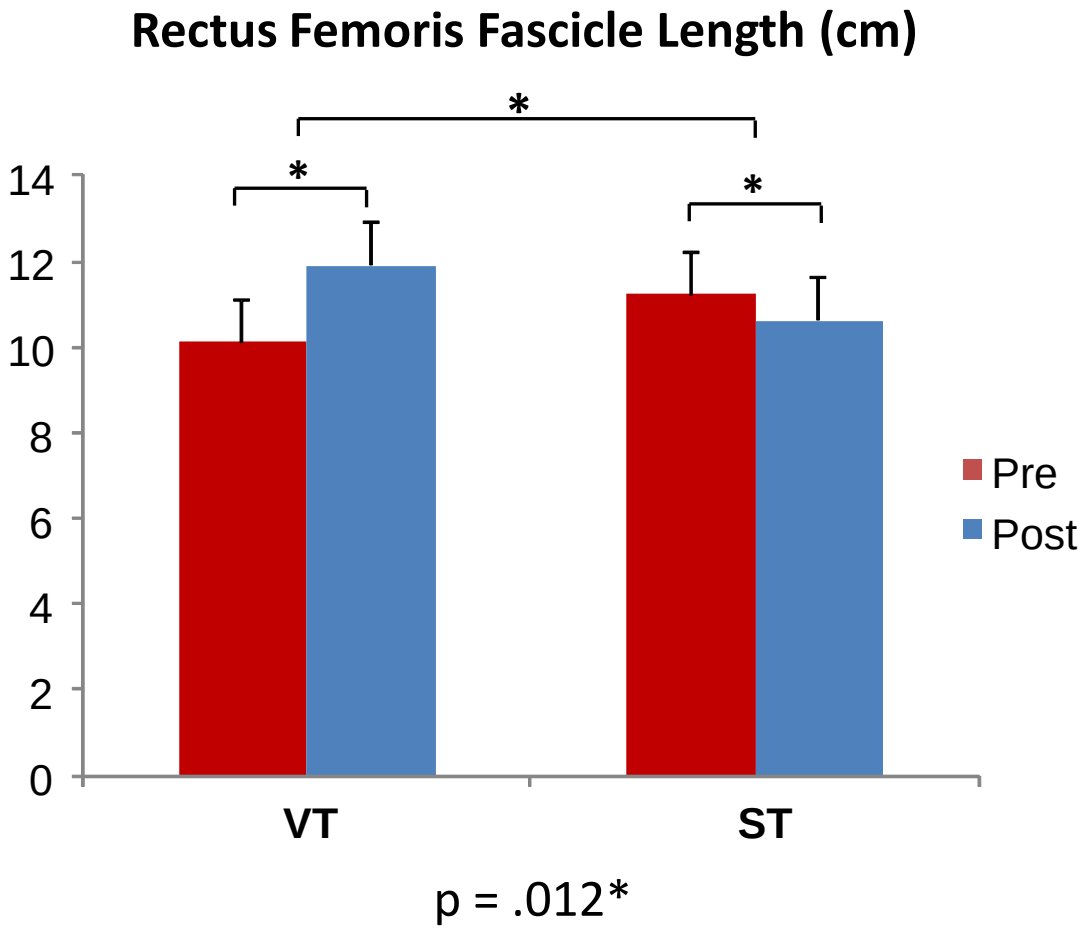
(Moreau et al, *NNR*, 2013)

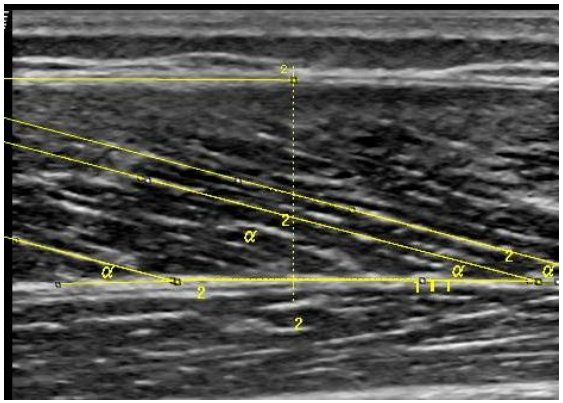
Frequency: 3x week/8 weeks

Volume & Velocity

- **ST:**
  - **6 sets of 5 reps (30°/s)**
- VT:
  - Set 1 of 5 reps (30°/s)
  - Set 2 of 5 reps (60 °/s)
  - Set 3-6 of 5 reps (targeted speed) (60 , 75, 90, 120 °/s)
- **Intensity:** Maximum effort

Results - Muscle Architecture





RF Fascicle length increased after VT and decreased after ST

(Moreau et al, *NNR*, 2013)

Walking Speed and Functional Walking Performance Improved after VT only!

(Moreau et al, *NNR,* 2013)

- 10-m Walk test
  - Self-selected walking speed
  - Fast walking speed

  Met or exceeded MCID of 0.1m/s!
- Timed-Up-and-Go (TUG)
  - 12% improvement (1.52 sec)
- 1-minute walk test
  - 9% improvement (7.9 m)

Skeletal Loading

- No consensus about guidelines for exercise interventions to promote a healthy skeleton in children with CP
- Bone Health should be monitored, be concerned about mass and strength of bone
  - DEXA vs PQCT
- Team approach as medications, nutrition, and anabolic agents can be used
- No direct link to activity or participation in short term

Gannotti et al 2014 PTJ

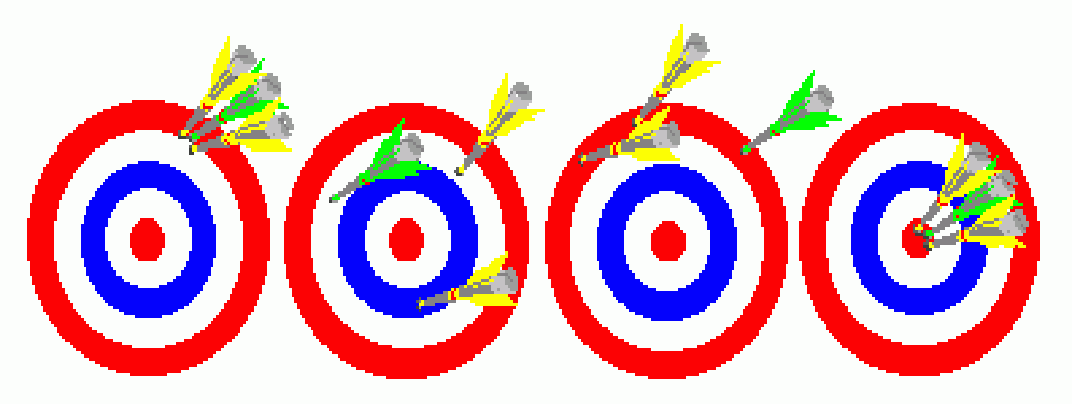
Skeletal Loading

- Frequency & Duration of Loading in Standers (Paleg et al 2013)
- Site specificity
  - Tibial Plateau
    - WBV and closed chain exercises
  - Distal Femur
    - WB activities (Chad et al J Musculoskel Neuron Int)
    - Cycling (Chen et al 2012)
  - Lumbar Spine & Femoral Neck
    - Axial Loading ?? No evidence
- High Intensity Novel Loading
  - Dynamic vs. Static Standers (Gudjonsdottir & Stemmons 2002 Pediatr Phys Ther)
  - Multimodal: aquatics, BWSTT, PRE's (Stark et al 2010 J Musculoskel Neuron Int)

Target Muscle Force and Power

- **Resistance Training**
  - High intensity (increase weights!)

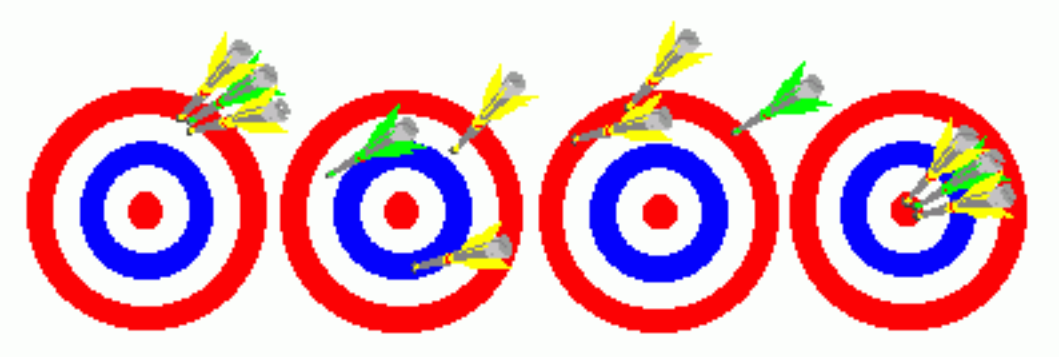
- **Power Training**
  - Fast concentric, and slow controlled eccentric



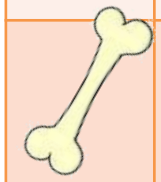
Target Bone Strength and Mass

- **Skeletal loading**
  - On continuum of osteogenic activities that is appropriate for individual

- **Multi-directional Forces**
  - Novel activities or diverse loading forces

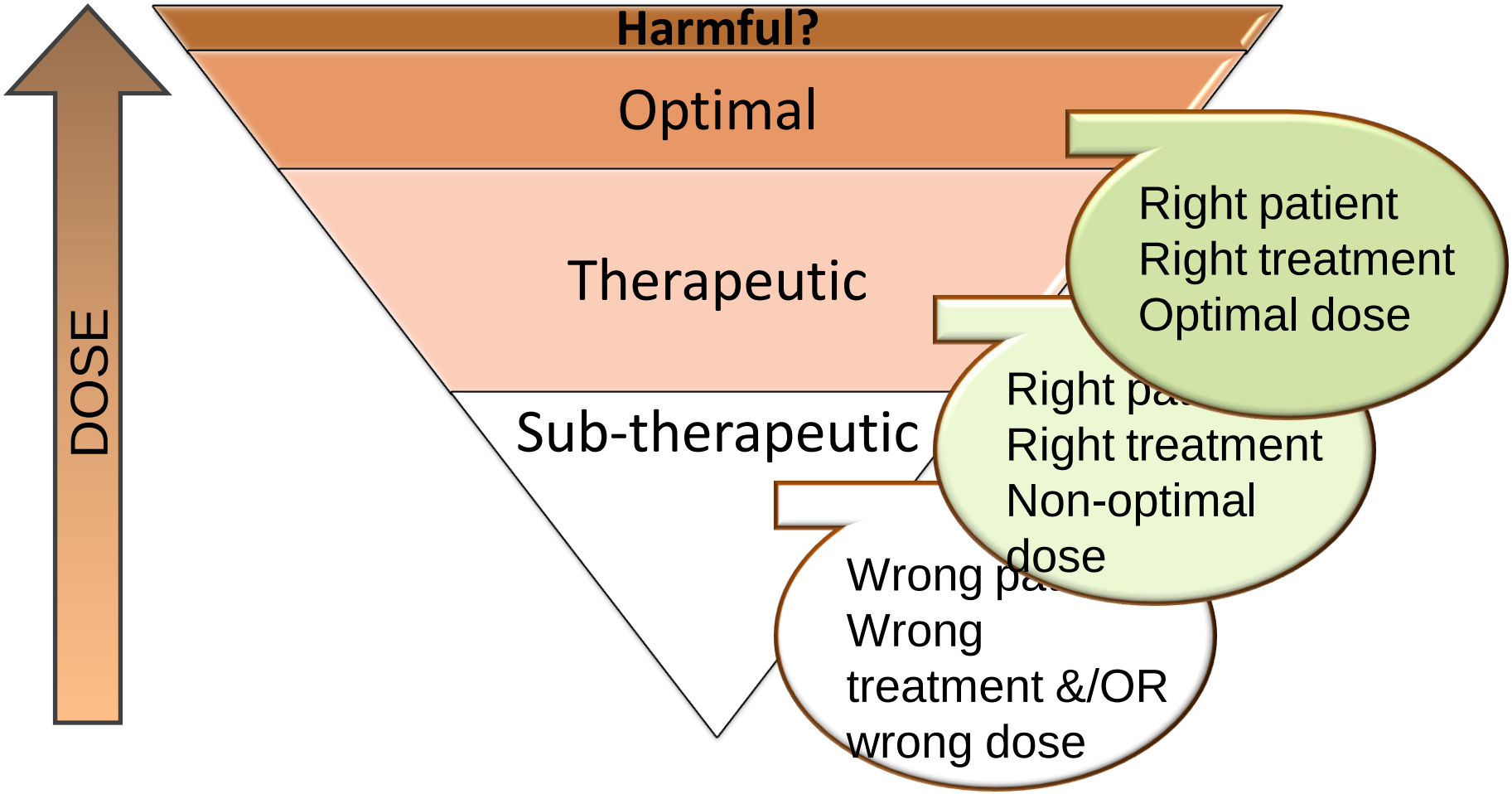


Optimal Dosing Parameters

		Intensity	Volume	Speed	Frequency	Rest	Duration
	Muscle Strength (High resistance)	≥85% of 1RM	Build to 3 sets of 6-10	Slow to moderate; controlled	2–3 x/wk (non-consecutive)	1-2 min between sets; 24 hrs btw sessions	8-20 weeks
	Power (High resistance & High speed)	40-85% of 1RM	Build to 6 sets of 5-6	Concentric part "as fast as possible"	2–3 x/wk (non-consecutive)	1-2 min between sets; 24 hrs btw sessions	8-20 weeks
	Bone Mass & Structure	High ground reaction force	50-100 repetitions 10 minutes	High strain	3-6 x/wk (non-consecutive)	1-10 sec btw reps; 24-48 hrs btw sessions	9-12 months (min 3 months)

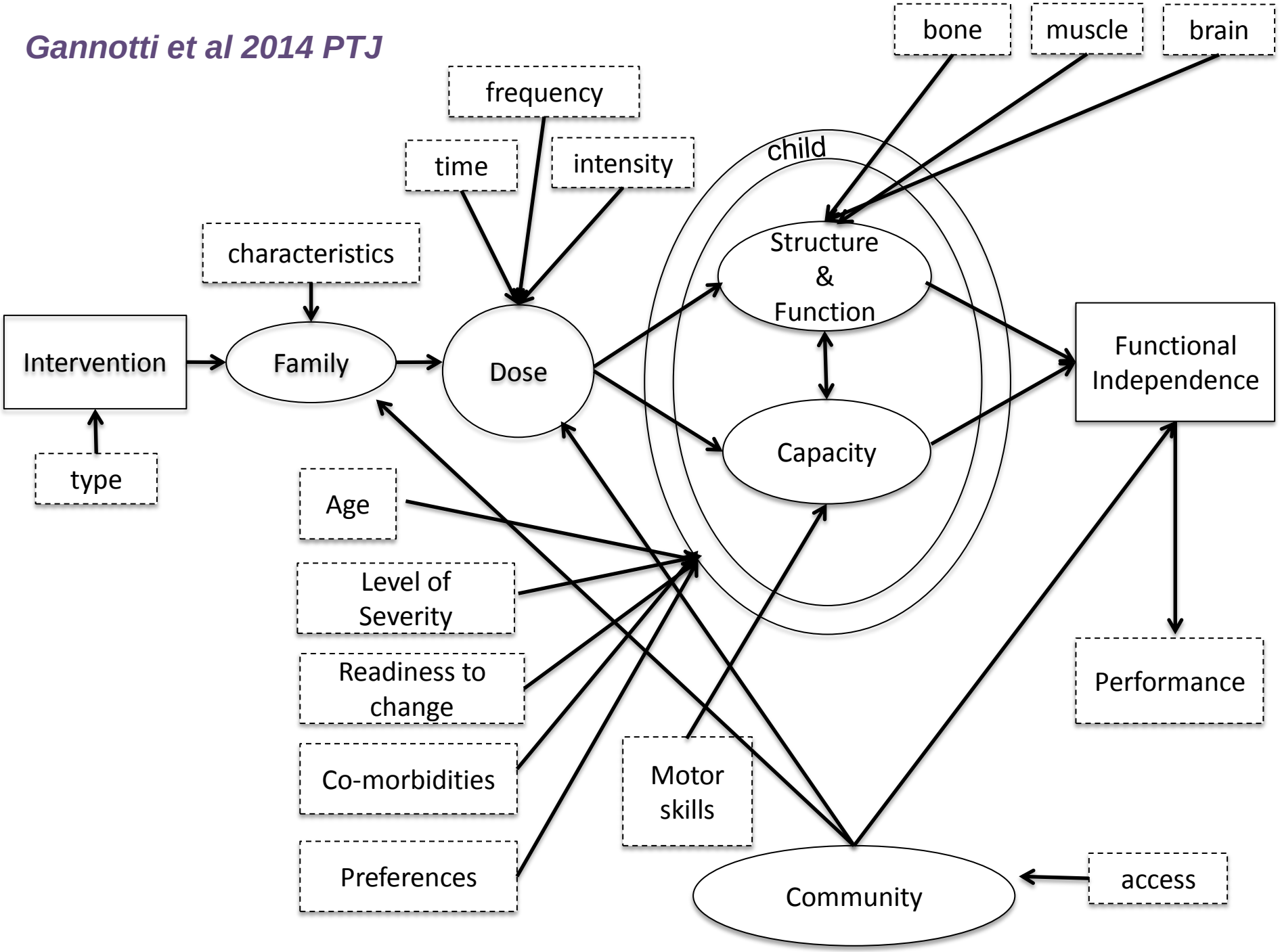
CRITICAL PERIODS PRE-PUBERTY BUT LIFE TIME COMMITMENT

Patient + Treatment + Dose



How Can I use this information for my practice?

Gannotti et al 2014 PTJ



Explicit about Goals

- Increase muscle mass?
- Increase rate of force production of a muscle?
- Increase gait/reaching velocity?
- Increase skeletal health and strength?

SELECT INTERVENTIONS THAT PROVIDE BEST RESULTS FOR GOALS
And DOSE THAT YIELDS RESULTS

Optimize Interventions Given Context

- What resources can we use to augment PT or OT treatment to optimize frequency, intensity, or time?
  - Family
  - Community: Karate, Swimming, Gym class?
  - Child's age, preferences, readiness to change
  - What can we do in the environment to promote success?

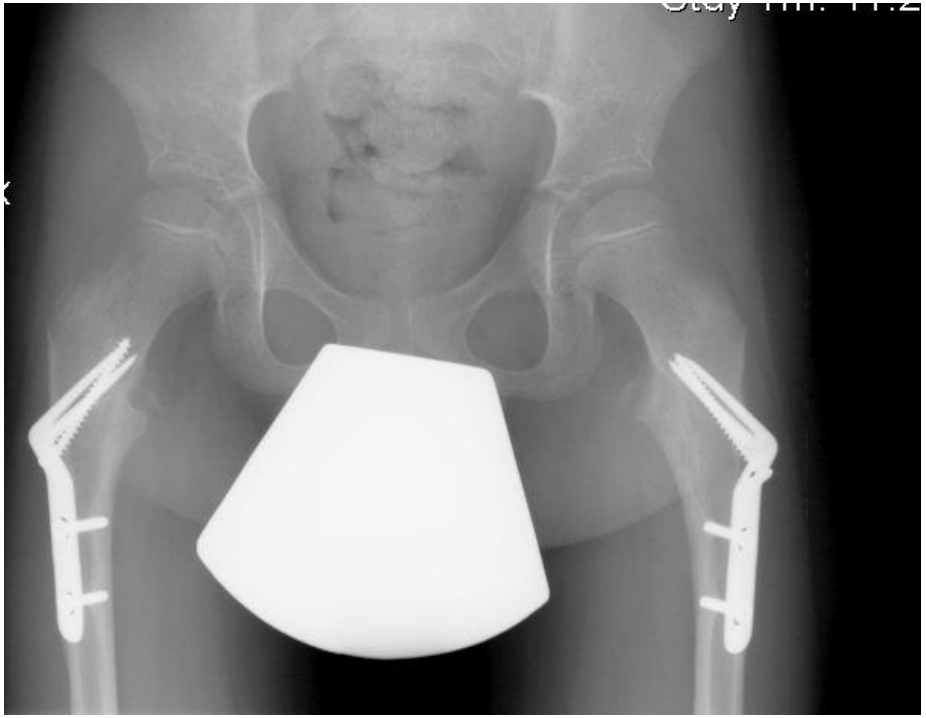
Potential Practice Changes

- PT/OT in Community Context
  - YMCA, afterschool programs, school athletics
  - PT/OT as Personal Trainer or part of “Exercise Team” of Recreational Therapists and Adaptive Physical Educators

- ADVOCACY for enabling programs in community
  - Development of and Payment of Services
  - Severely involved children may need direct services
  - Less severe may need skilled PT/OT for evaluation and development of evidence based program

“Roll with the Punches”

- Ian Cannon, young man with spastic quadriplegia CP GMFCS IV developed an exercise program that combines these components….
- And is fun!
- (and slightly ironic..)



Dosing Parameters

Strength

- Frequency: 3-5 x week
- Volume: 2 sets of 12-20 reps
- Intensity: 50-75% of 1 RM;
- Velocity: Moderate

- ***Recommend 85% of 1 RM max***

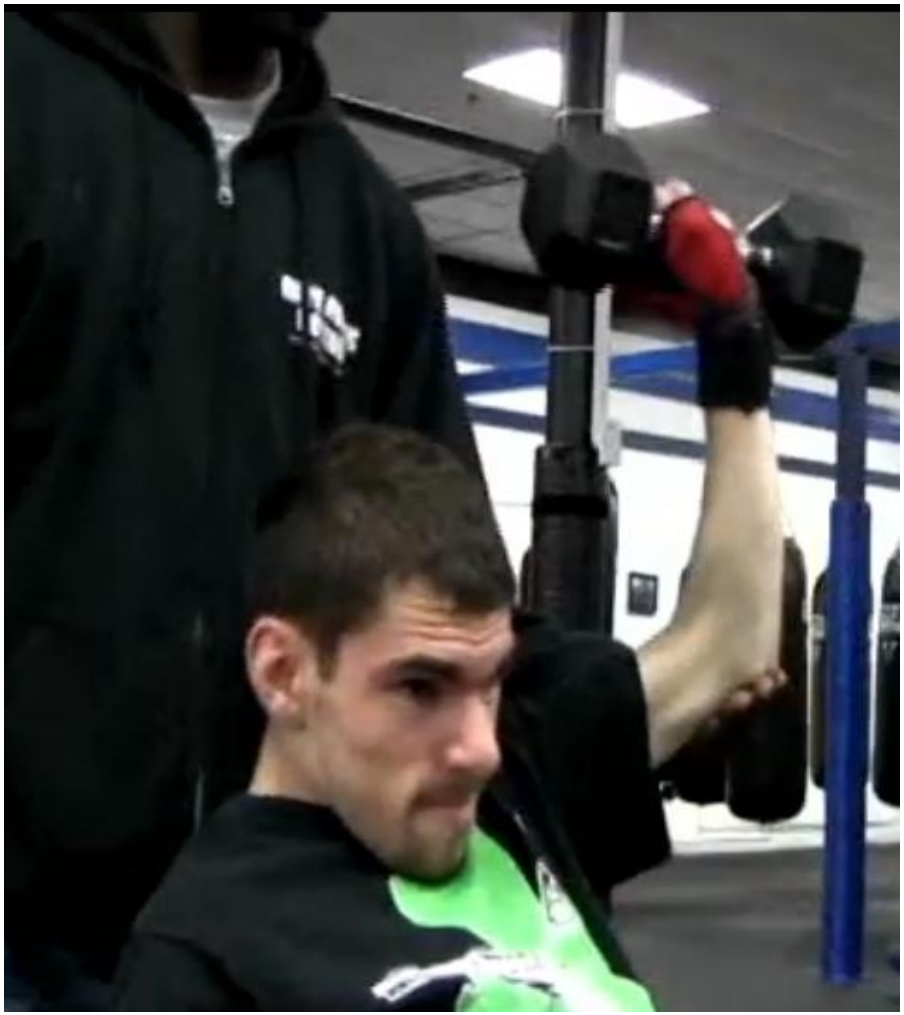
Duration over several years…

Moreau & Gannotti J Hand Ther 2014

Power

- Frequency: 3-5 x week
- Volume: 4 sets, 20 reps
- Intensity: 65-70% 1 RM; 40lbs.
- Velocity: as fast as possible with concentric, slow eccentric
- ***Recommend increase sets to 6; decrease reps to 3-6***
- ***Increase intensity to ≥ 80% 1RM***

Resistance Training: High Intensity



Upper Extremity and Spine Loading: Power Training

Benefits to Muscle

- ↑ Muscle mass of upper extremities
- ↑ Muscle strength throughout
- ↑ Spinal and hip flexibility
- ↑ Range of motion on Left upper extremity
- Back pain resolved,

  MD now not interested in doing spinal fusion

Bone Benefits

- Lumbar spine BMD Z scores prior to initiating program were -2.5
- After 3 years slight improvement to -2.3

- Overall increase in bone mass throughout; remarkable as many individuals with his level of severity bone is lost in adolescence

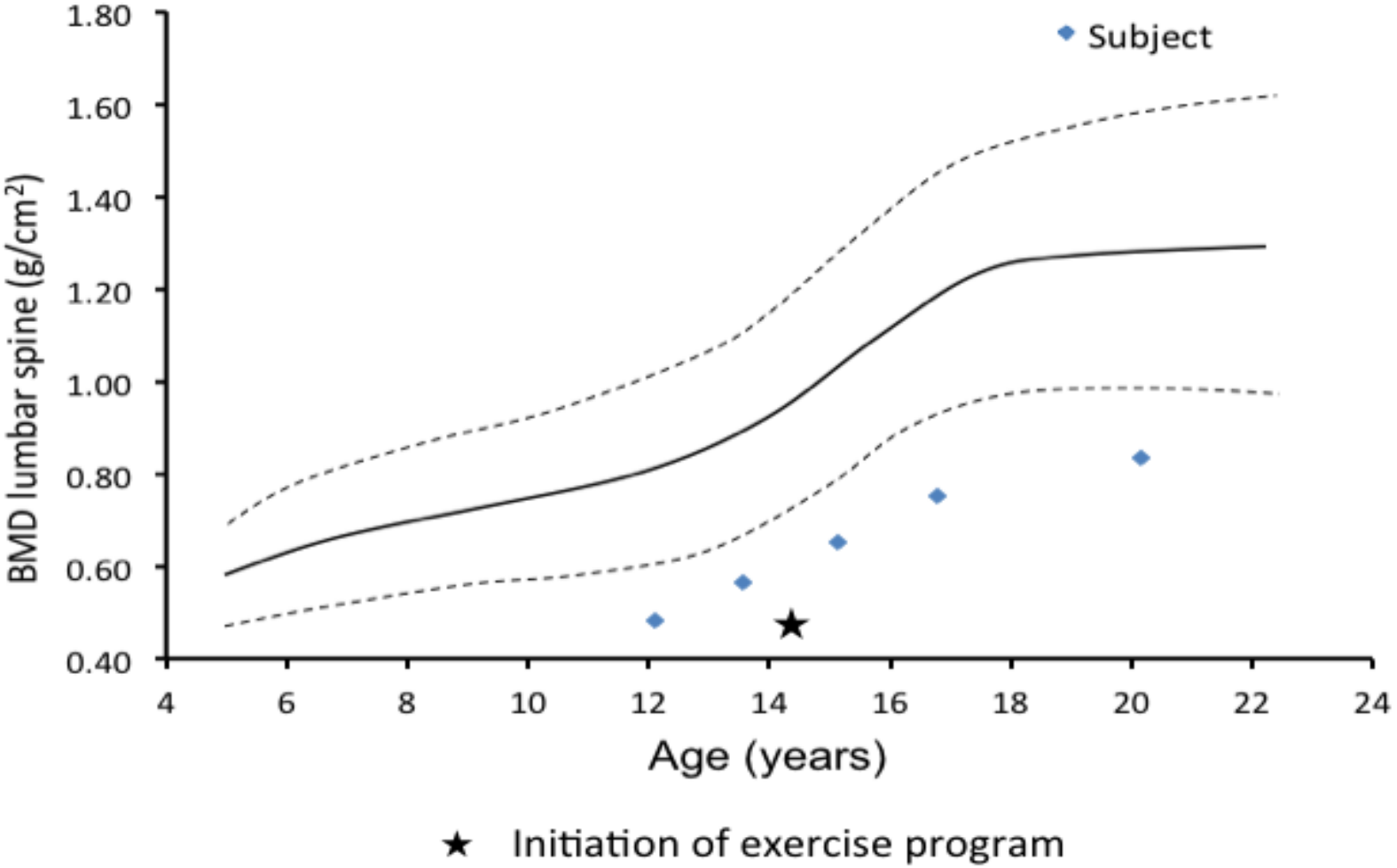


Figure 1A. A comparison of bone-mineral density between "our subject" and the data from van der Sluis et al. (2002) of DXA results from white boys, with the dotted lines representing +/- 2 SDs.

Functional Benefits

- Increased speed and available range for reaching
- Improved eye hand coordination and visual tracking
- Improved trunk control in supported sitting
- Improved ability to assist with transfers

Health/Quality of Life

- Decreased reports of subjective fatigue
- Improved bowel control
- Improved appetite and decreased reflux
- Reduced “sick time”
- Increased opportunities for socialization
- Increased feeling of power, happiness, and fun!

Dosing Message

- People with severe motor involvement **CAN PARTICIPATE IN INTENSE EXERCISE** to increase ***Muscle and Bone Strength and Mass***
- Obtaining positive personal and clinical outcomes may take

  LONGER DURATION and INCREASED FREQUENCY of exercise
- Linked to ***HAPPINESS & WELL BEING***

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