Flexor Tendon Healing
The structure of tendon
Tendon Nutrition and Blood Supply
The vascular supply of tendon

- Musclotendinous junction
- Tendinososseous junction
- Mesotenon and vinculum
Mesotenon

Tendon

Artery

Layers of sheath (parietal, visceral)

Mesotenon
Vinculum
Nutrient pathways of flexor tendons in primates

The perfusion and diffusion pathways to the flexor profundus tendons of 40 monkeys were investigated by measuring the uptake of tritiated proline by various tendon segments. In the absence of all vascular connections, the process of diffusion provides nutrients to all areas of flexor tendon and in this study the process of diffusion was greater. The distal segment of tendon was observed to be profused most rapidly. The proximal tendon segment is perfused from both the muscular-tendinous junction and the vinculum longus; vincular segment perfusion is via the vinculum longus vessels alone; central segment perfusion is shared by the vinculum longus and vinculum brevis vasculature. The distal segment uptake is by both the process of diffusion or vinculum brevis perfusion. The osseous attachment at the distal phalanx contributes little to tendon nutrition.

Paul R. Manske, M.D., and Peggy A. Lesker, B.S., Saint Louis, Mo.
control

diffusion

perfusion
Diffusion

5 minutes

15 minutes
Perfusion
Area of the avascularity of the flexor tendon

The nutrition in this area was provided by the way of diffusional pathways from synovial fluid
A flow-through system supplies tenocytes with a fresh nutritional supply.
Nutrition pathways

synovial diffusion

blood perfusion

synovial diffusion

digital artery
Experimental History of Tendon Healing
Flexor Zones

“No Man’s Land”
My first attempt at repair of tendons in the fingers resulted in immediate success, but as the succeeding days went by motion become less and less, until at the end of a few weeks it was nil. The tendons became firmly imbedded in scar tissue and had united to the surrounding finger in a solid mass.
“If the flexor tendons have been severed opposite the proximal phalanx one cannot join them by suture with success, as the juncture will become adherent in the narrow fixed channel and will not slip. It is **better to remove the tendon entirely from the finger and graft a new tendon throughout its length.**”

(Bunnell)

- Supported by Pulvertaft, Littler, & Boyes in 1940’s, 50’s and 60’s
Tendons lacks the intrinsic biological capability to participate in their own healing.
Extrinsic Healing

In Extrinsic healing, the blood and the cells needed for tendon healing are supplied by Adhesions between tendon and surrounding tissue. (Potenza 1962)
DIGITAL FLEXOR TENDONS: AN EXPERIMENTAL STUDY

Part I.

The Significance of Each Component of the Flexor Mechanism in Tendon Healing

By W. K. Lindsay, M.D., F.R.C.S.(C), and H. G. Thomson, M.D.
mature fibroblast

immature cell

intermediate cell

immature daughter

Direction of growth.
Lindsay (1960)

In this study it appeared that all connective tissue cells comprising a tendon are capable of producing immature cells. The less differentiated and less specialized connective tissue cells, those in the epitenon and endotenon, react earlier and account for the greater amount of proliferating tissue. The more differentiated and specialized connective tissue cells, those in tendon bundles, react later.
Experimental intrinsic healing of flexor tendons based upon synovial fluid nutrition

The healing process of totally cut and subsequently resutured rabbit flexor tendons kept isolated in the knee joint cavity and free in the synovial fluid was studied by histological and ultrastructural techniques. This experimental model represents a "tissue culture in situ," where the tendon is nourished by diffusion from the synovial fluid only and where no adhesions are formed. Under these conditions there is a proliferation of tendon cells and deposition of collagen resulting in bridging of the suture line. On the basis of these findings, it is assumed that the tendon cells possess an intrinsic potential of repair, provided they obtain a sufficient nutritional supply. In the present experimental model, this nutrition was provided by way of diffusional pathways from the synovial fluid.

G. Lundborg, M.D., Ph.D., and F. Rank, M.D., Göteborg and Malmö, Sweden
Lundborg (1978)

Tendon repaired with two single sutures

Knee joint
Lundborg (1978)

- 3 weeks
- Both free ends are rounded off
- The surface including the suture site is smooth
- The suture material partly covered by newly formed tissue
- No adhesions are formed
Lundborg (1978)

Tendon cells possess an intrinsic potential of repair, provided they obtained a sufficient nutritional supply. In the present experimental model, this nutrition was provided by the way of diffusional pathways from synovial fluid. The synovial fluid may play a role as a nutritional medium for superficial parts and the gliding surfaces of flexor tendons under repair.
Summary

- Extrinsic healing
  - Adhesion is unavoidable
  - Free tendon graft
Summary

- Intrinsic healing
  - Tendon possesses an intrinsic healing potential without adhesion
  - Primary repair in the synovial sheath
Process of Tendon Healing
Mechanism of Tendon Healing

“one wound one scar concept”

Peacock (1970)

At the same site
Mechanism of Tendon Healing

- In clinical setting

  It is impossible to isolate the Intrinsic and Extrinsic healing
Tendon Healing Phases

- **Exudative Phase** 0 - 4 Days
  - Inflammatory Response
- **Fibroplasia Phase** 5 - 21 Days
  - Fibroblast Migration
  - Collagen Synthesis
- **Remodeling Phase** 3 Wks - 6 Mos / 1 Yr
  - Intramolecular Cross-Linking
  - Scar Remodeling
Exudative Phase

- **1st week**
- **Inflammatory cells from surrounding tissue** migrate into wound
- **Extrinsic Mechanism**
  - migration from periphery
- **Intrinsic Mechanism**
  - migration from within tendon & epitenon
Fibroplasia Phase

- Fibroplastic proliferation from endotenon and epitenon
  - Synthesis and resorption of collagen
- Fibroblasts and collagen are in a plane perpendicular to the long axis of the tendon
- Revascularization increases
Remodeling Phase

- 8 weeks
- Collagen is mature
- Collagen is realigned in linear fashion
- Adhesions are stimulated
How can we minimize the effect of extrinsic healing?

Only early motion could prevent the repaired tendon from adhering to the sheath or gliding floor.
Controlled Early Motion

- The Mobilized Tendons healed through Epitenon cellular migration without formation of Adhesions, and recovered Gliding Surface within 6 weeks.

(\textit{Gelberman 1982})
Effect of Cyclic Tension on Lacerated Flexor Tendons *in vitro*

Hideki Tanaka, MD, Paul R. Manske, MD, Donald L. Pruitt, MD, Brian J. Larson, MS, St. Louis, MO
Cyclic Tension

No Tension

At 14 Days
Cyclic Tension  No Tension

At 21 Days
Cyclic tension stimulates the intrinsic response of lacerated flexor tendons significantly more than no tension did by enhancing proliferation and migration of fibroblasts, as well as stimulating collagen synthesis.
Influence of Early Mobilization Exercise

- Decreased adhesions
- Increased strength of repair
- Accelerated Intrinsic healing
EPM vs. Delayed Mobilization

- Gliding surface restored earlier
- Tendon healed quicker
- Increased excursion (95%)
- Increased vascularity

- 19-63% excursion
- Random vascularity
What is an ideal method of tendon suture for healing
The Influence of Gap in Healing

- Increased callus
- Increased adhesions
- Disoriented fibroplastic proliferation
- Decreased overall tendon function
To assess the effect of gap size on the mechanical properties on the tendons

Effect of Gap Formation at the Repair Site on the Strength and Excursion of Intrasynovial Flexor Tendons:
An Experimental Study on the Early Stages of Tendon-Healing in Dogs*

GELBERMAN, RICHARD H  (JBJS 1999)
Solid line: < 1 mm gap
Dashed line: 1 mm~3mm gap
Dotted line: > 3mm gap

A gap of more 3 mm

Greater risk for rupture
Summary

- Sutures easily placed in the tendon
- Secure suture knots
- Smooth juncture of tendon ends
- Minimal gapping at the repair site
- Minimal interference with tendon vascularity
- Sufficient strength throughout healing to permit the application of early motion stress to the tendon

Stickerland (1995)
Fetal Tendon Healing: Development of an Experimental Model


Toronto, Ontario, Canada and Washington, D.C.
- Gap at the laceration site healed much earlier in the fetus than in the adult

- Healing process appears the same in both fetus and adult
Influence of Growth Factors for Tendon Healing
Growth Factors

- **TGF-Beta**
  - Regulates cellular migration and proliferation
  - Increase in mRNA expression of type I collagen
  - Regulates fibronectin binding interactions

- **VEGF**
  - Powerful stimulator of angiogenesis

- **PDGF**
  - Stimulates production of other growth factors
  - Aids in tissue remodeling
Growth Factors

- bFGF
  - Stimulates angiogenesis
  - Regulator of cell migration and proliferation
Experimental Manipulations

- Nakamura (1998) transferred PDGF gene into rat patellar tendon and found increases in angiogenesis and collagen synthesis.

- Aspenberg (1999) used collagen sponges implanted w/ GDF 6,7 (BMP) to increase tensile strength in rats during tendon healing.

- Other pharmacologic interventions.