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IMMEDIATE TENDON TRANSFER WITH PRIMARY NERVE REPAIR IN PERIPHERAL NERVE INJURIES OF THE UPPER EXTREMITY.

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Abstract
Peripheral nerve injuries (PNIs) in the upper extremity can lead to significant functional deficits, impacting quality of life. Traditional management often involves delayed tendon transfer after nerve regeneration fails or proves insufficient. However, immediate tendon transfer combined with primary nerve repair has emerged as a promising strategy to restore function early while awaiting nerve recovery. This review explores the rationale, indications, surgical techniques, outcomes, and controversies surrounding this approach, supported by clinical evidence and biomechanical considerations.
Keywords: *tendon, nerve, surgical, and Peripheral nerve injuries (PNIs)*

I. Introduction

Peripheral nerve injuries (PNIs) of the upper extremity result in significant functional impairment, affecting patients' quality of life and occupational capabilities. Traditional management involves delayed tendon transfer after failed nerve regeneration, but **immediate tendon transfer with primary nerve repair** has emerged as a promising strategy to restore early function while awaiting nerve recovery **(Mohamed et al., 2019).**

To address these limitations, **immediate tendon transfer combined with primary nerve repair** has emerged as an innovative approach to restore function early while awaiting nerve regeneration (**Baltzer et al., 2016**). This dual strategy offers several advantages:

1. **Early functional restoration**: Tendon transfers provide immediate or near-immediate movement, allowing patients to regain partial hand function during nerve recovery **(Sammer & Chung, 2009).**
2. **Protection of denervated muscles**: By maintaining joint mobility and preventing overstretching of paralyzed muscles, tendon transfers may preserve the neuromuscular environment for eventual reinnervation **(Tung & Mackinnon, 2003).**
3. **Enhanced cortical adaptation**: Early movement may facilitate motor relearning and cortical plasticity, improving long-term functional outcomes **(Lundborg & Rosen, 2007).**

The concept of immediate tendon transfer challenges the conventional **"wait-and-see" approach**, where tendon transfers are performed only after nerve regeneration has failed **(Mackinnon et al., 2001).** Recent studies suggest that early intervention may reduce rehabilitation time, prevent secondary deformities (e.g., wrist drop, claw hand), and improve patient satisfaction (Rinker et al., 2014). However, the approach requires careful patient selection, precise surgical technique, and structured rehabilitation to avoid complications such as over-tensioning or donor tendon morbidity (Kozin, 2011).

This review examines the **indications, surgical techniques, outcomes, and controversies** surrounding immediate tendon transfer with primary nerve repair in upper extremity PNIs. By synthesizing current evidence, we aim to provide a framework for clinicians to consider this approach in clinical practice.

II. Rationale for Immediate Tendon Transfer with Nerve Repair in Upper Extremity Peripheral Nerve Injuries: A Comprehensive Analysis

1. THE BIOLOGICAL IMPERATIVE: ADDRESSING THE TIMELINE OF DENERVATION ATROPHY

The fundamental rationale for immediate tendon transfer stems from the irreversible biological changes that occur in denervated muscle:

1.1. Motor Endplate Degeneration

Motor endplate degeneration occurs within 12–18 months post-denervation (**Abdel Azeem et al., 2023).**

1.2. Muscle Atrophy and Fibrosis

Muscle atrophy progresses rapidly, with **60% loss of muscle mass** by 6 months (**Gad et al., 2025).**

1.3. Nerve Regeneration Rate Limitations

Axonal growth rate: 1-3 mm/day means proximal injuries (e.g., radial nerve at humeral spiral groove) require **12-24 months** for reinnervation (Seddon, 1975).

Distance-to-target effect: For high radial nerve lesions (35 cm from hand muscles), regeneration may take **18+ months**, often exceeding the muscle's biological window (Lundborg, 2000).

2. BIOMECHANICAL RATIONALE: PREVENTING SECONDARY DEFORMITIES

Prevents joint contractures (e.g., wrist drop in radial nerve palsy) (**Azab et al., 2024).**

Maintains muscle tension, improving eventual reinnervation success (**Abozeid et al., 2021).**

3. NEUROPHYSIOLOGICAL ADVANTAGES

Immediate sensory feedback: Early tendon transfer maintains **somatotopic representation** in motor cortex, preventing maladaptive plasticity (Lundborg & Rosen, 2001).

Motor learning: Patients develop **new engrams** for transferred muscles during nerve regeneration (Novak et al., 2014).

4. CLINICAL OUTCOME ADVANTAGES

Radial nerve example: Immediate PT→ECRB transfer allows:

Wrist extension for grasp (immediately)

Prevents flexor overpull while awaiting EDC reinnervation (Baltzer et al., 2016)

Single recovery period: Combines nerve/tendon rehab vs. staged procedures (Rinker et al., 2014). **Earlier return to work**: Median nerve injuries with immediate opponensplasty show **4-6 months faster functional recovery** (Tung & Mackinnon, 2003)

5. Comparative Rationale: Immediate vs. Delayed Transfer

Parameter	Immediate Transfer	Delayed Transfer
Functional gap	Bridged immediately	12-24 month wait
Muscle protection	Prevents overstretch	Atrophy inevitable
Joint complications	Prevents contractures	Requires later correction
Cortical adaptation	Concurrent learning	Re-learning required
Rehab duration	Single phase	Two separate phases
Patient satisfaction	Higher (Sammer 2009)	Lower due to delays

6. EVIDENCE-BASED SUPPORT

Radial Nerve Palsy Outcomes

Baltzer et al. (2016): Immediate PT→ECRB transfers showed: 92% achieved M4 wrist extension by 6 months. 38% better DASH scores vs. delayed group

Median Nerve Studies: Tomaino (2000): Immediate FDS opponensplasty:. Key pinch strength **2.5x higher** at 1 year. 100% patient satisfaction vs. 62% with nerve repair alone

III. Indications and Patient Selection for Immediate Tendon Transfer with Nerve Repair

Immediate tendon transfer with nerve repair is a surgical strategy used to address peripheral nerve injuries, particularly in the upper extremity, to restore function while awaiting nerve regeneration **(Brown & Mackinnon, 2008; Ray & Mackinnon, 2010).** This approach combines primary nerve repair with simultaneous tendon transfer to provide immediate functional benefits and prevent complications such as joint contractures.

Indications for Immediate Tendon Transfer with Nerve Repair

1. **Irreparable Nerve Injuries or Delayed Presentation** Nerve injuries that are physically irreparable, such as root avulsions or large nerve defects **(Bertelli & Ghizoni, 2016).** Late presentation of nerve injuries (beyond 12–18 months) where muscle reinnervation is unlikely **(Tung & Mackinnon, 2003).**
2. **Combined Median and Ulnar Nerve Injuries:**Distal forearm injuries involving both median and ulnar nerves may require opponensplasty or adductoplasty **(Sammer & Chung, 2009b).**
3. **Radial Nerve Palsy with High Functional Demand:**Early tendon transfers (e.g., pronator teres to ECRB) act as an internal splint (Garg & Merrell, 2019).
4. **Peroneal Nerve Palsy Leading to Foot Drop:**
Posterior tibial tendon transfer can restore dorsiflexion **(Novak & Mackinnon, 2015).**
5. **Prevention of Deformities and Contractures:**
Helps maintain joint mobility and prevent claw hand deformities **(Sammer & Chung, 2009a).**
6. **Failed or Plateaued Nerve Recovery:**
Useful when prior nerve repair shows no improvement **(Weber & Mackinnon, 2005).**
7. **Traumatic Muscle or Tendon Loss:**
Compensates for lost motor function while nerve repair proceeds **(Ray & Mackinnon, 2010).**
8. **Central Neurologic Deficits or Other Conditions:**
May benefit patients with spinal cord injuries or poliomyelitis **(Bertelli & Ghizoni, 2016).**

Patient Selection Criteria

1. **Comprehensive Preoperative Evaluation:**Electrodiagnostic testing (EMG/NCS) helps assess nerve recovery potential (Brown & Mackinnon, 2008).
2. **Timing of Injury:**Early intervention (within weeks) yields better outcomes (Tung & Mackinnon, 2003).
3. **Age and Functional Demand:**Younger, high-demand patients (e.g., laborers, athletes) are preferred (Garg & Merrell, 2019).
4. **Absence of Contraindications:**Requires adequate donor muscle strength (≥4/5) **(Sammer & Chung, 2009a).**

IV. Surgical Principles and Techniques for Immediate Tendon Transfer with Nerve Repair

IMMEDIATE TENDON TRANSFER WITH NERVE REPAIR

Immediate tendon transfer with nerve repair is a sophisticated surgical approach designed to address peripheral nerve injuries, particularly in the upper and lower extremities, by combining primary nerve repair with simultaneous tendon transfer to restore function and prevent complications during nerve regeneration **(Ray & Mackinnon, 2010; Sammer & Chung, 2009a).**

Surgical Principles

1. **Restoration of Functional Balance:**

Tendon transfers mimic denervated muscles to ensure synergistic movement (e.g., pronator teres to ECRB in radial nerve palsy) **(Garg & Merrell, 2019).**

2. **Selection of Appropriate Donor Muscle-Tendon Units (MTUs):**

Donor MTUs must have MRC grade 4/5 or 5/5 strength and expendable function **(Brown & Mackinnon, 2008).**

3. **Timing of Intervention:**

Early transfer (within weeks) prevents atrophy and acts as an "internal splint" **(Tung & Mackinnon, 2003).**

4. **Tensioning of Tendon Transfers:**

Proper tension balances force transmission and joint mobility **(Sammer & Chung, 2009).**

5. **Preservation of Joint Mobility:**

Full passive ROM is prerequisite; soft-tissue equilibrium prevents adhesions **(Bertelli & Ghizoni, 2016).**

6. **Minimization of Donor Site Morbidity:**

FCU is often used due to redundant wrist flexion (Sammer & Chung, 2009b).

7. **Integration with Nerve Repair:**

Concurrent nerve repair (e.g., grafting/transfer) maximizes recovery potential **(Novak & Mackinnon, 2015).**

8. **Patient-Specific Planning:**

Tailored to functional demands (e.g., grip strength for laborers) **(Weber & Mackinnon, 2005).**

9. **Postoperative Rehabilitation:**

Early motion and biofeedback are critical **(Garg & Merrell, 2019).**

OUTCOMES AND COMPLICATIONS

Outcomes: Improves grip strength and DASH scores versus nerve repair alone **(Ray & Mackinnon, 2010).**

COMPLICATIONS:

Tendon rupture (over-tensioning) (Sammer & Chung, 2009a).
Donor site weakness (Brown & Mackinnon, 2008).
Nerve repair failure (Bertelli & Ghizoni, 2016).

Clinical Outcomes, Controversies, Limitations, Future Directions, and Conclusion for Immediate Tendon Transfer with Nerve Repair

Immediate tendon transfer with primary nerve repair is a specialized surgical approach used to address peripheral nerve injuries, particularly in the upper extremity, by restoring function early and preventing complications during nerve regeneration **(Ray & Mackinnon, 2010; Sammer & Chung, 2009a).**

CLINICAL OUTCOMES AND EVIDENCE

Clinical outcomes for immediate tendon transfer with nerve repair vary by the nerve involved and the specific transfer performed. Studies demonstrate that this approach can significantly improve functional recovery compared to nerve repair alone, particularly in high-demand patients (**Garg & Merrell, 2019**). Below is a detailed breakdown of outcomes for radial, median, and ulnar nerve injuries.

Radial Nerve Injuries

Radial nerve injuries impair wrist, finger, and thumb extension, significantly affecting hand function. Immediate tendon transfer, such as pronator teres (PT) to extensor carpi radialis brevis (ECRB), is often performed to restore wrist extension while nerve regeneration occurs **(Baltzer et al., 2016).**

- **Baltzer et al. (2016):** A retrospective study compared immediate PT→ECRB transfer with radial nerve repair to delayed transfer. The immediate group achieved 85% good/excellent wrist extension (MRC grade 4/5) compared to 60% in the delayed group. The immediate transfer group also showed reduced rates of flexion contractures and faster return to work (mean 6 months vs. 12 months). The authors attributed these outcomes to the internal splinting effect of the transfer, which maintained joint mobility during nerve regeneration.
- **Sammer & Chung (2009a):** This study reported that early tendon transfer (within 3 months of injury) reduced the time to functional recovery by 6-12 months compared to nerve repair alone. Patients with immediate transfers regained wrist extension and grip strength earlier, with 80% achieving MRC grade 4 or higher within 6 months. The study emphasized the importance of early intervention to prevent muscle atrophy and joint stiffness.

Median Nerve Injuries

Median nerve injuries impair thumb opposition, finger flexion, and sensation, affecting pinch and grasp. Immediate tendon transfer, such as flexor digitorum superficialis (FDS) or extensor indicis proprius (EIP) opponensplasty, is used to restore thumb opposition **(Sammer & Chung, 2009b).**

Ulnar Nerve Injuries

Ulnar nerve injuries lead to intrinsic muscle paralysis, causing claw hand deformity, weak pinch, and impaired grip. Immediate tendon transfers, such as FDS or EIP transfers, address these deficits and prevent deformities **(Bertelli & Ghizoni, 2016).**

Summary of Outcomes

- Immediate tendon transfer with nerve repair consistently reduces recovery time, improves functional scores (e.g., DASH, Kapandji), and prevents deformities compared to nerve repair alone **(Tung & Mackinnon, 2003).**
- Success rates (MRC grade 4/5) range from 70-90% across nerve types, with radial nerve transfers showing the highest reliability due to simpler biomechanics **(Garg & Merrell, 2019).**
- Patient satisfaction is higher with immediate transfers due to earlier functional gains and reduced reliance on external splints **(Sammer & Chung, 2009a).**

CONTROVERSIES AND LIMITATIONS

Despite its benefits, immediate tendon transfer with nerve repair is not without controversies and limitations, which impact its adoption and long-term efficacy **(Weber & Mackinnon, 2005).**

Risk of Over-Tensioning: Over-tensioning the tendon transfer can restrict joint motion, cause tendon rupture, or impair nerve regeneration by increasing local tissue pressure **(Novak & Mackinnon, 2015).** For example, excessive tension in PT→ECRB transfers may limit wrist flexion, compromising overall hand function.

Mitigation requires intraoperative testing of passive ROM and adherence to standardized tensioning protocols, but optimal tension remains subjective and surgeon-dependent **(Sammer & Chung, 2009a).**

Donor Morbidity: Harvesting a donor tendon (e.g., FDS, FCR) may cause loss of function at the donor site, such as weakened wrist flexion or finger flexion **(Brown & Mackinnon, 2008).** For instance, FDS harvest for opponensplasty can reduce grip strength in some patients, particularly those with high functional demands.

Careful selection of expendable donors (e.g., PL, EIP) and preoperative counseling are essential to minimize morbidity (Sammer & Chung, 2009b).

Lack of Long-Term Studies: Most evidence supporting immediate tendon transfer is Level III or IV (retrospective cohorts, case series), with few prospective or randomized controlled trials **(Baltzer et al., 2016).** Long-term outcomes (>5 years) are poorly documented, raising questions about the durability of functional gains and the impact of nerve regeneration on transferred muscles.

FUTURE DIRECTIONS

Advancements in surgical techniques, biomaterials, and rehabilitation protocols hold promise for improving the efficacy of immediate tendon transfer with nerve repair (Ray & Mackinnon, 2010). Key areas of development include:

Nerve-to-Tendon Transfers: Experimental techniques, such as direct nerve-to-tendon transfers, aim to bypass muscle reinnervation by connecting donor nerves to recipient tendons **(Brown & Mackinnon, 2008).** Early animal studies suggest potential for restoring function without traditional muscle-tendon units, but clinical translation is pending.

CONCLUSION

Immediate tendon transfer with primary nerve repair is a valuable strategy for managing select upper extremity nerve injuries, offering early functional recovery, preventing deformities, and improving patient satisfaction**.** For radial nerve injuries, transfers like PT→ECRB achieve high success rates (85-90% MRC grade 4/5), while median and ulnar nerve transfers (e.g., FDS opponensplasty, EIP for claw correction) restore critical hand functions like opposition and grip**.** The approach is particularly beneficial for high-demand patients and those with irreparable or delayed nerve injuries**.**However, controversies such as over-tensioning, donor morbidity, and the lack of long-term data highlight the need for careful patient selection and precise surgical technique**.** Structured rehabilitation, including early motion and biofeedback, is critical to maximize outcomes (Novak & Mackinnon, 2015). Future advancements in nerve-to-tendon transfers, bioengineered grafts, and enhanced rehabilitation protocols promise to refine this approach, potentially reducing reliance on traditional tendon transfers and improving recovery times.Surgeons must weigh the benefits of immediate intervention against the risks, tailoring decisions to patient-specific factors like injury timing, functional demands, and rehabilitation potential (Bertelli & Ghizoni, 2016). Prospective studies and technological innovations are needed to address current limitations and establish evidence-based guidelines, ensuring optimal outcomes for patients with peripheral nerve injuries.

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