Update on Flexor Tendon Repair in 2014

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Disclosures

- Multiple Federal research grants
- Treasurer, American Society for Surgery of the Hand
- Director, American Board of Plastic Surgery
- Member, ACGME Plastic Surgery Residency Review Committee
- Founder, Tendon-Bone Innovations
- Patents related to tissue engineering

Concentrate on this Specific Problem:
Zone II Flexor Tendon Laceration

47 Years Ago…
1967 ASSH Presentation:
Kleinert HE, Kutz JE, Ashbell TS, Martinez E.

“Primary Repair of Lacerated Flexor Tendons in No Man’s Land”

Manske PR. History of Flexor Tendon Repair. Hand Clinics, 2005
The Case Today

The Patient
- 30 year old Google exec
- Vacation in Jamaica
- Cuts hand on beer bottle
- In OR 5 days after injury
- Radial digital nerve and artery are cut
- FDP and FDS tendons are sharply cut in Zone II
- Proximal portion of A2 pulley intact

The Patient – 12 weeks post-op

My Next Patient…
- Develops CRPS
- Stiff in extension
- No tendon pull-through
- Undergoes extensor tenolysis and PIP capsulotomy
- More to come…
Flexor Tendon Repair: Challenges in 2014

- Margin for error is small
- Many repair techniques exist
- Biomechanical studies may not be relevant clinically
  - Cadaver studies: no healing
  - Animal studies: no therapy
- Clinical studies limited by
  - Differences in surgical skill
  - Patient compliance with therapy
  - Differences in follow-up & outcomes criteria

Every case is different

- Different injuries
- Different repairs
- Different post-op regimens
- One Cochrane review on postoperative therapy: inconclusive

PERTINENT ANATOMY

NORMAL TENDON HISTOLOGY –
Cells help create a gliding surface
FLEXOR TENDON ANATOMY – Avoid fraying the rope!

FLEXOR TENDON INJURIES
Verdan's Zone Classification – each has a different personality for repair

- Zone 1: Distal to FDS insertion
- Zone 2: Distal palmar crease to FDS insertion: “No man’s land”
- Zone 3: Palm
- Zone 4: Under transverse carpal ligament
- Zone 5: Proximal to the transverse carpal ligament

Tendon Sheaths – are a help and a hindrance

- Sheath includes pulleys
- Thumb and little finger sheaths contiguous with ulnar and radial bursae

Tendon Pulleys – know when and which to sacrifice

- Condensations within tendon sheaths
- 5 annular pulleys
- 3 cruciate pulleys
- Key pulleys = A2, A4
FLEXOR TENDON ANATOMY

- Independent FDS, conjoined FDP tendons in zone 5
- MF/RF FDS tendons most volar in zones 4 and 5
- FDP pierces FDS tendon at Camper’s chiasma
- FDS slips join dorsally to separate FDP from bone and PIP joint volar plate
- FDS splits again distally to insert on middle phalanx

How to identify flexor tendons in the wrist

FLEXOR TENDON NUTRITION

- Synovial fluid via diffusion through canaliculi increases with motion
- Blood supply
  - Longitudinal intratendinous vessels
  - Segmental from digital arteries through vinculae
  - Distal bony insertion

Vincular system
Flexor Tendon Orientation

- FDP pierces FDS tendon at Camper’s chiasma
- FDS slips join dorsally to separate FDP from bone and PIP joint volar plate
- Vincular blood supply enters dorsally

Unique anatomy of the FDS

Remember the Normal Twirl of the FDS

Repaired with Abnormal Anatomy
PRINCIPLES OF REPAIR

FLEXOR TENDON INJURIES
Diagnosis

- History
- Specific examination of FDS, FDP
- Strength testing
- Associated nerve, vessel damage
- Resting position
- Partial lacs → pain, triggering, weakness

The Normal Cascade
Loss of resting tone

Checking tenodesis effect

What’s cut?

What’s cut?
What's cut?

PARTIAL LACERATIONS

- Can lead to:
  - Delayed rupture
  - Entrapment
  - Triggering

- Bishop, 1986; Cooney, 1987:
  - >60% lac should be repaired

- Bolitho, 2002
  - <25% smooth edge
  - 25-50% peripheral suture
  - >50% core suture

FLEXOR TENDON RUPTURES
- require tendon grafting

- Rheumatoid arthritis
- Tenosynovitis
- Partial lacerations
- Calcification of TFCC
- Attritional rupture over bone prominence
Adhesion formation is the key problem

- Extrinsic tendon healing - sheath fibroblasts
- Intrinsic tendon healing
  - Tenocytes, vinculae, synovial fluid
  - Peripheral adhesions are not needed for healing
- Tensile forces at repair site improve strength
  - AROM, not PROM
  - ↑ cell proliferation, ↑ collagen matrix

General Principles

- Operating room setting
- Proper incisions
- Atraumatic technique
- Preservation of pulleys [A2 & A4]
- Repair lacerated nerves and arteries
- Deflate tourniquet before closure

FLEXOR TENDON REPAIR
Desired Characteristics

- Easily placed clinically
- Secure knots
- Minimal bulk
- Equal load across suture strands
- Minimal gapping
- Minimal ↓ vascularity
- Sufficient strength to allow early motion
Methods of Repair

FLEXOR TENDON REPAIRS
General Observations

- Strength of repair ↓ @ days 5-21
- Mobilization → ↑ strength
- Strength is proportional to # of suture strands crossing repair
- Strength is proportional to suture size

FLEXOR TENDON REPAIRS
General Observations

- Ruptures usually occur at knots
- Locking loops → ↓ gapping
- Braided better than monofilament sutures
- Dorsal stronger than volar
- Equal tension across all strands to ↓ differential loading

WOLFFE’S LAW

- The strength of the healing tendon is proportional to the stress applied to it
- Mobilized tendons are 2-3 X stronger @ 2-3 weeks

Gelberman, Woo. J Hand Therapy, 1989
FOUR-STRAND REPAIR
- Twice as strong as two-strand repair
- Allows early active motion
- ↑ bulk
- Possible ↑ in tendon adhesions
- Technically more demanding
- Requires meticulous technique to avoid “shredding” the tendon

MODIFIED KESSLER REPAIR
One Suture

FLEXOR TENDON REPAIR
Locking vs. Grasping Loops

FLEXOR TENDON REPAIR
Epitendinous Suture
- Decreases gapping
- Decreases bulk and surface irregularity
- Increases strength ~ 20%
EPITENDINOUS SUTURE

PREFERRED TECHNIQUE: EPITENDINOUS FIRST METHOD

- Running epitendinous suture [6-0 double-armed monofilament]
- 11 blade slit in tendon
- Locking Kessler suture [3-0 braided]
- Horizontal mattress suture to complete “4-strand repair” [3-0 braided]

My Favorite Flexor Tendon Repair

Effect of # of Suture Strands

Strickland JW, Indiana Hand Center, 1993
TENDON WOUND HEALING

Flexor Tendon Healing
- Potenza: early twentieth century
- Intact tendon has no intrinsic healing capacity
- Healing relies on adhesion formation for vascularity and fibroblast recruitment
- Overwhelming evidence for dual mechanism of repair
  - **Intrinsic Healing:**
    - Endotenon and epitenon cell recruitment
  - **Extrinsic Healing:**
    - Surrounding soft tissue (sheath, dermis, periosteum)
    - Adhesion formation to surrounding tissues

Goals of Tendon Healing
- Re-establish collagen fiber continuity
- Restoration of sliding surface

Phases of tendon healing
- 3 overlapping phases of healing
  - Inflammatory phase: 3-5 days, phagocytosis, strength from clot and suture repair
  - Fibroblastic phase: 5 days – 3 weeks, fibroblast proliferation and collagen production, ECM deposition, capillary formation.
  - Decreased strength of repair: Clot dissolution, suture relaxation
  - Remodeling phase: 3 weeks – 9 months, continued collagen synthesis, collagen fibers longitudinally oriented across repair site
- Increased strength of repair
TENDON HEALING WITHIN SHEATH

- Adhesions from sheath, surrounding tissue
- Intrinsic tendon healing (diffusion)
- Collagen synthesis by endotenon cells
- Phagocytosis of debris by epitenon cells
- Tendon mobilization improves healing

Why this is important

Four Papers, Each With A Point

Paper #1: 4 Strands or more are necessary for early active motion

- “Development of Flexor Tendon Surgery: Twenty-five Years of Progress”

  - Two strand repairs are at risk for rupture if early active motion is applied
  - Four strand repairs are strong enough to withstand light active motion
Paper #2: Grasping vs. locking sutures

- “Flexor Tendon Repairs: The Impact of Fiberwire on Grasping and Locking Core Sutures”
  - Grasping repairs failed by suture pull-out in 74%
  - Locking repairs failed by suture breakage in 99%
  - Fiberwire suture provided significant tensile strength in locking MGH repairs
  - Increased suture strength is only important in locking repairs

Paper #3: Rehabilitation force

- Boyer et al. JBJS 2001; 83:891-899 (Gelberman)
- “Intrasynovial Flexor Tendon Repair: An Experimental Study Comparing Low and High Levels of In vivo Force During Rehabilitation in Canines”
  - Increasing post-op rehabilitation force from 5 to 17 N did not accelerate accrual of stiffness or strength
  - Some motion is good (2 mm excursion); more forceful motion may not be better

Paper #4: The Effect of Gap

- Gelberman. JBJS 1999; 81:975-82
- “The Effect of Gap Formation at the Repair Site on the Strength and Excursion of Intrasynovial Flexor Tendons”
  - What happens if a significant gap forms?
  - Repair site gap of greater than 3 mm:
    - No increase in adhesions
    - Weaker, with increased risk of rupture

Flexor tendon repair: What we know in 2014

- Core suture: 3-0 or 4-0
- Epitendinous suture
- Gaps significantly weaken the repair
- Locking techniques prevent pullout and reduce gapping
- Some early active motion is beneficial
  - 4 strands or more will allow early active motion
Post-Operative Therapy

Static Postoperative Splinting
- Dorsal blocking splint (fingertip to forearm)
- 20-30° wrist flexion
- 60° MCP flexion
- Full DIP/PIP extension
- Avoid palmar block

FLEXOR TENDON INJURIES
Postoperative Motion Protocols
- Controlled passive ROM
  Immediate passive ROM
  Goal of 3-5 mm on tendon excursion
- Combined active and passive ROM
- Early active motion

FLEXOR TENDON REPAIR
Early Active Motion
- Passive ROM in first few days
  - Passive ROM → buckling
  - Active ROM → gliding
- Place and hold
- Blocking techniques to ↑ FDS/FDP differential gliding
- Wrist tenodesis effect @ 45° wrist extension
  ↓ force for active finger flexion
- Requires stronger repair, compliant/motivated patient, supple joints
Passive Motion Protocol Simplified

- 1st 3 weeks: active extension in dorsal blocking splint, passive flexion
- 2nd 3 weeks: place and active hold
- 3rd 3 weeks: wean from splint, light activities
- 4th 3 weeks: resistive exercises

From Trumble, Vedder, Seiler, Hanel, Diao, & Pettrone, JBJS 2010

Active Motion Protocol Simplified

- 1st 3 weeks: active extension in dorsal blocking splint, tenodesis splint: wrist 30° extended, fingers placed into full fist and actively held
- 2nd 3 weeks: wean off tenodesis splint
- 3rd 3 weeks: light activities
- 4th 3 weeks: resistive exercises

From Trumble, Vedder, Seiler, Hanel, Diao, & Pettrone, JBJS 2010

Growth Factors
The evolutionary pressure for wound healing has been SPEED.

Tissue Injury Cascade of Events


Tissue Repair Cascade

Adhesion Formation Cascade

Strategies to increase early strength of repair

Thomopoulos et al. – Enhanced Flexor Tendon Healing through Controlled Delivery of PDGF-BB. J Orthop Research 2009

- Platelet-derived Growth Factor BB: increases cell proliferation and matrix synthesis in vivo and in vitro
- Biodegradable fibrin/heparin-based delivery system
- Controlled delivery sustained for 10 days
- Dog model of flexor tendon repair
- Tensile strength not altered, but tendon gliding and PIP joint ROM improved
- Other growth factors using this delivery system?


- Basic fibroblast growth factor – promotes proliferation of cells, including tenocytes
- Adeno-associated virus-2 (AAV2) vector system
  - Nonpathogenic and noncytotoxic
  - Allows tenocytes to synthesize bFGF endogenously for extended periods of time
- Chicken model of flexor tendon repair
- Increases ultimate tensile strength, but not adhesions

Strategies to decrease adhesion formation
Transforming Growth Factor - Beta

- Family of growth factors - 3 isoforms
- Expressed in cells active in wound healing
- Implicated in the pathogenesis of fibrosis
- Inflammation
- Excessive collagen deposition
- Natural inhibitors of TGF-Beta
  - Decorin: 40,000 MW naturally occurring proteoglycan in extracellular matrix
  - Mannose-6-phosphate (M-6-P): Naturally occurring 6 carbon sugar

In Situ Hybridization of Flexor Tendon Wound Healing

Control: IL-2 mRNA

TGF-β1 mRNA

Rabbit Postoperative Range of Motion

Rabbit Postoperative Breaking Strength
Anti-TGF-Beta Therapy

- Rabbit model of flexor tendon repair
- Intra-operative addition of M6P significantly improved post-operative range of motion without decreasing strength of repair
- Clinical trials of M6P are ongoing for skin wound healing


The complexity of growth factors is challenging

Tendon Science in 2014:

- Growth factors & stem cells will not be magic bullets
- Based on current clinical trials, some may become available for testing soon
- May increase margin for error of current repair techniques

Until growth factors are available, how can we influence outcomes?

- Decrease inflammatory growth factors
  - Clean wound
  - Careful skin closure
  - Hemostasis with tourniquet down
  - Early short period of immobilization
  - Post-operative elevation
- Increase wound healing strength
  - Decrease gap formation
  - Vent pulleys to prevent tethering
  - Early active range of motion: 4 strand repair
Complications

Top three complications
- Flexor tendon repair rupture
- Flexor tendon adhesions
- Flexion contracture

Complication #1. Flexor tendon repair rupture
- Reasons
  - Weak repair > strong motion
  - Unsupervised motion/compliance
  - Open wound
  - Infection
- Most ruptures at 1-3 weeks (when repair is weakest)

Deciding when to explore
- Clues:
  - Feeling of “pop”
  - Palpating the tendon
  - MRI
- Early exploration and repair to preserve sheath
- Be prepared for two-stage reconstruction
Re-repair of flexor tendon

4 wks sp injury

Open sheath allows delayed repair

Complication #2.
Flexor tendon adhesions

Timing of flexor tenolysis

- Prerequisites
  - Involved patient
  - No joint contractures
  - Passive ROM is significantly greater than active ROM
  - Hand therapy has plateaued
  - Soft tissue “equilibrium”

- Earliest around 3 months

Tenolysis procedure

- Local anesthetic ideal
- Carefully examine old incision scars
- Worry about skin cover on naked tendons
- Proceed from normal to abnormal
- Preserve portions of A2 & A4 pulleys
- Carefully consider FDS excision
- Motion will never be better than in the OR
The problem with proximal retraction

A nice method for tenolysis from Kozin

Atraumatic Allis clamp

Allis clamp around FDS tendon

Allis clamp around FDP tendon
Prepare for tendon rupture and staged reconstruction

- 1st stage:
  - Silicone rod placement
  - Pulley reconstruction
- 2nd stage:
  - Tendon grafting

Stage I: Ruptured FDP with no pulleys

- Preserve distal tails during FDP/FDS resection
- Capsulotomies if necessary
- Can use FDS/FDP remnants for pulley reconstruction
- Silicone rod passed beneath pulleys
- Silicone rod sutured distally; left unattached proximally

First stage reconstruction
Stage I: Pulley reconstruction

Stage I: Sizer to Hunter rod transition

TENDON GRAFTS

- Options:
  - Palmaris longus
  - Plantaris
  - Extensor digitorum longus
  - Flexor digitorum superficialis
  - Extensor indicis proprius
  - Extensor digiti minimi

- Lower extremity if need long graft or multiple grafts

Stage II: Tendon graft
Stage II: Testing the distal juncture

Complication #3. Flexion contracture

Structures Limiting PIP Extension:
Simple Strategy - Go Volar to Dorsal

- Volar skin
- Fascia
- Tendon sheath
- Flexor tendons
- Volar plate [check-rein ligaments]
- Accessory and proper collateral ligaments
- Bony block

Lastly, Teaching a Good Repair
Hypothesis

- Many techniques for flexor tendon repair exist
- Trainees are confused about repair principles
- Teaching is sporadic and opportunistic

Flexor Tendon Repair: Human Tendon Simulation & Tutorial

Repair based on resident/fellow knowledge

- • 14 Residents & Fellows
- • Locking suture
- • Distance from cut end
- • Epitendinosus
- • 4 Strand

Tutorial with Standardized Repair

Post-tutorial Repair

• MTS for Gap Formation and Breaking Strength

Repair Technique Taught
MTS For Gap Formation & Breaking Strength

The “Optimal” Repair Technique
- Should incorporate the concepts of multi-strand repair with early motion
- Until science catches up, focus on:
  - Principles of repair
  - Standardized flexor tendon repair method
- The chosen repair technique should be simple to learn, with the goal of being able to be performed safely by all trainees

Results Pre & Post-Tutorial

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Thank you!