KEY CONCEPTS for Mobilizing the Stiff Hand

Judy C. Colditz, OT/L, CHT, FAOTA

STIFFNESS

- Difficult to bend; rigid
  - Lack of joint movement
    - Structures no longer move with respect to one another

Watson: 1994

STIFFNESS

- Injury
  - Begins a cascade of events to create healing

INJURY

- Immobilization
  - External
  - Internal

Tissue Response

Cortical Response

Early Motion

Return to Normal Motion

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STIFFNESS

- Intra-articular stiffness
  - Fixation of tissue layers
    - Motion between tissue layers not possible
  - Basic changes
    - Physical properties of collagen tissue

- Early motion
  - Soft tissue
    - Movement without wound disruption
  - Tendons
    - Movement without rupture
  - Fractures
    - Movement without instability
STIFFNESS

Chronic edema; fibrosis
Joint stiffness & extensive tissue adherence
Ineffectual pattern of motion; re-patterned motor cortex

Hard end-feel = P-U-S-H !!!

Response to mobilization
- Active ROM unproductive without blocking
- PROM = temporary response

Local tissue change
- Mechanical change
- Cortical change

PIP Dislocation

EVIDENCE
- Systematic review: therapy interventions for improving ROM
  - Moderate evidence after joint injury/fx
    - Use of splints or casts to increase ROM
    - Passive ROM to increase ROM

Michlovitz: 2004
EVIDENCE

- Predictors of contracture resolution with dynamic orthosis
  - Less pre-treatment stiffness
  - Shorter time since injury
  - Flexion rather than extension deficient stiffness

Glasgow et al: 2011

EVIDENCE

- Modified Weeks Test
  - Angle measurement
  - Heat & PROM (use of dynamic orthosis)
    - 30 minutes

Glasgow et al: 2011

EVIDENCE

- Modified Weeks Test
  - Large ROM improvement
    - Small degree of stiffness
  - Small ROM improvement
    - High degree of joint stiffness

Evidences

- Are we asking the right question?
  - Which orthosis to increase ROM
  - Passive ROM to increase ROM

EVIDENCE

1. Is orthotic mobilization, joint mobilization, and exercise, better than no intervention?
2. Do these interventions improve the resolution of impairments, functional limitation, and disability?
3. Is one particular type of intervention more effective than another?
4. What should be the intensity & frequency of intervention?

Michlovitz: 2004
EVIDENCE

- Question
  - Instead of
    • What is the best orthotic approach?
  - Why not
    • What is the problem & what is the best solution?

COLLAGEN

- Collagen
  - Main component of connective tissue
    • 25-35% of body protein

- Greek "kolla"
  - “Glue”
- Suffix "gen"
  - “Producing”

- Most numerous fibers in connective tissue
- Unique combination of flexibility & strength
COLLAGEN

- Inelastic
  - Tensile strength greater than steel
- Elastic quality
  - Due to relationship to other fibers

Junqueira & Carneiro, 1995

COLLAGEN

- Like nylon
  - Thread
    - Relatively inelastic
    - Knitted stocking
      - Very elastic


COLLAGEN

- New collagen
  - Less cross-linked & organized
  - Weaker

Noyes: 1977
McKee, Hannah & Priganc: 2012

COLLAGEN

New Collagen → Maturing Collagen

- Alignment depends on stress

Injury → New, disorganized, collagen → Stiffness

COLLAGEN

Injury → Immobilization

New, disorganized, collagen → Cross-linked collagen → Stiffness

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COLLAGEN

- Crosslinking
  - Creates tensile strength
  - Can prevent movement

Junqueira & Carneiro: 1995
McKee, Hanna & Priganc: 1980
Redrawn from Akeson, et al, 1980

Joint stiffness
- Crosslinked collagen due to immobility and/or
  - New, disorganized, collagen

Collagen Triple Helix


STIFFNESS


COLLAGEN

- Human tissue is viscoelastic
  - Increased deformation under a constant stress

E

time

“Soft end feel”
“Hard end feel”

New collagen/edema
Cross-linked collagen
STRESS DEPRIVATION

Tissue Response

- Peacock-1966
  - Joint stiffness caused by trauma + immobilization
- Arem & Madden- 1976
  - Elongation of new tissue subjected to stress
- Akeson et al-1980
  - Confirmed soft tissue primarily responsible for joint stiffness
- Light et al-1984
  - Low-load, prolonged stretch more effective than high load (knees)

STRESS DEPRIVATION

- Prolonged joint immobility
  - Non-physiological
  - Excessive collagen cross-linking

STRESS DEPRIVATION

Even uninjured immobilized joint:
  - Profound intra-articular & peri-articular changes
    - Histologically
    - Chemically
    - Mechanically

STRESS DEPRIVATION

Basic changes in the physical properties of collagen tissue
  - Elastic factors
    - Collagen
    - Elastin
  - Ground Substance
    - Extracellular matrix
    - Edema

Extracellular Matrix
  - Cross-linked type I collagen

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STRESS DEPRIVATION

Applied Immobilization
Mal-adapted Movement

Stress Deprivation
Joint Stiffness

Akeson et al: 1980
Akeson et al 1987
Akeson et al 1986
Arem et al 1985
Frank et al 1984
Grauer et al 1987
Meals: 1993
Noyes: 1977

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**STRESS DEPRIVATION**

- **Joint stiffness**
  - Increased cross-linking
  - Decreased water & glycosaminoglycan
  - Increased collagen turnover

- **Ligaments**
  - Lose fiber orientation
  - Have diminished mechanical properties
  - Effective shortening
  - Fibers not properly aligned

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**Lateral Collateral Ligament**

- Immobilized
- Control

- Graph: Load (Newtons) vs. Deformation (mm)

- Redrawn from Amiel et al: 1982

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**Fixation of tissue layers**

- Example: dorsal apparatus

- Photo courtesy of Marc Garcia-Elias, MD, PhD

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**Flexion of IP joints allowed by gliding**

- Laterally & distally

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**Injury** ➔ **Tissue adherence** ➔ **Mal-adapted movement** ➔ **Cortical Remapping** ➔ **NO CHANGE**
STRESS DEPRIVATION
Cortical Response

STRESS DEPRIVATION

- Representational area in brain depends on amount of stimuli
- Changes quickly!

STRESS DEPRIVATION

- Changes in input creates….
  “Cortical Competition”

STRESS DEPRIVATION

- Learned non-use
  - Monkeys with one forelimb denervation
    - “Get along quite well on 3 limbs and positively reinforce this pattern of behavior”

STRESS DEPRIVATION

Nerve injury & repair

Early
- “Silent” cortical area, deprived of sensory input

Late
- Functional reorganization of cortical hand map due to axonal misdirection

Redrawn from Silva et al 1996
Merzenich & Jenkins 1993

Taub 1977 & 1980

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STRESS DEPRIVATION

- Beyond 9 days, motor cortex representation diminishes with immobilization

Kleim et al: 1995
Liepert et al: 1995

STRESS DEPRIVATION

- Immobilization
  - Somatosensory cortex
    - Impaired tactile acuity
    - Reduced activation of finger representations
    - Compensatory effects contralateral side

Lissek et al: 2009

STRESS DEPRIVATION

- Human immobilized ankles
  - Longer the immobilization, greater the decrease in cortex area size

Liepert et al: 1995

STRESS DEPRIVATION

Unaffected muscle
Immobilized muscle
EDEMA

- Does not cause stiffness
  - Prevents motion
  - Which creates stress deprivation

- Initial effect of edema
  - Stiffness
- Prolonged edema
  - Chronic inflammation
    - Due to accumulation of plasma proteins

INTEROSSEOUS MUSCLE TIGHTNESS

- Single greatest contributor to prolonged digital joint stiffness

Mortimer: 1997
Casley-Smith: 1986
Guyton & Hall: 1997

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**INTEROSSEOUS MUSCLE TIGHTNESS**

- Elongate interosseous muscles
  - Passively
  - Actively

**INTEROSSEOUS MUSCLE TIGHTNESS**

- Active
  - MP Joint blocked in hyperextension
  - EDC cannot hold

**INTEROSSEOUS MUSCLE TIGHTNESS**

- Active
  - ONLY means to elongate the lumbral muscle

**INTEROSSEOUS MUSCLE TIGHTNESS**

- Blocking allows both interosseous & lumbral elongation

**INTEROSSEOUS MUSCLE TIGHTNESS**

- Active FDP
  - Elongates interosseous & lumbral muscles
  - Increases joint ROM
  - Decreases edema
INTEROSSEOUS MUSCLE TIGHTNESS

TISSUE RESPONSE TO STRESS

- RAT: Subcutaneous sponges & magnets in electromagnetic fields
  - Early mechanical force elongates newly synthesized collagen

Peacock & Cohen 1990

New collagen
- Mechanical stimuli affects crosslinking
  - Arrangement
  - Number
  - Thickness

Noyes 1977

TISSUE RESPONSE TO STRESS

RABBITS: wounds stressed by CPM compared to immobilization
- Wounds stressed by CPM significantly stronger, stiffer, & tougher
- Structural organization of collagen fibers superior

Grauer et al 1987

PROM only 5 min/day increased cellularity at 6 wks
- Healing tissues extremely sensitive to stress & motion

Gelberman et al 1982

Frank & Akeson et al 1984

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TISSUE RESPONSE TO STRESS

- Modulates proteoglycan synthesis
  - Akeson et al: 1977
  - Akeson et al: 1980
  - Donatelli & Owens-Burkhart: 1981
  - Frank et al: 1984
  - Noyes: 1977

- Elastic fiber
- Reticular fiber
- Macrophage
- Nerve fiber
- Lymphocyte
- Collagen fiber
- Neutrophil
- Plasma cell
- Ground substance
- Mast cell
- Fibroblast
- Fat cell
- Capillary

“Low-load prolonged stress” No formula for amount or duration
- Brand & Hollister: 1999
- Colditz: 1983
- Donatelli & Owens-Burkhart: 1981
- Kottke et al: 1966
- McClure et al: 1994
- Noyes: 1977
- Weeks & Wray: 1978

- Movement
  1. Maintains lubrication within the collagen cell matrix
  2. Prevents abnormal cross-link formation
  3. Orient new collagen fibers to resist stress
- Rx duration & contracture resolution with dynamic orthosis
  - Flexion gains faster than extension
  - Duration of treatment key to contracture resolution

- (Visco-)Elastic response
  Collagen “stretched” returns to original length & shape
- Plastic response
  Collagen is deformed by stress applied

Glasgow et al: 2012
The reality of visco-elastic behavior is what dooms stretching techniques (e.g. joint mobilization) to a very limited application in managing joint stiffness.

Most therapists believe stiff joints must be passively mobilized to create potential for active motion.

While it is broadly accepted that contracted tissues will elongate with stress, the body of literature is inconsistent with respect to the definitions of creep and stress relaxation as they pertain to living tissues.

"PROM is the gold standard in monitoring joint stiffness---rather than AROM."
Positive relationship between time stiff joint is held at end range & improvement in **PROM**

No proven correlation between increases in PROM & increases in AROM

**Flowers & LaStayo**: 1994

TERT not found to be associated with contracture resolution

**Glennon et al.**: 2011

“*I never said joint mobilization was a treatment for joint stiffness.*”

– Comment by John Mennell

Injured elbow: 3 weeks of immobilization

After Novocain: initial ROM

Repeated at weekly intervals; response progressively less

**Dehne**: 1971

Cycling of ligaments resulted in the load required to stretch the ligament a given distance decreased during the time of cycling

**Weisman et al.**: 1980
QUESTION (12/26/13)
Do you have a good explanation for patients as to why their fingers loosen up with heat/stretch and then within 2-3 hours go back to being stiff again?

ANSWER:
It is likely a relocation of extracellular fluid in the ligaments and joint capsules. When we do stretching exercises, we actually do not stretch the ligaments but just make them more supple with less extracellular fluid. When they are left alone for a while, fluid tends to re-accumulate, especially in areas recently inflamed. Patients with trigger fingers frequently comment that the triggering is worst in the morning and subsides as the day progresses.

Cartilage
- Requires slow cyclical compression & decompression
  • To absorb nutrients & expel waste

CPM: joint regeneration
- ORIF of fractures
- Joint injuries
- Arthrolysis
- Synovectomy
- Septic arthritis
- Joint release
- Total arthroplasty
- Tendon repair
- Ligament reconstruction

No laboratory or clinical studies have demonstrated effectiveness of CPM for treating joint stiffness

Rabbit model: 3 wks post fx
- Daily PROM: CPM
- Contralateral ankle immobilized
- Stiffness measured weekly
Results

- **Ankle stiffness:**
  - Significantly reduced immediately post PROM (p <0.01)
  - Exercised limbs (between sessions) significantly stiffer than immobilized limbs (p <0.01)

Grauer et al: 1987

PROM limbs

- Progressively & significantly stiffer (3 wks) than contralateral unexercised limbs
- Increased limb swelling

Grauer et al: 1987

- **Same model as Grauer**
  - Tested ankle joint stiffness & limb volume
  - Drugs, intra-articular hematoma, pressurization (10mmHg) & CPM

Meals et al: 1993

**Groups:** 3 Weeks of CPM

- 4 hrs/day
- 8 hrs/day
- 12 hrs/day
- 16 hrs/day
- 24 hrs/day

Meals et al: 1993

**Time** | **Limb Swelling** | **Joint Stiffness**
--- | --- | ---
4 hrs. | ↑ | ↑
8 hrs. | ↓ | ↓
12 hrs. | ↓ | ↓
16 hrs. | ↓ | ↓
24 hrs. | ↓ | ↓

Meals et al: 1993

**Negative response?**
Applying a mobilization orthosis is not movement!

- Early stiffness
  - Gentle PROM
- Stiffer the hand
  - PROM less effective
  - Prolonged/repeated active stress
    - To change tissue
    - To change cortical representation

Cortical Response

- Movement
  - Magnifies cortical representations
- Lack of use
  - Decreases cortical area

Active ROM with joint stiffness
- Unproductive without blocking
- Magnifies cortical representation of the wrong muscles
CORTICAL RESPONSE

▪ Squirrel monkeys trained on a small object retrieval task
  – Showed expansion of digit representation within the primary motor cortex

Nudo: 1996

CORTICAL RESPONSE

▪ Beginning of activity
  – Brain more active

▪ Habit set
  – One unit of behavior with limited brain activity

Graybiel & Smith: June 2014

CORTICAL RESPONSE

▪ Constraint induced therapy
  – Overcome learned non-use
  – Create plastic reorganization through use

Uswatte & Taub: 2013

CORTICAL RESPONSE

▪ Constraint induced therapy
  – Increased use of arm in 2 weeks
  • Retained when tested at 2 years

Taub et al: 1993

Cortical maps remain stable unless monkeys are required to learn a NEW motor skill

Plautz et al: 2000

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CORTICAL RESPONSE

- Stroke patients: 72 hours
  - Improvement 2PD in non-immobilized hand
  - Redistribution of hemispheric dominance
- Confirms
  - Rapid inter-hemispheric plasticity

Weibull et al: 2011

CORTICAL RESPONSE

- Constraint induced therapy
  - Shaping
    - “Desired motor behavior approached in small steps”
      1. Explicit feedback
      2. Verbal reinforcement
      3. Appropriate task selection

Uswatte & Taub: 2013

CORTICAL RESPONSE

- 4 Components
  1. Intensive training/multiple days
  2. Use of small steps
  3. Behavior techniques
    • Designed to transfer gains to real world use
  4. Restraint of other arm

Uswatte & Taub: 2013

CORTICAL RESPONSE

- Reactivation previous cortical mapping
  - Original cortical patterns persist
  - Can be easily re-activated

Kaas: 1991
Liepert et al: 2000

QUESTION

- If we can change the brain with direct injury...why not harness the uninjured brain to reduce motor reorganization in the stiff hand???

TRADITIONAL TREATMENT
TRADITIONAL TREATMENT

- 9 stroke patients
  - 1 wk usual physiotherapy
  - Then 1 wk constraint
    - Motor output of APB prior to & after treatment

Liepert et al.: 1998

TRADITIONAL TREATMENT

- Before treatment
  - Cortical representation significantly smaller on affected side
- After 1 wk conventional therapy
  - No change
- After 1 week constraint
  - Motor output map significantly enlarged & significant improvement in dexterity

Liepert et al.: 1998

TRADITIONAL TREATMENT

- Stress alters collagen
- NO basic research supports any particular treatment regimen for joint stiffness

Grauer & Kabo et al. 1987
Meall: 1995

TRADITIONAL TREATMENT

- Example: PIP joint stiffness
  - Hyperextension of MP joint

TRADITIONAL TREATMENT

- EDC pull proximal to MP
  - MP extension/hyperextension
  - Slight PIP extension
  - Very slight DIP extension

Kaplan: 1959

TRADITIONAL TREATMENT

- Example: PIP Joint Stiffness
  - Hyperflexion of MP joint
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TRADITIONAL TREATMENT
- Static
- Serial Static
- Static Progressive
- Dynamic

TRADITIONAL TREATMENT
1. Passive force
2. Immobilization
3. Constriction
4. No cortical involvement

TRADITIONAL TREATMENT
- Based on an unproven assumption
  – PROM is necessary to gain AROM

CASTING MOTION
TO MOBILIZE STIFFNESS (CMMS)

CMMS
Active
- 9 months following distal radius fracture

CMMS
Active
- 9 months following distal radius fracture

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CMMS

“Old Ideas”
- PROM before AROM
- Never immobilize MP joints in extension
- Never lose motion in one direction to gain another
- Never immobilize any part of a stiff hand

Edwin Land
Creator of Polaroid

CMMS

“Cyclical active motion”
- Mobilizes stiff joints
- No previous model

CMMS

“Plaster of Paris casting”
- Selectively immobilizes proximal joints to direct distal joint motion

CMMS

“What other treatment can gain flexion & extension simultaneously?”

CMMS

TC: TAM vs TPM of Long Finger

Chronic edema; fibrosis
Ineffectual pattern of motion: re-patterened motor cortex

Joint stiffness & extensive tissue adherence

Chronic Stiffness

1. Active motion mobilizes stiff joints

2. Active motion re-patterns the cortex

3. Active motion pumps stagnant lymphatics

CMMS - MECHANICAL

CMMS - MECHANICAL
- Abnormal pattern of movement

CMMS - MECHANICAL
- Joint blocking
  - Force directed to stiffest joints

CMMS - CORTICAL
- Once novel motor task is learned, functional topography remains altered for long time
- Repeated motion over time is required for effective re-patterning
CMMS - CORTICAL

1. Conscious attention
2. Re-activate previous representations
3. Requires time

- Repetitive, passive motion without attention
  - insignificant changes
- Focused attention with motion required

CMMS - LYMPHATIC

- Limited AROM restricts pumping of lymphatic system
  - May or may not be injury to lymphatic system

CMMS - LYMPHATIC

- Excess fibrosis caused by high-protein edema impedes flow of fluid & proteins to the initial lymphatics

CMMS - LYMPHATIC

Stagnant lymphatic system mobilized by:
1. Active motion
2. Consistent light pressure
3. Warmth
4. Light massage/pressure

Casley-Smith & Casley-Smith: 1986

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1. **Active motion**
   - The SINGLE most effective stimulator of the lymphatic system

   Ryan and Mortimer et al: 1986
   Leduc et al: 1984
   Casley-Smith & Casley-Smith: 1986
   Guyton: 1987
   Mortimer: 1997

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2. **Consistent light pressure**
   - Lymphatic vessels
     - Weak, thin, fragile structures

   Ryan et al: 1986

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3. **Warmth**
   - Direct relationship between
     - Ambient temperature
     - Permeability of initial lymphatics

   Xujian: 1990
   Ohkuma: 1990

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4. **Light massage**
   - Initial lymphatics (in skin) require minimal pressure
     - Movement
     - External compression
     - Arterial pulsation
     - Gentle compression/relaxation is best

   Ohkuma: 1990
   Ryan et al: 1986
   Miller & Seale: 1980

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ACTIVE REDIRECTION

- New belief
  - Active motion can increase passive motion

Adherence
Passive ROM/Orthosis
ICAM (Immediate Controlled Active Motion)
- Relative Motion Orthosis
- Yoke Orthosis
- Merritt Orthosis

Howell et al. 2005

PIP FLEXION

PIP EXTENSION
ACTIVE REDIRECTION

- Example
  - Increased participation by the lateral bands

ACTIVE REDIRECTION

- Directing FDP power to IP joints
  - Mobilizing joints
  - Elongating interosseous muscles

ACTIVE REDIRECTION

Orthosis
- Only one direction
- Edema increased?
- No cortical change

Active Redirection
- Differential glide
  - Edema reduced
  - Cortical re-mapping

THE FUTURE
THE FUTURE

- Cortical re-patterning as part of rehab of stiff joints

- Silver nanowires
  - New wearable, stretchable, multifunctional sensor

- Mirror visual feedback (MVF)

- Cerebral Preparation During Immobilization

- Nature documentary
- Action observation
- Motor imagery

- Roll et al. 2015

- Bassolino et al. 2013

- Before
- After (50 hrs.)

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THE FUTURE

- 8 Subjects
  - Full immobilization
    - Vibration: fingers & wrist to simulate movement perception
  - Controls
    - No stimulation

- After 5 days
  - Immobilization group
    - fMRI: preserved sensorimotor networks
  - Control group
    - Significantly altered

Roll et al. 2012

CONCLUSIONS

CONCLUSION

- The question is no longer just about passive dosage
- Active (redirected) motion
  - Provides ideal dosage
  - Mechanical stress AND
  - Cortical stress

Active change the mechanics to change the motor cortex

CHALLENGE

I dare you to prove it!!

ADDITIONAL INFORMATION

www.HandLab.com
- Clinical Pearls explaining interosseous & lumbrical muscle tightness testing

Conflict of Interest
- Nuances of Mobilizing the Stiff Hand: Online Course