Flexor Tendon Injuries

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Objectives

1. Describe the benefits of early motion on flexor tendon healing.
2. Prioritize interventions based on excursion, force, and optimal timing.
3. Rationalize immobilization in terms of timing and positioning.

Part 1: Tendon Healing & Biomechanics

Early Conservatism

- *Mason & Allen (1941)*
  - Exudative and formative stages
  - Immobilization during exudative
  - Stimulation of strength and tendon glide deferred until formative
- *Potenza (1963)*
  - Immobilization protocol; injured tendons depend solely on extrinsic processes for healing
- *Peacock (1965)*
  - “One-wound” concept

Tendon Healing

Extrinsic Healing
Paradigm Shift

- Lundborg & Rank (1978, 1980)
  - Intrinsic healing nourished by synovial fluid
- Gelberman et al. (1980-1989)
  - Application of stress through early passive motion leads to more rapid recovery of tensile strength, fewer adhesions, improved excursion, better nutrition, and minimum repair site deformation
- Hitchcock, Light, & Bunch (1987)
  - Loss of strength and softening of tendons often observed post-operatively are not inevitable; rather a consequence of immobilization

Clinical Implications

- Intrinsic healing capability of flexor tendons
- Beneficial effects of early motion
  - Increased strength and excursion
  - Fewer peritendinous adhesions

The practice of immobilization following flexor tendon repair, unfortunately not obsolete, should be replaced by early motion protocols in the vast majority of situations.

Work of Flexion

Timing of Early Motion

- Inflammatory phase
  - 48-72 hours
- Fibroblastic phase
  - 4 days through 5 weeks
- Remodeling phase
  - Through 112 days

(Strickland, 2005)

Work of Flexion (WOF)

- Mayo Clinic: Amadio and colleagues
  - Work necessary for active flexion
  - Influenced by intrinsic and extrinsic factors
    - Surface friction, bulk of the repaired tendon, tendon adhesions, mass of the digit, joint stiffness, soft tissue resistance, and resistance of the antagonistic musculature

Work of Flexion (WOF)

- Tanaka et al. (2003)
  - Interaction between gliding resistance and WOF
  - WOF decreased on 5th post-operative day
  - Increased at day 7 with notable adhesions and stiffness
  - Increased number of strands correlated with increased WOF
Work of Flexion (WOF)

- Zhao et al. (2004)
  - Day 7 as least favorable
  - Day 5 as optimal
- Zhao et al. (2005)
  - “Safe zone” for early motion
  - Lower limit: WOF
  - Upper limit: repair site strength
  - Day 5 with decreased WOF as compared to day 1

Edema and WOF

- Cao et al. (2005-2008)
  - Increased gliding resistance proportional to area and severity of edema
  - Gentle motion noted to reduce gliding resistance
  - No significant difference in tendon gliding force or WOF between days 3-9
    - Day 4 or 5 as ideal
    - Day 7-9 as acceptable
  - Observation of edema should inform the range, frequency, and speed of exercise

Clinical Implications

- Timing of referral to hand therapy?
- Optimal initiation of early motion at day 4-5
- Day 7 as potentially least favorable
- Moderate to maximal edema creates increased resistance on the healing tendon
  - Decrease range of motion and frequency of exercise
  - Tendon glide with slow and controlled movement

Biomechanics

Length-Tension Relationships

- A muscle is capable of increased force production at its’ optimal length
- If lengthened or shortened beyond optimal length, the amount of active tension that the muscle fiber is able to generate decreases
  *Levangie & Norkin, 2001*

Active Insufficiency

- The diminished ability of a muscle to produce or maintain force at the extremes of joint motion
- A muscle that crosses multiple joints is unable to work at all joints simultaneously
Passive Insufficiency
- Insufficient length of a muscle to be simultaneously stretched over all the joints the muscle crosses
- Non-contractile muscle components
  - Connective tissue
  - Tendons
  - Fascia

Synergistic Motion
- Agonist-synergist balance
- Negates active insufficiency
- Wrist extensors act as synergists during digital flexion; facilitating the length-tension relationship and therefore, force production of the extrinsic finger flexors
- The opposite occurs during the digit extension when wrist flexors take over the synergist role

Tenodesis
- Natural phenomenon based on the length-tension relationship of the extrinsic wrist and digit musculature
  - Passive digital flexion during active wrist extension
  - Passive digital extension during active or gravity-induced wrist flexion
- Tenodesis uses passive insufficiency as a functional advantage

Close-Packed Position
- Optimal position for immobilization
  - Ligaments maximally taut
  - Joint surfaces maximally congruent
  - Joint spaced minimized
  - Wrist extension with ulnar deviation
  - Maximal MP flexion
  - Digital PIP/DIP extension
  - Thumb anteposed
  - Thumb MP/IP extension

Part 2:
Analysis of Therapeutic Exercise

Flexor Tendon Protocols
Modified Duran Protocol
With Duran’s passive range of motion
(AAOS: Duran & Houser, 1975)

Kleinert Protocol
with Brooke Army Hospital modification
(Kleinert et al., 1975; Chow et al., 1988)

Indiana Protocol
(Cannon, 1993, 2002)

Indiana Protocol
- Prior to week 4
  - Synergistic place and hold exercises in splint
- Week 4
  - Synergistic place and hold exercise out of splint
- Week 5
  - Composite flexion and extension of wrist/hand
- Week 6
  - Isolated PIP and DIP flexion

Pyramid of Progressive Force Application
(Journal of Hand Therapy: Groth, 2004)

Modified Synergistic
(Journal of Hand Therapy: Amadio, 2005)
Evolution of the Literature

Focus on digital motion

- Duran & Houser (1975)
- Klienert et al. (1975)
- Lister et al. (1977)
- Strickland & Glogovac (1980)
- Creekmore et al. (1984)
- Gelberman et al. (1980-1989)
- Hitchcock et al. (1987)
- Chow et al. (1988)
- Knight (1987)
- Citron & Forster (1987)
- Dovelle et al. (1988)
- Small (1989)
- Cullen et al. (1989)
- Lee (1990)
- Evans & Thompson (1993)

General conclusions

“Protected early motion can effectively restore the tendon’s gliding surface and lead to improved repair site strength and excursion.”

(Gelberman et al., 1986)

- Early mobilization of digits as more effective than immobilization
- Multiple splint and exercise regimens focused on digital motion

Savage, 1988

- Least active force to produce motion as “minimal active tension”
- Measurement of passive tension
- Increased passive tension results in increased “minimal active tension”
- Wrist extension with MP flexion as producing least passive tension, and therefore decreasing “minimal active tension”
Cooney et al., 1989
- Cadaveric study of 4 arms
- Comparison of Klienert and Brooke Army Hospital splints/motion with “synergistic” motion
  - Passive wrist and digital motion
- “Synergistic” motion demonstrated highest amount of FDS, FDP, and differential excursion

Strickland & Cannon, 1993
- The Indiana Protocol
- Place and hold digital flexion with the wrist extension, followed by active digital extension with wrist flexion
- Ambiguous as to active versus passive wrist extension and flexion

Evans & Thompson, 1993
- Minimal Active Muscle Tendon Tension
  - MAMTT
  - 45° wrist extension
  - 83° MP flexion
  - 75° PIP flexion
  - 40° DIP flexion

Lieber et al., 1996-1999
- “Normal” tendons; canine model
- Forces exerted on the flexor tendon as highly dependent on passive wrist position
- Synergistic motion resulted in low passive forces on the flexor tendon with high excursion
Zhao et al., 2002
- 80% laceration; canine model
- Passive digital flexion during passive wrist extension as effective "pulling force" to facilitate proximal glide

Synergistic Motion
1. Decreases passive tension
2. Decreases active tension
3. Increases excursion
4. Effectively facilitates proximal glide

"The ideal postoperative therapy would use the smallest force to achieve the largest tendon excursion."
(Zhao et al., 2002)

Combined Digit and Wrist Flexion
1. Increases passive tension
2. Increases active tension

*Asking your patient to either perform place hold or active fisting when the wrist is flexed actually demands MORE force than the same motions performed with the wrist extended!*

Tendon Excursion
Excursion

- Synonymous with *tendon glide*
- The amount of differential motion that occurs between the tendon and the surrounding structures
  - Other tendons
  - Tendon sheath
  - Local bony architecture
- Calculated using mathematical models and measurement of actual tendons

“The ideal postoperative therapy would use the smallest force to achieve the largest tendon excursion.” (Zhao et al., 2002)

Passive, protected digital extension

3-8mm
Distal

*Duran & Houser (1975)*

Place and hold synergistic flexion

FDS 26mm
FDP 33mm
Proximal

*Wehbe & Hunter (1985)*

Active straight fist

FDS 28mm
FDP 27mm
Max FDS
Proximal

*Wehbe & Hunter (1985)*

Active hook fist

FDS 13mm
FDP 24mm
Max differential
Proximal

*Wehbe & Hunter (1985)*
Active composite fist
FDS 24-26mm
FDP 32-33mm
Max FDP
Proximal

Wehbe & Hunter (1985)

Active, isolated PIP flexion

~13mm (calculated)
FDP
Proximal

Active, isolated DIP flexion

~6.5mm (calculated)
FDP
Proximal

Clinical Implications
• Straight fist: maximal FDS excursion
• Hook fist: maximal differential excursion
• Synergistic motion: increases total and differential excursion
• Limited range of motion to avoid adhesions
  • Between 30-40° at the PIP and DIP

Understanding Forces
• Increased force in rehabilitation does not accelerate accrual of strength (Boyer, 2001)
• Force analysis enables safe progression within reasonable time frames
• Force analysis tells us both:

  HOW TO PROGRESS
  AND
  HOW NOT TO PROGRESS
Active wrist flexion

300gm

Schuind et al., 1992

Active wrist extension

400gm

Schuind et al., 1992

Passive, protected digital extension

200-300gm

Urbaniak et al., 1975
Schuind et al., 1992
Lieber et al., 1996-1999

Place and hold synergistic flexion

900gm

Lieber et al., 1999
Evans et al., 1993

Active straight fist

1100gm

Greenwald et al., 1994
Active hook fist

1300gm

Greenwald et al., 1994

Active composite fist

400-4000gm

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

Active, isolated PIP flexion

900gm

Schuind et al., 1992

Active, isolated DIP flexion

1900gm

Schuind et al., 1992

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Excursion</th>
<th>Force</th>
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</thead>
<tbody>
<tr>
<td>Passive protected extension</td>
<td>3-8mm distal</td>
<td>200-300gm</td>
</tr>
<tr>
<td>Place and hold synergistic flex</td>
<td>26/33mm proximal</td>
<td>900gm</td>
</tr>
<tr>
<td>with active wrist extension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active straight fist</td>
<td>28/27mm</td>
<td>1100gm</td>
</tr>
<tr>
<td>Active hook fist</td>
<td>13/24mm differential proximal</td>
<td>1300gm</td>
</tr>
<tr>
<td>Active composite fist</td>
<td>24-26/32-33mm</td>
<td>400-4000gm</td>
</tr>
<tr>
<td>Active, isolated PIP flexion</td>
<td>~13mm FDP proximal</td>
<td>900gm</td>
</tr>
<tr>
<td>Active, isolated DIP flexion</td>
<td>~6.5mm FDP proximal</td>
<td>1900gm</td>
</tr>
</tbody>
</table>

Strickland, 1993; Urbaniak et al., 1975
Joint Motion

Production of Motion

- Dependent on two structural factors
  - the integrity of the tendon
  - the ability of the tendon to glide smoothly within the sheath and past adjacent structures

The integrity of the repaired tendon is observed as a function of its ability to translate forces from the musculotendinous unit towards the bony insertion, ultimately producing joint motion.
Observation of Motion

- Employed by surgeon to confirm the diagnosis
- Employed by therapist as a clinical indicator of the integrity of the repair
  - A gap occurs when the repaired ends retract from one another, leading to decreased active range of motion
  - In the unfortunate case of a rupture, active range of motion is lost, as the repair has been compromised

Tendon Gliding and Motion

- During flexion, shortening of the muscle fibers exerts contractile forces on the musculotendinous junction, resulting in proximal glide of the tendon and movement of the tendinous insertion towards the muscle belly
- Passive lengthening of both contractile and non-contractile components allow for distal glide of the flexor tendon as the digit achieves composite extension

Evaluation of Motion

- Comprehensive and consistent goniometric measurement
  - proximal interphalangeal (PIP) to assess the flexor digitorum superficialis (FDS)
  - distal interphalangeal (DIP) to assess flexor digitorum profundus (FDP)

Comparison of Motion

- Tendon gliding is readily measured as the comparison between active and passive composite flexion
- Place and hold flexion can be employed as a means to safely assess the healing tendon without subjecting it to unnecessary forces
- A discrepancy between active/place and hold and passive range of motion is considered indicative of adhesion formation between the healing tendon and the surrounding structures (Strickland, 1985)

American Society for Surgery of the Hand (ASSH)

- 1983 Report of the Committee on Tendon Injuries
- Total Active Motion (TAM) System

\[
\text{TAM} = (\text{MP} + \text{PIP} + \text{DIP}) - (\text{MP} + \text{PIP} + \text{DIP})
\]

Flexion - Extension lag
**ASSH**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>normal</td>
</tr>
<tr>
<td>Good</td>
<td>&gt;75% of normal side</td>
</tr>
<tr>
<td>Fair</td>
<td>&gt;50% of normal side</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt;50% of normal side</td>
</tr>
<tr>
<td>Worse</td>
<td>worse than before surgery</td>
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**Strickland & Glogovac, 1980**

Active PIP + DIP flexion – extension lag \( \times 100 \)

179°

= % of normal active PIP and DIP motion

**Strickland’s Original Classification**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Percentage</th>
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<td>Excellent</td>
<td>85-100%</td>
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<tr>
<td>Good</td>
<td>70-84%</td>
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<tr>
<td>Fair</td>
<td>50-69%</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt;50%</td>
</tr>
</tbody>
</table>

**Groth, 2004**

- Use of change scores to indicate whether the tendon is *responsive* or *unresponsive* to progressive interventions

\[
\text{Current DIP flexion} - \text{previous DIP flexion} \times 100
\]

\[
\frac{\text{Current DIP flexion}}{\text{previous DIP flexion}} \times 100
\]

= % resolution of active lag between therapy sessions

**Groth, 2004**

*Adhesion Grading System*

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absent</td>
<td>&lt;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>

**Pyramid of Progressive Force Application**

*Journal of Hand Therapy: Groth, 2004*
**Additional Studies**

- Steelman, Groth & Taras (2007)
  - Unresponsive lag as “passive flexion greater than active flexion of 15 degrees or greater”

- Sueoka & LaStayo (2008)
  - Flexor lag as PROM – AROM = ≥ 15 degrees

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**Part 4: Case Examples**

**Case Example #1**

Force-based progression
- 15 y/o male
- R ring FDS, FDP, radial digital nerve laceration 2/2 broken window, zone II
- 4-strand repair 3 days after injury
- Place and hold synergistic motion and Duran’s PROM initiated on 1st postoperative day; 30° flexion block at PIP
- 9 weeks, 6 days, 16 visits
- 2 days: -31/80
  - 13/35
  - 40.6%

**Case Example #2**

Excursion-based progression
- 46 y/o female
- L small FDP laceration 2/2 knife injury; zone II
- 4-strand repair 6 weeks after injury
- Place and hold synergistic motion and Duran’s PROM initiated on 2nd postoperative day
- 14 weeks, 15 visits
- 2 days: 0/60
  - 0/40
  - 57.1%
Case Example #3

Questionable progression
- 55 y/o female
- L small FDS, FDP, radial digital nerve laceration 2/2 knife injury; zone II
- 4-strand repair 2 days after injury
- Place and hold synergistic motion and Duran’s PROM initiated on 2nd postoperative day

5 days:
- 0/82
- 0/56
- 78.9%

Case Example #3

5 days:
- Place and hold synergistic motion out of splint
2 weeks, 6 days: (tendon glide increased)
- Active, composite fist, use of injured digit for opposition tasks in clinic
3 weeks, 6 days: (tendon glide decreased)
- Differential tendon gliding, Indiana protocol: 4th week, use of injured digit for opposition tasks in clinic
4 weeks, 6 days (tendon glide decreased)
- Isolated PIP/DIP AROM, use of injured digit for opposition tasks in clinic

5 weeks, 6 days: (tendon glide increased)
- Composite passive extension, resisted hook fist
6 weeks, 1 day:
- D/C protective splint
6 weeks, 5 days: (tendon glide decreased)
- Resisted, isolated PIP/DIP, BTE program
7 weeks, 6 days:
- Tendon rupture in clinic

The Bottom Line

Rehabilitation of a patient with a flexor tendon injury in zones I-II will optimally be initiated on postoperative day 4-5 and include the following:

Fabrication of a splint that offers protection while allowing synergistic motion.
**Objectives**

1. Describe the benefits of early motion on flexor tendon healing.
2. Prioritize interventions based on excursion, force, and optimal timing.
3. Rationalize immobilization in terms of timing and positioning.
Thank You!