**Significance of Tendon Injuries**
- Occur in young working population
- Failure or residual impairment 20-30%
- Tendon rupture rate is 5-10%
- Require 3-4 months of rehab on avg.
  - Hand is unable to perform work during this time

**Flexor Tendon Rehabilitation**
**KEYs to Successful Treatment**
- Use the following resources
  - Understand anatomy
  - Understanding of tissue healing and tensile strength
  - Surgeons- op report
  - Protocols as a guide to progression and timing
    - Discuss with surgeon
    - Choose according to patient factors, type of injury, type of repair.
    - Modify according to patient progress
  - use references

**Personal Factors To consider when choosing a protocol/ treatment plan**
- Age- vincula decrease in size with age, affect healing response
  - Will the patient be able to follow through responsibly
- Smoking- cause vasoconstriction, can cause infarct to the tendon, use more caution with smokers
- Alcohol- toxic to nerves, can increase incidence of pain syndromes
- Nutrition
- Availability to therapy- will they be able to return

**Injury must be considered**
- Mechanism/Type of Injury-
  - Crush or untidy laceration/ quality of the repair
  - Other tissues involved - Blood vessels, nerve, muscles, bone
  - Delayed repair- sooner is better- before 2 weeks
  - Amount of scar tissue
  - Tension on the repair
  - Infection- increased scarring

**Flexor Digitorum Profundus (FDP)**
- One common muscle belly
- Flexes both DIP and PIP
- Only flexor of the DIP
- Index finger may be separate- surgeon's call
- Splint includes all fingers
- No pinching with any fingers!!!
Quadrigia effect

Because FDP has one muscle belly
If one tendon is shortened
Strength of the uninvolved fingers is compromised

Paradoxical Extension

- paradoxical extension - when the patient tries to flex the finger, the lacerated proximal flexor digitorum profundus pulls on the intact lumbrical muscle, which then tensions the lumbrical tendon, and extends the IP joints
- Lumbrical muscle originates off of the profundus tendon
- May occur with scarring which creates excessive pull on the lumbrical when the FDP is flexed

Flexor Digitorum Superficialis

- 4 muscle bellies
- PIP flexion only
- Often absent in the Small finger
- 21% of the population
- 26% is asymmetrical

Flexor Pollicis Longus (FPL)

- can be interdigitated with the index finger FDP
- Index finger flexion with thumb flexion
- Try it!!!
- Can use it in rehab with IF and Thumb used together

Zone II Chiasm of Camper
Relation of the two tendons in the finger is complex

- Reason that it is referred to as NO MAN's LAND

FDP and FDS Interrelationship
Annular and Cruciate ligaments Pulley System- Zone II

Flexor Pulley System
- A2 and A4 pulley traditionally felt to be most important
- All that is needed when gliding is normal
- But it is less efficient, requires full gliding
- Variations made to allow better gliding with repair distal to A4 it may be sacrificed and A123 preserved

History of Zone II repairs
- Bunnell 1940’s
  - Zone II not repaired
  - Tendon graft was recommended so there would be a smooth surface to glide through the Zone II
- Lindsay and Thomson 1960’s researched healing of tendons
  - “Chicken Club” research done on chicken tendons
  - Originally thought that vinculae were the only source of nutrition- if cut could not regenerate
  - Began to see tenocytes and fibroblasts with improved magnification of microscopes
- Kleinert 1967
  - Began doing first tendon repair in Zone II
  - Started movement in 3 days

Tenocytes and fibroblasts

Extrinsic vs Intrinsic Healing
- Extrinsic- Adhesion
  - Through peritendinous adhesion
  - Immobilization theory
  - Peacock “one wound” concept
- Intrinsic
  - Synovial fluid
  - Vascular perfusion
  - Can heal without adhesions
  - Tendon cells proliferate
Nutrition to the tendon
Perfusion vs diffusion
- Perfusion via vinculum brevis vinculum longus
- 4 Vincula
  - V1-V2 supply FDS
  - V3-V4 supply FDP
  - Arise at the neck of the Proximal and distal phalanges.

Synovial Sheath
- Surrounds flexor tendons
- Produces synovial fluid
  - Smooth gliding
  - Lubrication - highest lubricating capacity known to man.
  - Nutrition - synovial diffusion

Anatomy of a Tendon

Surgical Repair of Flexor tendons

Retrieving the tendon end
- Tendon retracts proximally
  - With flexion injury
  - May go to Carpal tunnel
- Milking proximal to distal
- Needle and catheter/feeding tube
- Any Trauma/touch leads to adhesions

Surgical Repair of flexor tendons
- Core suture
  - 4 strand is preferred
- Suture material
  - 4-0 fiberWire less bulky and stronger
  - 3-0 or 4-0 braided synthetic suture commonly used
  - Placed in the volar 1/3 of the tendon
Many types of suture techniques

- Multiple strands add strength
- Also add bulk
- Allow early active motion
- New suture materials add strength to repair
- Thinner sutures may break
- Thicker suture more likely to fail at the knot

Epitendinous Cross Stitch

- Adds strength to the repair
- Reduces gapping by 10-50%
- Improves gliding – decreases friction
- Combined with core suture technique 4 strand allows early active protocols

Zones

- Zone I: FDP only
- Zone II: No man’s land FDP and FDS within the finger pulleys
- Zone III: Over metacarpals
- Zone IV: within the carpal tunnel
- Zone V: Proximal to the Carpal tunnel

Zone 1

- Only FDP-
- Distal to FDS insertion
- Amount of retraction varies
- Vincula may be intact
- Mechanism of injury
- Laceration- open
- Jersey finger- closed
- Forced extension while FDP is maximally contracted
- 4th finger most common

Zone II- distal to A1 pulley and proximal to FDS insertion

- Greatest technical difficulty in obtaining Maximal function
- Both flexor tendons are confined within the sheath
- Pulleys may be sacrificed as well as 1-2 slips of the FDS
- A2 and A4 preserved (in the past although this may be changing)

Zones III – Proximal to the A1 pulley and distal to the transverse ligament of the Carpal Tunnel

- Less complications/adhesions
- No tight pulleys
- Repair may glide through carpal retinaculum
- Lumbricals can become adhered PARADOXICAL EXTENSION
- Hook fist - differential gliding
- Individual finger extension
Zone 4- Carpal tunnel

- Uncommon
- Often involve nerves
- Must move each finger individually
  - Superficialis tendon gliding
  - Hook fist

Acute Flexor tendon Treatment Considerations

Goal: Tendon Gliding- Prevent Gap
Factors controlled in therapy

- Joint stiffness
- Edema
- Soft tissue adherence
- Limit the amount of flexion to control stress
- Gradually increase each week
- WORK OF FLEXION
  - Controlled by the therapist

Limiting force during Active motion

- Lalonde: 10 mm of glide is produced with the 1st 1/2 of composited flexion
- Tang: Final 1/3 of fist produces 5-10x more force than the first 2/3 of the motion
- Steep increase in force in the last 1/3 of finger flexion motion
- More reps shows greater benefit (10-15)

How much glide is needed to prevent adhesion

- Passive motion does not produce tendon glide proximally
  - Wet noodle through a tube
  - Duran Protocol: 3-5 mm (1975) of distal glide
- How much active motion is needed
  - Silverskiold 6-9 mm (1992)

Normal Reported Tendon Excursion

<table>
<thead>
<tr>
<th></th>
<th>FDS</th>
<th>FDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight fist</td>
<td>28 mm</td>
<td>27 mm</td>
</tr>
<tr>
<td>Hook fist</td>
<td>13 mm</td>
<td>24 mm</td>
</tr>
<tr>
<td>Full fist</td>
<td>23 mm</td>
<td>34 mm</td>
</tr>
</tbody>
</table>

- Max FDS occurs in Straight fist
- Max FDP occurs in Full fist
- Max differential is in Hook fist
**Flexor tendon tensile demands**

- Normal tendon tensile demand
  - PROM 500 gm
- Light grip 1500 gm
- Strong grip 5000 gm
- Tip pinch 9000 gm (Index FDP)

**Estimated strength of tendon repair with epitendinous suture**

<table>
<thead>
<tr>
<th>Type of Repair</th>
<th>0 weeks</th>
<th>1 week</th>
<th>3 weeks</th>
<th>6 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 strand</td>
<td>2500 gm</td>
<td>2200 gm</td>
<td>1700 gm</td>
<td>1200 gm</td>
</tr>
<tr>
<td>4 strand</td>
<td>4300 gm</td>
<td>2150 gm</td>
<td>2800 gm</td>
<td>5200 gm</td>
</tr>
<tr>
<td>6 strand</td>
<td>6000 gm</td>
<td>3000 gm</td>
<td>4000 gm</td>
<td>7200 gm</td>
</tr>
</tbody>
</table>

**Applying Basic Science Clinically to Early Motion Programs**

- Tendon gaps at 2/3 of the full reported repair strength
- Tendon softening decreases repair strength
  - Decreases another 10-20%
  - Weakest between 10-14 days
- Safe zone: begin with the reported strength and subtract 43-53%
- Importance of controlled stress during active flexion

**Physiologic Response to controlled stress**

Gentle active motion

- Tensile Strength increases
- Improved tendon gliding
- Improved synovial profusion
- Collagen organization
  - Intrinsic and extrinsic scar
  - Weakest at 10-14 days
  - 3 weeks collagen is formed
  - 8 weeks- significant change

**Savange: Effect of Wrist Position on Force on Flexors**

<table>
<thead>
<tr>
<th>Movement</th>
<th>Recorded force FDS</th>
<th>Recorded force FDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist 30 degrees flexion With fingers flexed to palm</td>
<td>7.2 N</td>
<td>5.7 N</td>
</tr>
<tr>
<td>Wrist 0 degrees Fingers flexed to palm</td>
<td>3.2 N</td>
<td>4.7 N</td>
</tr>
<tr>
<td>Wrist 30 degrees flexion</td>
<td>3.1 N</td>
<td>4.0 N</td>
</tr>
<tr>
<td>Wrist 0 degrees Extend the fingers</td>
<td>4.8 N</td>
<td>4.6 N</td>
</tr>
</tbody>
</table>

**Flexor Tendon Protocols The Evolution**
**Types of Protocols**

- **Immobilization**: no stress on tendon
- **Immediate Controlled Passive Mobilization**
  - Modified Duran Houser/ Duran Houser
  - Modified Kleinert- rubber bands not used any more
  - Washington Regimen
- **Immediate controlled active mobilization**
  - Klein- passive flexion, rubberband traction with place hold first 4 weeks (2003)
  - Short Arc active (SAM): MAMTT- Minimal Active Muscle Tendon Tension- Evans 1995
  - Indiana Tenodesis/ Place Hold
  - Wide Awake Protocol- Lalonde
  - Tang 4.3 A finger Technique

**Evans Protocol- Zone 1**

- **LEAF**: Limited extension Active flexion (2005-Evans)
- **Dorsal blocking splint**
- **Second dorsal splint on the finger blocking the DIP in 40 degrees of flexion**
- **Exercise- Passive protocol with PIP place hold**
- **Rationale: Placing the DIP in flexion reduces the tension on the repair, eliminating potential for gap formation**
- **Problems: Development of a flexion contracture of the DIP**

**Outcomes with protocols**


<table>
<thead>
<tr>
<th>Passive motion results</th>
<th>Short Arc active</th>
<th>Strickland</th>
<th>Early active motion protocol Lalonde 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>3%</td>
<td>43%</td>
<td>96% (not reproduced)</td>
</tr>
<tr>
<td>Good</td>
<td>25%</td>
<td>32%</td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td>94%</td>
<td>44%</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>27%</td>
<td>1%</td>
<td>4% ruptured (122 subjects) Non compliant</td>
</tr>
</tbody>
</table>

**Indications for Protocols**

- **Immobilization** (child, or severe injury limiting motion)
  - Used when cognition is impaired, too young <8-12 y/o
- **Immediate passive mobilization** (2 strand repairs)
  - Used when the surgeon was unable to achieve a 4 strand repair or strong repair.
  - Not used often, should call to confirm this is what the MD wants
  - May add in place hold with MD consent
- **Immediate controlled active mobilization** (4 strand+)
  - **Higher level of controlled stress** on repaired tendon
  - **Gentle active contraction, with minimal force** of the repaired musculotendinous unit to allow the minimum needed for glide
  - Results in definite proximal gliding of the repaired tendon.

**Dorsal blocking Splinting**

- **Dorsal blocking splint** (DBS) including all fingers
- **Purpose: limit stretch force on the repair site**
  - Wrist position: 0-20 degrees of flexion
  - MP Flexion 45-60
  - IP’s allowed to extend
  - Except if nerve is repaired

**Key Concepts**

- **‘Controlled stress**
  - Optimal force application- least amount to achieve tendon glide without gap
  - Varies according to the time in the healing process
- **No single protocol** is appropriate for all repairs.
  - Surgeon/therapist interaction is vital to this process.
  - May deviate from protocol
  - Understand the force place on the tendon with different exercises
- **Frequency**
  - Exercises on the lower end of the pyramid- greatest frequency
  - Literature will vary in exact time guidelines reported, reps and times per day.
Concepts of Tendon Rehab: Pyramid of Progressive Force Application by Groth

Pyramid of progressive force exercises

- The force must be appropriate for stage of tendon healing - clinical discretion gap vs adhesion
- The active lag is measured by the difference between the AROM and the PROM.
  - ≤ 10% active lag = no adhesion
  - Stay at same level
  - >10% advance one level
  - Reassess next session

Pyramid of progressive force exercises Level 1

- Passive Protected Digital Extension
- All joints are flexed while one is extended slowly
- First post-op visit
- Hand can be taken out of the splint to allow full wrist flexion
- Achieve distal glide 6 mm
- Frequency - 5x/day or every hour

Level 2 - place and hold
May use limited arc of motion

- Warm-up passive ROM done first
- Passively flex to loose fist
- Allow fingers to "slip back a bit"
- The patient is asked to hold 3-5 sec
- Can be used with 2 strand repair with MD consent, short range

Level 3 active fist

- Limit force - varies greatly
- Frequency based upon response
- Wrist protected
- Tenodesis may be used

Level 4
Hook and Straight fist

- No Force
- Wrist protected
- Maximal differential glide between FDP and FDS
Level 5 Isolated joint motion blocking exercises
- ? blocking to small finger
- Careful not to resist FDS if repaired
- Minimal resistance- let go if pressure is felt
- Splint is d/c'ed after level 5

Level 6- Discontinue splint resisted compostite fist-
- putty or hand helper/ rubber band resistance
  - X-soft
  - Paper crumbling
  - sponge

Level 7 Resisted hook and straight fist

Level 8 Resisted isolated joint motion
- Putty drag
- pinch

Active Motion Protocol
- Initiate day 3-5 post op
- Passive flexion first!!!
- Edema Control-
  - Elevation
  - Manual edema mobilization
  - Rest
  - Limit active flexion motion initially 50%
    - Increase 1 cm per week - 1st 4 weeks

Tang 4-3-2-1 finger technique
- First week flex to 4 fingers
- Week 2 go to 3 fingers
- Week 3 go to 2 fingers;
  - full IP extension in the splint
- Week 4 go to 1 finger
- Week 5 full fist
- Concept is gradual application of stress to avoid gap and influence healing tensile strength
Home Program Instruction
- Always review precautions
  - Don’t forcefully pinch with the other fingers if only the small finger was repaired
  - Too much activity produces swelling
  - Must use the splint at all times, even bathing 1st 4 weeks
    - Remove for hygiene, dressing changes, keeping the flexed position
  - Move it Don’t Use it: Light ROM every 2 hours
    - do the exercises gently, carefully, passive first
    - Limit flexion Week 1-increase every week
- Finger extension
  - in the splint only for the first 4 weeks
  - Careful of nerve repair- protect 3-4 weeks post op
  - May begin extension splinting in the DBS at 4 weeks p.o. if contracture develops

Week 4- flat fist to hook fist
- Advance tendon gliding
- Slowly begin hand flat on table
- Wrist motion is allowed wi fist
- Active functional activities
- May buddy tape- re-ed
- Extension night splint in DBS
- Manual therapy
  - Scar mobilization

Late phase- 8 weeks post op
- If tendon gliding is unrestricted keep the DBS until 8 weeks- go slowly!
  - Light putty
  - Dowel grip
  - May advance earlier if adhesions are present
  - Groth Pyramid
  - Assess progress

Recent Trends in Tendon Rehab
- Wide Awake procedure
  - Done widely in Canada, DH Lalonde, MD
    - Tang in China
    - Local anesthetic only, no sedation
    - No tourniquet is used- Epinephrine
    - Patient is asked to move the tendon through full active flexion and extension before the wound is closed
    - Observe tendon gliding
    - Repair any gapping or triggering, pulley venting
    - Patient education in pain free active motion which is continued on a EAM post op rehab program

Belfast and Sheffield (UK)
- Similar to Tang 4-3-2-1
- Exercise frequency every 4 hours
  - Full passive flexion
  - Full active extension in DBS
  - Limited partial range flexion gradually increasing
  - Goal is flexion range of PIP 90 and DIP 60
  - Splint discontinued (5-6 weeks post-op)
  - Except in those patients that achieve goal in 2 weeks
    - Held back in splint an additional 2 weeks
Passive motion protocols

Kleinert

- First 4 weeks
- Rubber band traction
  - Assist flexion
  - Assisted extension
- Flexion positioning at rest
  - Flexion contractures
- Passive extension of each joint separately

Modified Duran Houser

Most common passive protocol

- Used on 2 strand repair
  - Rare
  - Check with surgeon—recommend active if 4+ strands
- No rubber band traction
  - Extended splint to finger tips
  - Added extension strapping to prevent flexion contracture
  - Careful!!!
    - Involuntary flexion spasms can occur at night

place and hold

- Can be used with 2 strand repair if MD ok’s
  - Slow passive movement, let the joint loosen up 5-10x
  - Back off motion to 50% of motion first week
  - Ask patient to hold gently—no resistance
  - Frequency varies—may do 3x/day or hourly
  - Not a natural motion

Immobilization Protocol

- Adhesions are going to be present
- Will see these
  - Help!!! It won’t move!!!
- Immobilized tendon is weaker initially than mobilized
- Scar protects the tendon

Immobilization Intermediate stage 3-4 weeks to Late stage

- DBS
- Passive motion, scar mobilization
- Active hook, straight and full fist
  - Buddy taping
  - Reassess in 3-4 days
  - Advance to next stage if more than 30 degrees of difference between active and passive motion in composite flexion (MP+PIP+DIP)
  - Initiate functional training
  - Groth Pyramid

Treatment of Adhesions

- Manage edema
- Scar mobilization
  - Self scar mobilization
- Soft tissue Mobilization
- Modalities
  - Heat
  - Ultrasound low intensity
Dowel Light grasp Target
Blocking splint

Thumb
Flexor Pollicis Longus

Thumb pulleys

Splinting
- Dorsal blocking splint Wrist neutral
  - Thumb CMC flexed and abducted under the second metacarpal
  - Thumb MP in full extension

Flexor Pollicis Longus Rehabilitation
- Only one tendon in the sheath
- Pulleys can still cause limited gliding
- Early active and place hold are recommended as in the fingers
- Opposition to 5th MP- goal
- Overall improved results

Partial Tendon Lacerations
- Repair is recommended when over 60% of the tendon is lacerated
- Does not retract-
  - Vincula are intact
  - Do well with early active protocols
- Untreated tendon complications
  - Triggering
  - Entrapment
  - Rupture
When Tendons Stick
Tenolysis

Tenolysis p.o. therapy
- Consult surgeon
- Condition of tendon
- Pulley reconstruction
- Capsulodesis
- ROM intraoperatively
  - Extension splinting static vs progressive
- Splinting:
  - Maintain extension if flexion contracture
  - Rest tissue between hourly exercises
  - Night only after 1 week usually

Exercise
- Precautions: No resistive exercises, No excessive stretching
- Goals: Control edema, achieve full intraoperative AROM, maintain A/PROM gains
- Exercises: Patient to perform differential tendon gliding every hour 10 reps; Daily therapy 1st week, may use US early to control edema

TENDON RECONSTRUCTION

2 Stage Tendon Reconstruction
- Primary vs. Staged
- Indications
  - Repair is not possible
  - Tendon bed scarred – graft would probably fail
  - Injuries requiring fracture fixation, flexor and extensor repair
- Contraindication
  - Infection

Function: Stage 1
- Maintain Fibroosseous canal and regenerate tendon sheath
- Enables passive flexion and active extension
STAGE II

- Active tendon graft is used
- Surgeons preferred tendon protocol
- Usually 3-6 months after stage I

References


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