Objectives
- Tendon healing
- Controlled stress
- Tensile strength
- Protocols

Keys to successful treatment
- Doing the wrong thing can lead to injury
- Not doing enough of the right thing can cause poor outcomes
- Use the following resources
  - Mentors
  - Surgeons
  - Protocols
  - Evidence

Tendon Healing

Tendon healing
- Extrinsic healing
  - Adhesion formation between tendon and surrounding tissue
  - Potenza and Peacock (1960-70s)
    - Tendons healed by fibroblastic response (adhesions)
    - Tendon cells were incapable of proliferating
    - “One wound” concept = tendon healing though adhesion formation

- Intrinsic vascularity and synovial diffusion
  - Fibroblasts needed for healing
  - Supplied by the endotenon and epitendon
  - Tenocytes appearing at 2-3 weeks

  - Gelberman et al., Manske et al., Lundborg et al. (1980s)
Factors that affect tendon healing
- Age
- Individual biochemical response
- Nutrition
- Mechanism/type of injury
  - Crush or untidy laceration
  - Associated fractures or blood vessel injury
  - Controlled stress

Controlled stress
- Promotes intrinsic healing
- Encourages longitudinal orientation of adhesions
- Decreases joint stiffness

Physiologic response
- Improved tensile strength
- Improved tendon excursion
- Improved repair site cellularity
- Enhanced nutrition and intrinsic healing via synovial fluid
- Reorganization, elongation, and reorientation of extrinsic scar

Consideration for application
- Type of injury
- Zone of injury
- Repair technique
  - Number of strands
  - Epitendinous suture
  - Ensure strong enough repair for controlled stress
- Patient factors
  - Age, cognitive status, adherence

Precise transmission
- Provide enough stress to move tendon a controlled amount
  - 3-5 mm as determined by Gelberman and Duran
- Avoid gapping or rupture
Minimal Active Muscle Tendon Tension (MAMTT)

- Minimal tension required to overcome the viscoelastic resistance of the antagonistic muscle-tendon unit
- MAMTT not a "protocol" but a concept used to guide therapy in addition to early passive protocol
- Wrist extended to 20-30°
- MP flexion to 80°
- PIP flexion to 75°
- DIP flexion to 30-40°

Tendon tensile strength

- Decreases during the first week following a repair
  - Mason & Allen, 1941
- Progressive increase after the first 2-3 weeks
- Increase in strength proportional to the amount of stress provided
- Immediate controlled stress to the healing tendon facilitates a reversal of the initial weakening process
- Maximum collagen synthesis occurs at 3 weeks

Estimated repair strength

<table>
<thead>
<tr>
<th>Strands</th>
<th>0 week</th>
<th>1 week</th>
<th>3 weeks</th>
<th>6 weeks</th>
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<tr>
<td>2</td>
<td>2500gm</td>
<td>1250gm</td>
<td>1700gm</td>
<td>2700gm</td>
</tr>
<tr>
<td>4</td>
<td>4300gm</td>
<td>2150gm</td>
<td>2800gm</td>
<td>5200gm</td>
</tr>
</tbody>
</table>

Active wrist flexion

up to 300gm of force
Schuind et al., 1992

Active wrist extension

up to 400gm of force
Schuind et al., 1992
Passive, protected digital extension

up to 400gm of force
Urbaniak et al., 1975; Schuind et al., 1992; Lieber et al, 1996-1999; Groth, 2004

Place and hold synergistic flexion

up to 900gm of force
Evans et al., 1993; Groth, 2004

Active straight fist

up to 1100gm of force
Greenwald et al., 1994; Groth, 2004

Active hook fist

up to 1300gm of force
Greenwald et al., 1994; Groth, 2004

Active composite fist

range 400-4000gm of force
Urbaniak et al., 1975; Schuind et al., 1992; Greenwald et al., 1994; Evans, 1997; Silva et al., 1998; Gelberman et al., 1999; Boyer et al., 2001; Groth, 2004

Active, isolated joint motion

up to 1900gm of force
Schuind et al., 1992; Groth, 2004
**Protocols**

- **Key Concepts**
  - The therapist MUST
    - Understand concepts of applying controlled stress
    - Know the type of injury and repair performed
  - No single protocol is appropriate for all repairs
    - Surgeon/therapist interaction is vital to this process
  - Literature will vary with regard to timing

- **Types of Protocols**
  - **Immobilization**
    - Little to no controlled stress on a repaired tendon
  - **Early passive mobilization**
    - Controlled stress on the healing tendon with active IP extension and passive flexion
  - **Early “active” mobilization**
    - Higher level of controlled stress on repaired tendon
    - Gentle contraction of the repaired musculotendinous unit
    - Results in proximal gliding of the repaired tendon

- **Protecting the repair**
  - Joints supported in flexion
  - Puts flexor tendon on slack
  - Prevents gapping or rupture through excessive traction on the tendon

- **Treatment Progression**
  - If adhesions are significantly limiting tendon gliding
    - PROGRESS treatment
  - If tendon gliding is good
    - PROTECT the tendon from resistance and potential rupture for a longer period of time
  - How do you know??

- **Measurement**
  - Strickland & Glogovac, 1980
  - \[
  \text{Active PIP + DIP flexion – extension lag} \times \frac{100}{175} = \%
  \]
  - % of normal active PIP and DIP motion
  - Excellent: 85-100%
  - Good: 70-84%
  - Fair: 50-69%
  - Poor: <50%
**Immobilization**

- **Rationale/Used for:**
  - Children (those under age 10-12)
  - Cognitively impaired
  - Non-adherent patients

- **Extrinsic Healing**

  - **Early stage** (up to 4 weeks)
    - Dorsal blocking orthosis or cast
    - Wrist 10-30° flexion
    - MP 40-60° flexion
    - IP in extension
    - If therapy is provided:
      - Passive flexion of the digits
      - Mobilization of uninvolved joints
      - Wound/scar management
    - Cifaldi-Collins & Shwarze, 1991

  - **Intermediate Stage** (3 to 6 weeks)
    - Orthosis modified to wrist neutral
    - Removed for hourly exercises to include:
      - Passive flexion and extension of fingers with wrist in 10° extension
      - Active flexion: hook, straight, and full fist.
      - Synergistic motion
    - **BE GENTLE...immobilized tendon is generally weaker**

  - **Late Stage** (5 to 6 weeks)
    - D/C dorsal blocking orthosis
    - Add serial extension splinting
    - Begin gentle blocking exercises
    - After 1 week of gentle blocking, may initiate light resistance
      - If tendon gliding is good, delay any resistance

- **After 3-4 days, assess tendon gliding**
  - Measure full MP/PIP/DIP flexion passively and actively
  - If >50° difference is present, move to the late stage
  - If <50° difference noted, continue with intermediate phase of the program until 6 weeks post-op
Early Passive Mobilization

**Rationale:**
- Promoting *synovial diffusion for healing*
- Inhibit dense adhesion formation
- Facilitate a stronger repair at an earlier stage

**Two main protocols**
- Duran & Houser
- Kleinert

"Original" Duran & Houser

- **0-4 ½ Weeks**
  - Orthosis
  - Dorsal block with wrist in 20° flexion, and MPs in a relaxed state of flexion:
    - Orthosis ends at PIP joints to allow full IP extension
    - Rubber band traction to the injured finger (loosely) during the day
  - Between exercises stockinette is applied over the fingers and pinned to forearm
    - All fingers resting in flexion within stockinette to prevent impulsive grasping

"Original" Duran & Houser

- **Exercises:** 6-8 repetitions, 2x/day within orthosis that blocks MP in flexion
  - Passively extend DIP while PIP is held passively in flexion
  - Passively extend PIP while DIP rests in flexion

"Original" Duran & Houser

- **4 ½ Weeks**
  - Replace dorsal block with a wrist band with rubber band traction
  - Exercises: 10 repetitions every 2 hours as previous
  - Add gentle active extension against the rubberband traction.

"Original" Duran & Houser

- **5 ½ Weeks:**
  - Hourly exercises: 10-12 repetitions
  - Remove wrist band and nail suture for rubber band attachment
  - Active flexion is initiated: gentle blocking, FDS gliding, and composite fist
  - Passive flexion of all joints
  - IP passive extension with MP flexed
**“Original” Duran & Houser**
- 6 Weeks
  - Begin gentle PIP extension
  - Dynamic splinting if needed
- 7 ½ Weeks
  - Initiate gentle resistance
  - No strong resistance to the tendon for another 2-4 weeks

**“Modified” Duran**
- Eliminate the rubber-band traction
- Extend the DBS hood to the fingertips
- Strap the fingers in IP extension at night
- Exercises:
  - Passive flexion: isolated and composite
  - Active IP extension
  - Passive protected extension
  - Protected tenodesis in therapy if appropriate

**Modified Kleinert Protocol**
- Dorsal blocking orthosis
  - Wrist in 45° flexion
  - MPs 40° flexion
  - IPs allowed full extension
  - Volarly applied “PFT” (postoperative flexor tendon)

**Modified Kleinert Protocol**
- The PFT is a prefabricated orthosis
  - Rubber band traction runs from the fingernail under a rolling bar at the palm, to a coiled lever at the forearm.
  - Coiled lever and rolling bar on the PFT
  - Designed to minimize resistance within the rubber band during IP extension
**Modified Kleinert Protocol**

- Exercises: 20 repetitions per hour
- 0-4 to 6 weeks
  - Active IP extension against rubber bands
- 3-6 weeks
  - Remove orthosis for wrist motion at 4 weeks
  - Begin gentle active flexion
- 6 weeks
  - Discontinue orthosis
  - Add differential tendon gliding exercises
- 6-8 weeks
  - Begin gentle resistance

**Washington Regimen**

- Dorsal blocking orthosis
  - Wrist at 20-45° flexion
  - MP at 40-60° flexion
  - IPs allowed full extension
- A safety pin is applied to the palmar strap at the distal palmar crease, and on the forearm strap
  - A nylon line is run from the fingernail of the injured finger(s) only, under the safety pin at the DPC, attaching to 2 rubber bands
  - One rubber band is cut, so that it is only a single strand
  - One rubber band with exercise; 2 at rest

**Washington Regimen**

- Full finger flexion to the distal palmar crease strap is attempted with singular rubber band traction

**Washington Regimen**

- 0-3 weeks
  - Therapist performs protected passive flexion and extension
  - Active extension against traction x10 reps, hourly
  - Rubber band traction on 24 hours/day
- 4 weeks
  - Discontinue rubber band traction
  - Begin active flexion with an active hold in flexion for 10 seconds, passive flexion, and active extension

**Washington Regimen**

- 5 weeks
  - May be allowed out of orthosis for hygiene and light activity
- 6 weeks
  - Discontinue orthosis
- 8 weeks
  - Add blocking if needed
  - Gradual increase in use and resistance
  - Heavy lifting above 5lbs not allowed until after week 12 post-op

**Zone I Protocol: LEAF**

- Limited extension active flexion (LEAF)
  - Evans, 1990
- Rationale:
  - Place the repaired FDP tendon in a shortened position
  - 4.5mm proximal to normal resting length
  - Decrease gap formation
  - Therapy initiated at 24 – 48 hours post op
Zone I Protocol: LEAF

Early Stage (0-3 Weeks)
- Dorsal blocking orthosis
- Wrist at 30-40° flexion
- MP at 30° flexion
- Full IP extension allowed
- A separate finger based dorsal gutter is taped on with the DIP joint at 40-45° flexion

Weeks 0-4
- Exercises- 10-20 reps/hour:
  - Passive DIP flexion to 75° in orthosis
  - Passive composite flexion
  - Passive IP flexion with MP's resting at 30° in orthosis (modified hook position)
  - Full active PIP extension while other hand holds MP's at 90° flexion
  - With distal strap holding adjacent fingers in extension, place and hold PIP joint flexion of injured finger

In therapy, orthosis removed for:
- Passive wrist tenodesis
- Slow repetitive motions to loosen finger
- Short arc motion (SAM) place and hold against 15-20g of force in the following position:
  - Wrist extension = 20
  - MP flexion = 75-80
  - PIP flexion = 70-75
  - DIP flexion = 40

Weeks 3-4
- Discontinue DIP dorsal blocking gutter
- Add gentle place/hold flexion

Week 4 ½
- Add synergistics, hook fist, and gentle DIP blocking for FDP glide
- Orthosis remolded to wrist neutral
- May begin DIP extension orthotic PRN

Week 6-7
- Discharge orthosis

Zones III through V
- Repairs are most commonly placed in the preferred Zone II protocols
- Less complications and better results
  - Do not have the tight pulley/sheath system
  - Adhesions are often less dense
- Watch intrinsic scarring and/or paradoxical extension in zone III

EARLY “ACTIVE” MOBILIZATION
**Indiana Protocol**

- **Repair technique**
  - Tajima core suture plus horizontal mattress
  - Equal to 4 strand repair plus epitendinous suture
- **Criteria**
  - Motivated, understanding patients
  - Minimal to moderate edema which does not restrict passive flexion
  - Minimal wound complications

- **Week 0-4**
  - **Dorsal blocking orthosis**
  - Wrist 20° flexion, MPs 50° flexion, IPs allowed full extension
  - Worn continuously
    - Once hourly: remove and apply hinged wrist splint
    - Immediately reapply dorsal blocking splint after exercises

- **Synergistic orthosis with hinge**
  - Allows full wrist flexion and 30° extension
  - MPs blocked at 60° flexion
  - IPs allowed 0° extension

- **Week 0-4**
  - Passive:
    - 15 reps of passive flexion/extension to the PIP joint, then the DIP joint, then entire digit
    - Apply synergistic orthosis for 25 reps of place/hold
      - Passively flex digits & simultaneously extend wrist
      - Gentle place/hold contraction for 5 seconds
      - Simultaneous wrist flexion with digit extension to orthosis

- **Week 4:**
  - Discharge synergistic orthosis
  - Continue dorsal blocking orthosis between exercise
  - Exercises
    - Synergistic motion: 25 reps every 2 hours
    - Add light active finger flexion and extension
    - Avoid combined finger and wrist extension

- **Week 5**
  - Exercises
    - Continue week 4 exercises
    - Add tendon gliding and hook fisting

- **Week 6**
  - Discontinue dorsal blocking orthosis
  - Exercises
    - Continue previous exercises
    - Add blocking exercises
    - Do not perform blocking exercises to the small finger FDP
**Indiana Protocol**

- Week 7
  - Add passive extension exercises
- Week 8
  - Add light resistance
- Week 14
  - Return to normal activity

**Pyramid of Progressive Force**

- Pyramidal series of eight exercise levels in ascending order of increasing force
  - The patient progresses up a level in the pyramid if the tendon is unresponsive
    - Unresponsive = ≤ 10% resolution of active lag between therapy sessions
    - Continue progression until the tendon is responsive
      - > 10% resolution of active lag between therapy sessions

**Pyramid of Progressive Force**

- The active lag is measured:
  \[
  \frac{\text{Current DIP flexion} - \text{previous DIP flexion}}{\text{previous DIP flexion}} \times 100 = \% \text{ resolution of active lag between therapy sessions}
  \]

<table>
<thead>
<tr>
<th>Active Lag Status</th>
<th>Resolution of Active Lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absent</td>
<td>≤ 5 degree discrepancy between active and passive flexion</td>
</tr>
<tr>
<td>Responsive</td>
<td>≥ 10% resolution of active lag between therapy sessions</td>
</tr>
<tr>
<td>Unresponsive</td>
<td>&lt; 10% resolution of active lag between therapy sessions</td>
</tr>
</tbody>
</table>

**Nantong**

Tang, 2007
Mass & Saint John
Coats et al., 2005; Clancy & Mass, 2013; LaLonde, 2013

Manchester Short Splint
Peck, 2014

Manchester Short Splint
Peck, 2014
- 62 forearm-based
- 40 Manchester short
  - Significantly less flexion contracture at PIP at 6 and 12 weeks
  - Significantly greater arc of flexion at DIP
  - Greater proportion of excellent/good results

Review of Objectives
- Tendon healing
- Controlled stress
- Tensile strength
- Protocols

Thank you!