Objectives

- Describe general goals, principles, and mechanical considerations of tendon transfers
- Explain general preoperative and postoperative rehabilitative guidelines for tendon transfers
- Apply anatomical and surgical considerations to the rehabilitation of specific tendon transfers, with emphasis on median, ulnar, and radial nerve palsies

Overview

- **Restore balance** that has been lost or compromised through disease or injury
- Indications
  - Substitute for weak or paralyzed muscle
  - Replace damaged tendon or muscle
  - Correct muscle imbalance caused by CNS lesion
- Potential diagnoses
  - Peripheral nerve injuries, cerebral palsy, spinal cord injury, thumb hypoplasia, rheumatoid arthritis

Fundamentals

- (Brand, 2011; Brand, Beach, & Thompson, 1981; Brand & Hollister, 1985; Jones, 2013; Livermore & Tueting, 2016; Peljovich, Ratner, & Marino, 2010; Ratner & Kozin, 2011; Sammer & Chung, 2009a, 2009b; Wilbur & Hammert, 2016)

Mechanism

- “Altering the insertion or origin of a nearby, redundant, strong, and voluntarily controlled muscle”
  - (Peljovich, Ratner, & Marino, 2010, p. 1365)
- Muscle is redirected by changing the insertion site of its tendinous portion
- Tendon-tendon coaptation
- Blood and nerve supply unaffected

**Differentiate from free muscle transfer or nerve transfer**

Principles

- Donor properties
  - Must be expendable
  - Adequate power to motor the recipient tendon
  - Similar tendon excursion as the recipient
  - Function synergistic with the recipient
- Normal PROM
- Tissue equilibrium
- Straight line of pull
- Single function per transfer
**Strength & Work**

- **Strength**
  - Ability to generate tension
  - Proportionate to cross-sectional area
  - Does not change with transfer due to factors such as drag
- **Work**
  - Force x distance
  - Proportionate to muscle mass

**Potential Excursion (Amplitude)**

- The distance a muscle can contract if
  - Freed from all its connective tissue attachments
  - Stimulated from its fully stretched position
  - Proportionate to muscle fiber length
  - Dependent on number of sarcomeres in muscle fiber

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**Required Excursion**

- The distance a muscle needs to contract to move the joint(s) through full range of motion
- Typically less than potential excursion
  - i.e. ECRB – 6 cm of potential excursion but only ~3.5 cm of required excursion

<table>
<thead>
<tr>
<th>Wrist extensors and flexors</th>
<th>33 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger extensors</td>
<td>50 mm</td>
</tr>
<tr>
<td>Finger flexors</td>
<td>70 mm</td>
</tr>
</tbody>
</table>

**Available Excursion**

- The distance a muscle can contract as permitted by the surrounding connective tissue
- Varies from person to person
- Dependent on recent use of joints and tendons
- Assessed intra-operatively after cutting tendon at its insertion
  - Measured by stimulating after placement at full stretch
  - Maintained with transfer only if minimal change in position and minimal scarring

**Leverage**

- Ability of a force to cause rotation on a lever
- Moment arm
  - Perpendicular distance between axis of rotation and tendon as it crosses the joint
  - Force → Torque
  - Torque = Force x moment arm
- Mechanical advantage
  - Moment arm of force / Moment arm of load
  - “Price of increased power is reduced range” (Brand, 2011)

**Drag**

- “Internal resistance in the form of friction and the need to stretch passive soft tissues” (Brand, 2011)
- Friction
  - Resisting force that occurs whenever two objects move against each other
- Soft tissue
  - A transferred tendon becomes attached to its new area by soft tissue
  - Living tissue has the ability to remodel or to grow in response to mechanical force
Synergy

- Facilitates post-operative retraining
- Increases excursion

Neuroplasticity

(Schultz, 2006, CC 3.0; https://commons.wikimedia.org/wiki/File:DTI-sagittal-fibers.jpg)

New Considerations

- Wide-awake surgery
  - “Tendon transfer is actually best indicated for such wide-awake surgery” (Tang, 2015, p. 280)
  - Improved ability to obtain optimal tension of transfer

Rehabilitation:

General Guidelines

(Duff & Humpl, 2011; Schwartz, 2014)

Preoperative Considerations

- Evaluation
  - Assess capabilities and impairments
  - Identify potential donor muscles
  - Establish goals
- Intervention
  - Increase joint and soft tissue mobility
  - Isolate and strengthen donor muscles
  - Orthosis fabrication
  - Patient education

Preoperative Evaluation

- History
- Physical Exam
  - AROM and PROM
    - Note joint contractures
  - Sensibility
  - Manual muscle testing, grip/pinch
    - Observe muscle substitution or motor signs
  - Motor learning aptitude
  - Functional tests
Preoperative Orthoses

- Temporarily restore balance via external support
  - Prevent or correct joint contractures or adaptive shortening
  - i.e. Web spacer, PIP extension serial casts
- Prevent overstretches or maladaptive compensatory patterns
  - i.e. Dynamic digital/thumb extension orthosis, Anti-claw orthosis
- Increase function
  - i.e. Short opponens orthosis, Dynamic digital/thumb extension orthosis, Anti-claw orthosis

Preoperative Treatment

- Joint and soft tissue mobilization for ROM
- Muscle training and strengthening
  - Isolate donor muscle
  - Provide feedback via biofeedback and/or NMES
- Patient education
  - Realistic expectations
  - Timeframes of recovery
  - Anticipated rehabilitation demands

Communication with Surgeon

- Specific muscle-tendon units affected
- Anatomical route of the transferred tendon
  - Pulleys and retinaculum
- Site of coaptation
- Quality of soft tissue and strength of suture
- Appearance of wound bed and potential for scarring
- Source of tendon grafts if used

Immobilization/Early Phase

- Protect transfer
  - Post-op cast generally for 3-4 weeks
  - Immobilize in protective position to minimize tension on juncture
- Control edema
- Protect areas of diminished or absent sensation
- Prevent stiffness of uninvolved joints

Mobilization/Intermediate Phase

- Protect transfer between exercises with orthoses
- Initiate activation of transfer
  - Avoid overstretches
    - Isolated joint ROM prior to composite
    - Dynamic orthosis with stop blocks for limited tendon gliding
    - No PROM against transferred tendon
  - Monitor early motion to avoid muscle substitution
    - i.e. Wrist flexion to extend digits; thumb flexion/adduction instead of opposition
    - Short, frequent exercise sessions
Mobilization/Intermediate Phase
- Biofeedback and/or electrical stimulation (at sub-tetany contraction)
- Mobilize surrounding soft tissue to increase available excursion
  - Scar management
  - Sensory reeducation
  - Introduce functional activities

Resistive/Late Phase
- Add resistance to transfer
  - Initiate when can activate transfer without assistance
  - Motion against gravity
  - Strengthen gradually
  - Continue to avoid muscle substitution patterns
- Restore passive motion
  - Gentle passive stretches, monitoring effect on transfer
- Focus on hand function
  - Blocked vs. random task practice
  - Feedback

Transfer Activation – Facilitation
- Preoperative preparation
- Place and holds
- Start exercises in gravity eliminated plane
- Light tasks that result in unconscious activation
  - i.e. Opponensplasty – touch thumb to the SF tip
- Perform the original motion of the donor muscle
  - i.e. RF FDS → FPL

Transfer Activation – Facilitation
- Tapping/vibration over muscle belly
- Biofeedback/NMES to encourage correct action
- Visual cues as adjunct
- Mirror visual feedback (Grangeon et al., 2010)
- Training orthoses
  - i.e. Lumbrical bar as assist following intrinsic transfer
- Perform movements bilaterally

New Considerations
- Early mobilization
  - Systematic review
  - Within 1 week of surgery
  - Safe (no incidence of ruptures or pull-outs)
  - Improved hand function in short-term, reduced costs, and decreased treatment time compared to immobilization
  - Inconclusive findings for long-term outcomes
  (Sultana, MacDermid, Grewal, & Rath, 2013)

Common Tendon Transfers: Anatomy, Surgery, & Rehabilitation

Median, Ulnar, & Radial N. Injuries
(Chadderdon & Gaston, 2016; Cheah, Etcheson, & Yao, 2016; Cook, Gaston, & Lourie, 2016; Diaz-Garcia & Chung, 2016; Duff & Humpl, 2011; Giuffre, Bishop, Spinner, & Shin, 2015; Isaacs & Ugwu-Oju, 2016; Ratner & Kozin, 2011; Sammer & Chung, 2009a, 2009b; Schwartz, 2014)
### Median Nerve

#### Muscle loss & Functional deficit

<table>
<thead>
<tr>
<th>Muscle loss</th>
<th>Functional deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGH LEVEL</strong></td>
<td></td>
</tr>
<tr>
<td>PT, PQ*</td>
<td>Weak/absent forearm pronation</td>
</tr>
<tr>
<td>FCR</td>
<td>Weak wrist flexion / radial deviation</td>
</tr>
<tr>
<td>FDS IF/MF/RF/SF, FDP IF/MF*</td>
<td>PIP/DIP flexion – absent IF/MF, weak RF/SF</td>
</tr>
<tr>
<td>FPL*</td>
<td>Loss of thumb IP flexion</td>
</tr>
<tr>
<td><strong>LOW LEVEL</strong></td>
<td></td>
</tr>
<tr>
<td>Lumbricals IF/MF</td>
<td>MP flexion/IP extension deficit of IF/MF</td>
</tr>
<tr>
<td>APB, OP, superficial FPB</td>
<td>Loss of opposition, palmar abduction (deficits in functional prehension)</td>
</tr>
</tbody>
</table>

* = AIN innervation

* Restore thumb opposition
* Restore thumb IP joint flexion
* Restore digital flexion

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### Median Nerve – Opponensplasty

- Camitz (PL → APB)
  - Allows excellent palmar abduction but limited pronation
  - Used with long-standing CTS
- Superficialis (RF FDS → APB)
  - Uses pulley at pisiform to pull thumb into pronation/opposition
- Huber (ADM → APB)
- Other potential donors
  - EIP, EDQ, ECU

### Median Nerve – Other

- Fewer motors to choose from for high-level
  - ECRL → IF/MF FDP
  - FDP of RF/SF → IF/MF FDP
  - BR → FPL
- Often need concurrent nerve transfers for sensation

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### Ulnar Nerve

(Young, Fattah, & Falmign, 2008)
### Ulnar Nerve

<table>
<thead>
<tr>
<th>Muscle loss</th>
<th>Functional deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCU</td>
<td>Weak wrist flexion / UD</td>
</tr>
<tr>
<td>FDP RF/SF</td>
<td>Loss of power grip</td>
</tr>
</tbody>
</table>

#### HIGH LEVEL
- AP and 1st DI: Loss of key pinch (Froment’s/Jeanné’s sign)
- FPB deep head: Impaired thumb stability during pinch
- Lumbricals RF/SF: Clawing of RF/SF (Duchenne’s)
- Interossei: Wartenberg’s sign, flattened palmar arch (Masse sign)

#### LOW LEVEL
- Correct clawing for functional grasp: Restore intrinsic function via MCP joint flexion (and IP joint extension if negative Bouvier test)
- Restore pinch: Restore thumb adduction (and IF abduction prn)
- Restore RF/SF DIP flexion

### Ulnar Nerve – Intrinsic Plus

- Brand: ECRB with PL free graft to intrinsics via lateral bands
- Modified Stiles-Bunnell: FDS of RF/MF inserted into lateral band or P1
- Zancolli Lasso: FDS passed through pulley and sutured back to itself
- Other donors: EDQ, EIP, ECRL, BR

### Ulnar Nerve – Other

- Adductorplasty
- Restore thumb adduction and lateral pinch
- Most transfers provide improved stability and improved pinch strength of 25-50%
- Boyes: BR extended with free graft
- Smith-Hastings: ECRB → AP/1st metacarpal
- Gross composite flexion
- ECRB → FDP
- IF/MF FDP → RF/SF FDP

### Radial Nerve

<table>
<thead>
<tr>
<th>Muscle loss</th>
<th>Functional deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Level</td>
<td>Brachioradialis: Weak elbow flexion</td>
</tr>
<tr>
<td></td>
<td>ECRB: Weak wrist extension / radial deviation</td>
</tr>
<tr>
<td>Low Level</td>
<td>Supinator: Weak supination (test in extension to eliminate biceps)</td>
</tr>
<tr>
<td></td>
<td>ECU: Weak wrist extension / ulnar deviation</td>
</tr>
<tr>
<td></td>
<td>EDC, EIP, EDQ: Lost digital extension</td>
</tr>
<tr>
<td></td>
<td>EPL, EPB, APL: Lost thumb extension / radial abduction</td>
</tr>
</tbody>
</table>

*Variable, may be innervated by PIN and may be lost in low-level

- Restore wrist extension
- Restore MCP extension
- Restore thumb extension
Radial Nerve

PT → ECRB/L to restore wrist extension
FCU, FCR, or FDS → EDC to restore finger extension
PL or FDS → EPL to restore thumb extension

Radial Nerve – Postoperative

- Post-op immobilization
- Long-arm orthosis
  - 90° elbow flexion, forearm pronation, 30-45° wrist extension, MP extension, IPs free, thumb radial abduction
  - Protective orthosis is continued for a total of ~8 weeks
  - May be able to switch to wrist cock-up at 6 weeks
- Mobilization starts at 3-4 weeks
  - Gentle isolated AROM of each joint is performed
  - Avoid composite wrist/digital flexion until ~8 weeks
- Resistance initiated ~8 weeks

Other Tendon Transfers

(Ashworth & Kozin, 2011; Biednar, 2016)

Thumb Tendon Ruptures

- EIP → EPL
  - Rheumatoid arthritis
  - Distal radius fracture
- FDS MF/RF → FPL
  - Mannerfelt lesion
  - Volar plating s/p distal radius fracture

Elbow

- Restore elbow flexion
  - Latissimus dorsi → biceps
  - Pectoralis major → biceps
  - Triceps → biceps
  - Steindler flexorplasty (flexor-pronator mass)
- Restore elbow extension
  - Posterior deltoid → triceps
  - Biceps → triceps

Shoulder

- Restore shoulder external rotation
  - L’Episcopo: teres major → posterior cuff
  - Modified L’Episcopo: teres major and latissimus dorsi → posterior cuff

A Word (or Two) on Nerve Transfers

- Sensory and/or motor
- Potential advantages over tendon transfers
  - Restore sensation and motor
  - Restore function to multiple muscles
  - Preserve muscle balance
- Limitation
  - More time-sensitive – cannot be done after motor end plate degeneration (12-18 months)

References


References – Images

- When designated, images are courtesy of Primal Pictures
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