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# Enhancing Recovery: Investigating Outcome in Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer

Tachit Jiravichitchai, *The University of Western Ontario*

Supervisor: MacDermid, Joy C., *The University of Western Ontario*

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# Abstract

Navigating the complexities of proximal ulnar nerve lesions presents a formidable challenge, prompting an urgent call for standardized outcome measures in the realm of supercharged end-to-side (SETS) anterior interosseous nerve (AIN) to ulnar nerve transfer, compounded by the intricacies of ulnar nerve transposition. This thorough thesis takes a dual-method approach, utilizing a rigorous Delphi study in addition to a scoping review methodology to clarify the complex terrain of SETS procedures.

The scoping review comprehensively delves into the outcomes and associated factors of SETS procedures, unraveling the intricate recovery trajectories while shedding light on the hurdles of standardization. Additionally, it incorporates an expert insight consultation part, providing a unique perspective from seasoned practitioners in the field. Meanwhile, the Delphi study engages expert practitioners in discerning a consensus on essential outcome measures for AIN to ulnar nerve transfers, encompassing SETS and ulnar nerve decompression. Through iterative rounds of questionnaires, the study distills expert insights into a core set of outcome measures, providing a comprehensive framework for post-operative evaluation.

The culmination of these endeavors yields vital conclusions, emphasizing the imperative of bridging the knowledge gap surrounding outcome measures and advocating for the utility of SETS procedures, particularly in addressing severe cubital tunnel syndrome. The significance of this work transcends academic boundaries, extending its reach to guide both research and clinical practices, offering a nuanced understanding of upper extremity nerve transfers and charting a course for future advancements in the field.



# Keywords

Cubital Tunnel Syndrome, Proximal Ulnar Nerve Lesions, Supercharged End-to-Side (SETS) Transfer, Ulnar Nerve, Anterior Interosseous Nerve (AIN), Outcome Measures, Scoping Review, Delphi study

# Summary for Lay Audience

This research project delves into the complex world of hand function and nerve injuries, specifically focusing on the ulnar nerve, which plays a vital role in controlling hand movements and providing sensation to the ulnar side of the hand. When this nerve is disrupted, it can lead to a range of issues, including loss of pinch strength and digital dexterity, potentially resulting in a deformity known as claw hand. The project addresses the challenges associated with severe consequences of ulnar nerve injuries, particularly in cases of cubital tunnel syndrome or proximal ulnar nerve lesions.

We explore innovative surgical techniques, such as the supercharged end-to-side (SETS) transfer, to aid in the recovery of severe cases of ulnar neuropathy. Traditional approaches often face limitations, especially in cases where injuries are proximal, leading to poor motor function recovery. The SETS procedure overcomes these challenges by connecting nerves in a way that allows for quicker reinnervation, resulting in "double innervation" and potentially better functional outcomes.

To ensure the success of this surgical intervention, our project includes a scoping review with expert insights, comprehensively examining outcomes and factors associated with SETS procedures. We also conduct a Delphi study, engaging expert practitioners to establish a consensus on crucial outcome measures for the ulnar nerve decompression and the specific nerve transfer, providing a standardized approach for post-operative evaluations.

This research is crucial not only for clinicians and researchers but also for individuals facing the prospect of these surgeries. By addressing gaps in knowledge and standardizing outcome measures, our project aims to enhance the recovery process and guide future treatments for those affected by proximal ulnar nerve lesions. The findings have the potential to improve the lives of individuals dealing with the consequences of these injuries, offering hope for better functional recovery and overall hand health.

# Co-Authorship Statement

Tachit Jiravichitchai and his supervisor, Dr. Joy C. MacDermid, collaborated to formulate the core concept of the research question, design the study protocol, establish specific objectives, and outline the research design. Feedback from committee members, Dr. Stahs Pripotnev and Dr. Pulak Parikh, was sought regarding the main idea, details of milestones, and their expectations. Co-authors were brought in when additional assistance and expertise were needed, and their specific contributions are outlined below:

*CHAPTER 1: Introduction*

Tachit Jiravichitchai – responsible for study design, literature review, quality appraisal, data extraction, narrative synthesis, and manuscript writing

Joy C. MacDermid – study design, data analysis, and manuscript review

*CHAPTER 2: Exploring Outcomes and Mediating Factors following Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer: A Scoping Review with Expert Insight*

Tachit Jiravichitchai – Primary author, study design, search strategy running, study selection, data extraction, data analysis, and manuscript writing

Joy C. MacDermid – Co-author, conception of study idea and study design, manuscript revising for important intellectual content

Maryam Farzad – Co-author, second reviewer, second data extractor, manuscript writing, and manuscript reviewer

Stahs Pripotnev – Co-author and manuscript reviewer

Pulak Parikh – Co-author and manuscript reviewer

*CHAPTER 3: Forging Consensus: Establishing a Core Set of Outcome Measures in the Supercharged End-To-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer – A Delphi Study*

Tachit Jiravichitchai – Primary author, study design, ethics drafting, participants recruiting, data collecting, data analysis, result interpretation and manuscript writing

Joy C. MacDermid – Co-author, study design, ethics application maintaining, data analysis, manuscript reviewer, manuscript revising, and final manuscript approving

Maryam Farzad – Co-author, result interpretation, and manuscript reviewer, and manuscript revising

Stahs Pripotnev – Co-author, manuscript reviewer

Pulak Parikh – Co-author, manuscript reviewer

*CHAPTER 4: Grand Discussion*

Tachit Jiravichitchai – sole author

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# Chapter 1

## Introduction to the Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer and Literature Review

M.Sc. Thesis – Tachit Jiravichitchai;

University of Western Ontario – Health & Rehabilitation Sciences

# 1.0 Introduction

## *1.0.1 Ulnar Nerve Anatomy:*

The ulnar nerve arises from the ventral rami of the C8 and T1 nerve roots, which combine together to create the lower trunk of the brachial plexus. The ulnar nerve fibres in the anterior division of the lower trunk, which later forms the medial cord, split the trunk into an anterior and posterior division. The ulnar nerve passes from the axilla into the medial aspect of the anterior compartment of the upper arm after leaving the brachial plexus as a terminal branch of the medial cord. (Polatsch et al., 2007)

The ulnar nerve is located posteromedial to the brachial artery in the upper arm. It subsequently makes its way posteriorly through the medial intermuscular septum, going through the arcade of Struthers around 8 cm proximal to the medial epicondyle. (Spinner et al., 1978) Anatomically and electrophysiologically demonstrated, the arcade of Struthers is a known potential location of ulnar nerve compression. (Ochiai et al., 1992) The nerve stays anterior to the medial head of the triceps muscle and posterior to the intermuscular septum as it descends the lower arm. As it enters onto the medial epicondyle of the distal humerus, the continuous medial intermuscular septum thickens and flares out distally. (Polatsch et al., 2007) When anterior transposition occurs or a patient has an ulnar nerve that subluxes over the medial epicondyle due to congenital instability, the intermuscular septum may become a site of compression for the ulnar nerve. (Polatsch et al., 2002)

The ulnar nerve passes behind the medial epicondyle towards the cubital tunnel, situated posterior to the elbow's axis of rotation. The tunnel's roof, comprised of Osborne's ligament (cubital tunnel retinaculum (CTR)) and the deep layer of the flexor carpi ulnaris (FCU) muscle, prevents anterior subluxation of the nerve during elbow flexion. (O'Driscoll et al., 1991) Osborne's fascia, the deep layer of the aponeurosis of the flexor carpi ulnaris (FCU) muscle, constitutes the distal roof of the cubital tunnel and is commonly associated with ulnar nerve compression. The medial collateral ligament's posterior and transverse portions, along with the elbow capsule, make up the cubital tunnel's floor. (Polatsch et al., 2007) Beyond the cubital tunnel, the ulnar nerve runs beneath Osborne's fascia, nestled between the ulnar and humeral heads of the FCU muscle. The deeper layer of this fascia extends approximately 3 to 5 cm toward the tunnel's end. (O'Driscoll et al., 1991) The ulnar nerve subsequently pierces the fascia, positioning itself between the bellies of the FCU and flexor digitorum profundus (FDP) muscles. (Amadio et al., 1986) The ulnar nerve issues multiple motor branches within the cubital tunnel to the FCU and the ulnar half of the FDP muscles. (Tubbs et al., 2006)

The ulnar nerve descends beneath FCU muscle, running along the FDP muscle. In the mid-distal forearm, it passes ulnar to the ulnar artery, both beneath the FCU muscle. The palmar cutaneous branch, or 'nerve of Henle,' contributes to sympathetic innervation of the ulnar artery. (Balogh et al., 1999) In the distal third of the forearm, the dorsal cutaneous branch of the ulnar nerve separates and passes ulnar to the FCU. After piercing the FCU fascia, it enters the dorsal ulnar forearm, dividing into radial and ulnar branches, providing sensation to the dorso-ulnar hand and dorsum of the small and ring fingers. (Polatsch et al., 2007)

The main trunk of the ulnar nerve becomes superficial under the FCU, entering Guyon's canal with the ulnar artery. In the canal, it splits into superficial and deep branches, alongside the ulnar artery positioned radially. The nerve branches in the hand include the superficial branch, innervating palmaris brevis muscle and dividing into the fourth common digital nerve and the ulnar proper digital nerve for the small finger. (Polatsch et al., 2007) The ulnar nerve's motor branch, accompanied by the deep ulnar artery branch, passes between muscles near the pisohamate ligament. It then supplies hypothenar muscles, interosseous muscles, lumbricals, adductor pollicis, and the medial head of the flexor pollicis brevis. Additionally, it sends articular branches to adjacent carpal joints. (Polatsch et al., 2007; APFELBERG et al., 1973)

### *1.0.2 Ulnar Neuropathy at the Elbow (UNE) or Cubital Tunnel Syndrome*

The ulnar nerve is prone to experience dynamic yet physiological compression when the elbow is flexed, owing to a decrease in the volume of the cubital tunnel. (WADSWORTH et al., 1977) It has been demonstrated that when the elbow flexes and the

FCU muscles contract at the same time, the pressure inside the cubital tunnel increases 20 times. (Werner et al., 1985) Such activities with elbow flexion encompass sleeping with a bent elbow, engaging in weightlifting, extended airplane travel, driving, prolonged typing, and repetitive phone use. (Polatsch et al., 2007). In the position, the ulnar nerve undergoes an average stretch of 4.7 mm. Any disruption to its natural gliding increases pressure in the canal, causing damage and initiating a cycle of edema, ischemia, and structural alterations like perineural fibrosis. This leads to long-term nerve conduction problems. (Cambon-Binder et al., 2021)

Ulnar nerve injury at the elbow may happen with dislocation or subluxation during flexion, especially with CTR insufficiency and triceps brachii bulging, found in about 20% of cases and detectable clinically or via ultrasonography. (Rutter et al., 2019)

UNE can manifest in diverse ways, with common presentations including tingling sensations, hand clumsiness, hand atrophy, and weakness. The varying symptoms of UNE may be linked to the compression of the ulnar nerve at different locations around the elbow. Typically, patients report sensory deficits in the fourth and fifth digits of the affected hand, sensitivity around the medial elbow, and pain in the forearm and hand. (Stewart et al., 2006) Because of pain, paresthesia, and loss of motor function, neuropathy of the ulnar nerve in the elbow can cause a serious impairment of hand function. Within the vast majority of elbow ulnar nerve lesions, there is a 10–30% "idiopathic" category. (APFELBERG et al., 1973)

### *1.0.3 Diagnostic Processes*

Apart from sensory examination and manual muscle testing of intrinsic ulnar-innervated hand muscles by the Medical Research Council (MRC) scale, several studies have explored the use of clinical examinations for diagnosing UNE or cubital tunnel syndrome. Some of these studies concentrated on provoking symptoms by performing specific actions at the elbow or wrist along the nerve. These actions include tests like Tinel's sign, elbow flexion-compression tests, and palpation of the ulnar nerve to identify thickening or the presence of local tenderness along the nerve in both static and dynamic ways. These examinations were then compared to alternative diagnostic methods for UNE, such as ultrasound or nerve conduction studies. (Anderson et al., 2022)

The scratch collapse test entails scratching the patient's skin at the site of nerve entrapment, followed by resisting shoulder external rotation. A positive test is indicated when the arm collapses into internal rotation against resistance. Research has demonstrated consistent positivity rates for this test, regardless of the examiner conducting it. (Cheng et al., 2008; Blok et al., 2014; Simon et al., 2017) By the way, it's worth noting that the scratch collapse test lacks sufficient reliability to diagnose pathologies related to peripheral neuropathies. Its sensitivity is not high enough to be a dependable diagnostic tool for ruling out UNE. However, it does exhibit higher specificity compared to other clinical exams. (Montgomery et al., 2020)

When diagnosing UNE, electrodiagnostic (EDx) techniques like nerve conduction studies are frequently utilised. Visser et al. recommended the adoption of short-segment nerve conduction studies for all individuals with suspected ulnar nerve neuropathy at the elbow. This approach proved effective in pinpointing nerve lesions. (Visser et al., 2005) A 2023 systematic review suggests that a reduced or absent preoperative ulnar sensory nerve action potential (SNAP) may be indicative of poorer postoperative outcomes in UNE. According to higher-quality studies, the presence of a preoperative conduction block at the elbow might also predict unfavorable postoperative results. (Meiling et al., 2023)

Research has explored the utility of sonography in diagnosing UNE. A positive result is identified by an enlarged cross-sectional area of the ulnar nerve at different points around the elbow. Several studies indicate that ultrasonography exhibits high sensitivity in detecting ulnar nerve lesion near the elbow. (Bayrak et al., 2010; Ellegaard et al., 2015) As a result, physicians can employ ultrasound as an additional tool during follow-up consultations for a quick assessment of patients with UNE. (Yoon et al., 2008)

The primary EDx method commonly employed involved measuring motor conduction velocity along a 10 cm segment at the elbow. This method is considered the 'first-line' approach in widely followed guidelines for diagnosing UNE (AANEM 1999b).

Inching, among the EDx parameters, exhibited the highest sensitivity. Across the majority of selected studies, ultrasound demonstrated slightly superior sensitivity for diagnosing UNE compared to the most widely used EDx method. (Pelosi et al., 2021)

In conclusion, there isn't a single, well recognized test for UNE diagnosis. This is caused by test accuracy constraints, interrater variations observed across several tests, and positive test results observed in symptom-free patients. (Hutchison et al., 2011) As a result, the diagnosis of UNE should involve a physical examination, testing, and clinical suspicion. (Anderson et al., 2022)

### *1.0.4 Epidemiology*

UNE is often considered the second most common mononeuropathy in the upper limb, following carpal tunnel syndrome (CTS). (Mondelli et al., 2005)

Regarding a large national administrative database in the US, the adjusted incidence rate of UNE is estimated at 30.0 per 100,000 person-years. Among the 53,401 new cases identified from 2006 to 2012, 41.3% received surgical treatment. Men had a higher incidence (31.2 cases per 100,000 person-years) than women (28.8 cases per 100,000 person-years). Overall, incident cases increase with age in both genders. Additionally, both the incidence and the percentage of surgically treated cases rise with age, from 34.4% in the 18-30 age group to 48.8% in the 60-65 age group. (Osei et al., 2017) The mean annual crude and sex-specific incidences remained stable throughout the study. Age-specific incidences for the entire population and both genders exhibited an upward trend with each decade of age. (Mondelli et al., 2005)

Despite the common occurrence of work-related musculoskeletal disorders, there hasn't been extensive research on the connections between working conditions and UNE. Regarding work-related issue, the annual incidence of ulnar nerve entrapment at the elbow in repetitive work was estimated to be 0.8% per person-year, based on a 3-year prospective (1993-1995) survey of 598 workers. (Descatha et al., 2004)

The general population's prevalence of cubital tunnel syndrome might be greater than previously documented. The utilization of an active surveillance technique in the recent study may contribute to the increased reported prevalence when compared to earlier assessments of the disease burden. This indicates that a portion of individuals with symptoms may not recognize them or seek medical attention. (An et al., 2017)

However, many patients may exhibit severe disease despite having a normal nerve conduction study, making it an inconsistent and less effective diagnostic method for UNE. (Anderson et al., 2022) The typical age of UNE patients is 46 years, with a standard deviation of 15.7 years. (An et al., 2017)

### *1.0.5 Treatment Options*

There are operative and non-operative options for managing UNE. For mild to moderate cases of UNE, conservative treatment may provide benefits, with surgical approaches typically reserved for more severe instances. (Anderson et al., 2022) Various non-surgical interventions, such as patient education, the use of elbow splints and braces limiting flexion to 30-45° (Apfel et al., 2006; Shah et al., 2013), nerve gliding exercises (Coppieters et al., 2004), and the application of physical modalities (ultrasound and low-level laser therapy) (Ozkan et al., 2015) are suggested to alleviate symptoms of ulnar nerve entrapment at the elbow. A thorough history assessment is crucial to identify activities or movements that may exacerbate the condition.

Regarding surgical option, decompression by anterior transposition of the ulnar nerve and in situ decompression are the two primary methods. The goal of these methods is to release any pressure or tension that may be inside the elbow's cubital tunnel, affecting the ulnar nerve.

The in-situ decompression of the ulnar nerve involves releasing tissue at the site of compression. Decompression can be achieved through open or endoscopic procedures. Open decompression was the initial surgical technique employed for managing UNE. (Carlton et al., 2018) Endoscopic decompression methods involve making an incision between the medial epicondyle and the olecranon. Once the compression point is identified, the surgeon can incise the overlying tissue to relieve pressure on the nerve. (Carlton et al., 2018) Systematic review and meta-analyses have supported this, indicating no discernible difference in patient-reported outcomes and neurophysiologic testing between the two methods. (Aldekhayel et al., 2016) The procedure of medial epicondylectomy, occasionally performed alongside in situ decompression, has been associated with significantly higher satisfaction and reduced pain levels. (Geutjens et al., 1996)

Anterior transposition of the ulnar nerve involves mobilizing the ulnar nerve anteriorly to the medial epicondyle. Different sites, including subcutaneous, intramuscular, and submuscular, have been proposed for ulnar nerve placement. The intramuscular method positions the nerve within the pronator teres muscle, while the submuscular approach places it deep to the FCU muscle. (Carlton et al., 2018)

Severe cases of UNE and other high-level ulnar nerve injuries often result in poor outcomes. This is primarily due to irreversible degeneration of motor end plates occurring before regenerated ulnar nerve axons can effectively reinnervate the hand's intrinsic muscles. To expedite the reinnervation process of intrinsic motor end plates, a proposed approach involves an anterior interosseous nerve (AIN) to ulnar motor nerve transfer. (Dunn et al., 2021) In 1991, Brown, Yee, and Mackinnon introduced a technique involving the transfer of the pronator quadratus branch of the anterior interosseous nerve (AIN) to the deep motor branch of the ulnar nerve. This method aims to restore both motor and sensory functions in the hand associated with the ulnar nerve. (Brown et al., 2005) Subsequent reports have indicated excellent outcomes, suggesting that this procedure could be the preferred method for treating ulnar nerve injuries. (Novak et al., 2002; Haase et al., 2002) Initially, due to simplicity and familiarity, end-to-end (ETE) and end-to-side (ETS) methods were used frequently. Supercharge end-to-side (SETS) was later introduced by Mackinnon and colleagues in 2012. (Barbour et al., 2012)

## 1.1 Literature Review on Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer

SETS is an advanced variation of the end-to-side transfer. In SETS, additional measures are taken to enhance the success of axonal regeneration. (Kale et al., 2011) This often involves creating a small window or opening in the recipient nerve (ulnar nerve)'s epineurium and perineurium and placing a nerve graft between AIN and motor component of ulnar nerve. The ulnar nerve and dorsal cutaneous branch are identified. Interfascicular neurolysis exposes the motor and sensory parts of the ulnar nerve. The motor component, situated between the main sensory part and the dorsal cutaneous branch, undergoes a perineurial window procedure. A few sutures are then placed to ensure a tension-free coaptation. The SETS coaptation is finalized with additional circumferential sutures. (Barbour et al., 2012) The graft serves as a conduit for axons to travel from the donor nerve into the recipient nerve, potentially leading to more robust regeneration and functional recovery. (Kale et al., 2011)

### *1.1.1 Patient Selection Criteria*

Ulnar nerve injuries proximal to the elbow, classified as neurotmetic (Sunderland IV, V) (Sunderland et al., 1951), often require distal nerve transfers for a satisfactory outcome. In cases where a direct ETE transfer of the AIN to the primary ulnar motor is feasible, it is recommended. Direct repair of the ulnar nerve becomes the preferred approach for injuries located in the distal forearm, particularly when anticipating motor recovery. (Barbour et al., 2012)

For midlevel injuries near the elbow or high ulnar nerve injuries featuring a Martin Gruber anastomosis, consideration should be given to a SETS augmentation procedure. This SETS procedure is specifically recommended for patients with second- and third-degree Sunderland Classification (Sunderland et al., 1951) injuries exhibiting fibrillations (spontaneous activities) and motor unit potentials or nascent units (insertional activities) on electromyography (EMG). (Dengler et al., 2020) It is also indicated for cases with very proximal cell body lesions, cervical root injuries not amenable to surgical repair, and distal peripheral motor neuropathies like Charcot-Marie-Tooth. (Barbour et al., 2012)

However, the SETS procedure is not suitable for patients with first-degree conduction block at the cubital tunnel, provided there are normal motor units and no fibrillations on EMG, even in the presence of intrinsic muscle compromise. In such cases, the resolution of the conduction block through ulnar nerve transposition at the elbow and decompression at Guyon canal is deemed sufficient to correct intrinsic losses, eliminating the need for a SETS procedure. (Barbour et al., 2012)

### *1.1.2 Complications and Mitigation Strategies*

This procedure does not result in significant donor deficit postoperatively, as full pronation strength is maintained with an intact pronator teres muscle. Potential complications include extended operating time, temporary reduction in sensory or motor function due to neurapraxic injury to the ulnar nerve, and a risk of postoperative bleeding or wound infection. (Barbour et al., 2012)

Some studies noted minor complications, including infection (treated with antibiotics), seroma, hematoma, wound breakdown, keloid formation, hypersensitive scar, and allergic reactions. These issues were generally controllable and did not markedly affect the overall success of the procedure. (Doherty et al., 2021; Xie et al., 2021)

### *1.1.3 Functional Recovery Assessment*

In animal investigations, functional results following SETS transfer have typically been reported as being on track with or better than results following ETE repair without SETS protection. (Fujiwara et al., 2007; Li et al., 2014) The most popular method for demonstrating improved motor recovery following SETS transfer is stimulated isolated muscle contraction force at sacrifice. It has been demonstrated that the SETS transfer increases muscle mass, albeit this conclusion has not held up well in other experimental models. (Fujiwara et al., 2007)

Because rodent models with short experimental endpoints and short distances between the SETS transfer and proximal recipient nerve injury are used, it may be more challenging to determine the mechanism of functional improvement following SETS transfers. (Fujiwara et al., 2007; Li et al., 2014) Greater regenerative lengths in larger animal models may highlight functional variations resulting from early axon reinnervation of muscle targets or from the influence of donor axons on native axon regeneration. An additional advantage of these models would be their increased resemblance to clinical circumstances. (von Guionneau et al., 2020)

### *1.1.4 Cost-Benefit Analysis*

As of now, there is a notable absence of a direct cost-effectiveness analysis specific to the SETS AIN to ulnar nerve transfer procedure. However, in the broader context of nerve transfer interventions, a study has indicated the cost-effectiveness of such procedures in restoring shoulder function for individuals with upper brachial plexus injury (UBPI). The research suggests that nerve transfer is a more cost-effective intervention compared to alternative operative and nonoperative treatments for UBPI, presenting an incremental cost-effectiveness ratio (ICER) of $5776.73 per quality-adjusted life year (QALY) compared to no treatment. (Khalifeh et al., 2019) Drawing parallels from this finding, one might assume that SETS AIN to ulnar nerve transfer could yield similar results. Nevertheless, the absence of a direct analysis warrants future research specifically focused on the cost-benefit aspects of the SETS AIN to ulnar nerve transfer procedure to provide a comprehensive understanding of its economic implications.

### *1.1.5 Patient Experience and Quality of Life*

The future of qualitative research on patients' experiences following SET AIN to the ulnar nerve holds significant importance. Currently, there is a noticeable gap in direct research focused on this specific aspect. Exploring the qualitative dimensions of patients' postoperative experiences, including factors such as pain levels, functional improvements, and psychosocial adjustments, is crucial for obtaining a comprehensive understanding of the outcomes of SET AIN to ulnar nerve transfer. Qualitative research can delve into the nuances of patients' perspectives, shedding light on the subjective aspects of their journey, which quantitative measures may not fully capture. Additionally, investigating the impact of SET AIN to ulnar nerve transfer on patients' overall quality of life can provide valuable insights into the holistic implications of this surgical intervention. By conducting in-depth qualitative studies, researchers can contribute substantially to enhancing the clinical knowledge base and refining the therapeutic approaches for individuals undergoing this particular nerve transfer procedure.

## 1.2 Thesis Rationale and Objectives

The dynamic landscape of peripheral nerve surgery, particularly within the realm of SETS AIN to ulnar nerve transfer, underscores the imperative need for a thorough exploration of recovery landscapes. As this specific procedure gains prominence, a comprehensive understanding of the outcomes and factors influencing recovery becomes paramount. Presently, a discernible gap exists in the literature, necessitating a scoping review to systematically map and synthesize existing knowledge on outcomes and influencing factors in SETS AIN to ulnar nerve transfer.

This scoping review aims to provide a holistic view of the recovery dynamics associated with this surgical intervention. By synthesizing diverse sources, it will not only consolidate existing knowledge but also shed light on gaps and limitations in the current understanding of recovery trajectories. Also, the expert insight will fulfill and enhance the knowledge on outcome assessment after this procedure. This exploration lays the foundation for future research endeavors, directing attention toward areas requiring further investigation, and fostering a nuanced comprehension of the recovery landscapes intrinsic to SETS AIN to ulnar nerve transfer.

In tandem with this exploration, the thesis acknowledges the necessity of standardizing outcome measures in AIN to ulnar nerve transfer, especially when incorporating ulnar nerve transposition. To achieve this, a Delphi study is proposed, engaging experts in the field to iteratively collect and distill their opinions on the essential outcome measures in this surgical context.

The overarching objectives of this thesis are twofold:

**Exploring Recovery Landscapes (Scoping Review with Expert Insight)**:

- Conduct a systematic scoping review with expert insight to comprehensively map and synthesize existing literature on outcomes and factors influencing recovery in SETS AIN to ulnar nerve transfer.
- Identify patterns, trends, and gaps in the current knowledge landscape.
- Incorporate expert insight from healthcare practitioners specializing in ulnar nerve surgeries to provide a comprehensive analysis of the existing literature, enriching the scoping review with real-world clinical perspectives and practical insights.
- Offer critical insights into the multifaceted aspects of recovery, laying the groundwork for a nuanced understanding of the procedure's outcomes.

**Forging Consensus on a Core Set of Outcome Measures (DELPHI Study)**:

- Initiate a DELPHI study, leveraging expert opinions to establish a consensus on a core set of outcome measures for AIN to ulnar nerve transfer, incorporating ulnar nerve transposition.
- Iteratively gather, analyze, and refine expert opinions to ensure a thorough exploration of the diverse facets of recovery assessment.
- Develop a robust and widely accepted framework for outcome measurement, fostering standardization and comparability across studies in the evaluation of AIN to ulnar nerve transfer outcomes.

Through these dual objectives, the thesis endeavors to contribute to the refinement of research methodologies, the establishment of consensus-driven assessments, and the overall advancement of knowledge in the realm of SETS AIN to Ulnar Nerve Transfer and its associated outcome measures.

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# Chapter 2

**Exploring Outcomes and Mediating Factors following Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer: A Scoping Review with Expert Insight**

Tachit Jiravichitchai, MD[a,b,c], Maryam Farzad, PhD[a,b,d], Joy MacDermid, PhD[a,b], Pulak Parikh[a], PhD, Stahs Pripotnev, MD[b], Hand Surgery Expert Group

[a] *Department of Health and Rehabilitation Sciences, Faculty of Health Sciences, University of Western Ontario, London, ON, Canada*

[b] *Roth | McFarlane Hand and Upper Limb Center, St. Joseph's Health Care, London, ON, Canada*

[c] *Department of Rehabilitation Medicine, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand*

[d] *Department of Occupational Therapy, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran*

**Abstract**

This scoping review critically examines the effectiveness of supercharge end-to-side (SETS) anterior interosseous nerve (AIN) to ulnar motor nerve transfer in treating ulnar neuropathy. Our search across several online databases, including MEDLINE, Embase, PubMed, and Google Scholar, strengthens the rigor and comprehensiveness of our findings. By scrutinizing 17 studies encompassing 300 patients, we elucidate notable improvements in both functional and neurological recovery post-surgery. Key outcomes include enhancements in pinch and grip strength, claw correction, and markers of nerve regeneration. Expert consultations further enrich our understanding, emphasizing crucial factors like forearm posture assessment, dorsal web atrophy, and the utility of Tinel's sign. With compelling evidence and expert consensus, supercharge nerve transfer emerges as a promising intervention for managing ulnar neuropathy, poised to significantly improve patient outcomes and quality of life.

**Keyword:** Cubital tunnel syndrome; Ulnar neuropathy; Nerve transfer; Anterior Interosseous Nerve; Supercharged end to side; Scoping review; Expert insight

**Introduction**

The ulnar nerve's critical role in hand function, governing the majority of motor functions and providing sensation, underscores its significance. Disruption of the ulnar nerve can lead to imbalances in muscle control, diminishing lateral pinch strength and digital dexterity, potentially resulting in claw hand deformity. In adults, the consequences of proximal ulnar nerve damage are severe, often impeding functional recovery due to irreversible degeneration of motor endplates before reinnervation. This occurs particularly when a significant gap exists between the endplates and the site of nerve injury, hindering complete functional restoration.(1)

Nerve transfers to the distal portion of the ulnar nerve have become increasingly popular as an adjunct procedure in severe cubital tunnel syndrome.(2) Anterior interosseus nerve (AIN) to ulnar nerve transfer was first described in the 1990s. However, at this time, nerve transfers were exclusively done as end-to-end (ETE) coaptations.[3] Subsequent research in nerve transfers looked at reverse end-to-side, later more commonly known as supercharged end-to-side (SETS), neurorrhaphy to examine the impact of the axonal supercharging approach on peripheral nerve repair in a rat model.[4] The findings indicated that functional recovery of denervated targets is promoted by axonal augmentation by reverse end-to-side neurorrhaphy.

Susan E. Mackinnon and colleagues then combined the knowledge of nerve transfers for ulnar reinnervation with the novel end-to-side techniques to describe the first series of AIN to ulnar motor fascicle SETS transfers in 2012.[5] It is a noteworthy method for protecting and maintaining distal motor end plates in patients undergoing regeneration from proximal ulnar nerve injury. According to their study's findings, SETS can both preserve the injured nerve and, in circumstances of incomplete regeneration, potentially speed up reinnervation by adding more axons to the regenerated neuron. In particular, SETS is used to transmit, as described in the original study[5], the terminal AIN to the pronator quadratus muscle (PQ) end-to-side to the motor fascicle of the ulnar nerve in the distal forearm. This technique has the potential for many clinical uses, especially in cases of second and third-degree axonotmetic nerve damage. SETS may be essential in encouraging the best possible results until native parent axons successfully regenerate and reach their target muscles by improving partial recovery and protecting motor end plates.[5-7]

Recent advancements in the surgical treatment of severe ulnar neuropathy, including SETS AIN to ulnar nerve transfers, underscore the urgent need for robust and standardized outcome measures. The recent publication[8] introducing the abduction hand diagram as a novel outcome measure reflects ongoing innovation and underscores the variability and lack of standardization across current methodologies. This variability not only complicates the comparison of surgical outcomes but also hampers the generalization of successful techniques, making the need for standardized measures more pressing than ever.

While the abduction hand diagram offers a new and straightforward method for assessing recovery, the diversity of outcome measures reported—over 24 in recent studies—demonstrates a fragmented approach to evaluating surgical efficacy. These measures range from subjective assessments like the Medical Research Council (MRC) muscle testing to more objective yet technically demanding methods such as nerve conduction studies (NCS) and electromyography (EMG).

This scoping review is essential to comprehensively map the existing evidence, critically evaluating both the traditional and innovative outcome measures used to treat ulnar nerve entrapment post-SETS. By synthesizing the available literature and incorporating expert views and potentially unpublished data, the review will assess the efficacy of these measures in capturing actual clinical improvements both in the short term and long term.

The primary aim of this scoping review is to systematically map the existing evidence regarding the variety of outcome measures used following SETS AIN to ulnar nerve transfers to treat ulnar nerve entrapment. This encompasses clinical, patient-reported, and electrodiagnostic measures in short-term and long-term follow-ups. Additionally, this review will strengthen the body of evidence by integrating expert opinions and potentially unpublished data, assessing the consistency and relevance of these measures in capturing true clinical improvements.

The secondary aim is to explore the surgical rationale behind using SETS transfers, focusing on specific patient populations, diagnoses, and documented recovery trajectories to facilitate a deeper understanding of why these surgical interventions are chosen and their broader implications, providing insights that could guide future clinical practice and research.

Together, these aims will provide a comprehensive overview of the outcome measures utilized in SETS transfers, identify gaps and inconsistencies in the literature, and pave the way for the standardization of methodologies to enhance the quality and consistency of patient care in nerve transfer surgeries.

## Methods

We followed the framework proposed by Arksey and O'Malley[9] with additional suggestions by Levac et al.[10] to conduct a scoping review to unravel the nuanced dynamics of SETS AIN to Ulnar Nerve Transfer. The review was conducted in five stages: identifying the research question, identifying relevant studies, selecting studies for more detailed analysis, charting the data, and collating, summarizing, and reporting the results. In addition to the thematic analysis, we incorporated an expert panel as part of our scoping review methodology. Recognizing the value of expert input and their specialized knowledge in deepening our understanding of SETS nerve transfer beyond the confines of published literature, ensuring a rich, multi-dimensional exploration of this complex subject. We sought to gather insights beyond what could be solely derived from the literature.[11]

## Data Sources and Searches

To identify relevant peer-reviewed articles, we searched several online databases, including MEDLINE, Embase, PubMed, and Google Scholar, with the last search completed in December 2023. We developed a broad search strategy and used terms such as (i) ulnar nerve, (ii) anterior interosseous nerve, (iii) nerve transfer, (iv) cubital tunnel syndrome, and (v) ulnar neuropathy at the elbow.

## Study Selection

We included full-text, peer-reviewed English language studies that discussed outcomes and influential factors following SETS AIN to Ulnar Nerve Transfer in adults. Our inclusion criteria spanned various study designs, including qualitative, quantitative, mixed methods, and knowledge syntheses such as narrative, systematic, and scoping reviews, as well as case reports and case studies. Exclusions were made for conference abstracts, research letters, editorials, opinion pieces, letters to editors, annotations, and project evaluation reports without imposing any time restrictions on our search criteria. Exclusions applied to studies not directly related to SETS nerve transfers, lacking focus on patient outcomes or procedural efficacy, or those not subjected to peer review. We prioritized peer-reviewed articles available in English or translatable via Google Translate for analysis. The article selection process is depicted in Figure 1, adhering to the PRISMA-ScR checklist for reporting and guided by the PRISMA-ScR Protocols for protocol registration on the Open Science Framework.(12) Two independent reviewers meticulously carried out the literature search and screening, with discrepancies resolved through discussion with a senior author. A comprehensive search strategy, developed in collaboration with a librarian, targeted databases such as PubMed, Embase, and MEDLINE, employing Google Scholar and specific keywords "(ulnar OR anterior interosseous) AND nerve AND transfer AND (cubital tunnel OR (ulnar neuropathy AND elbow))" to filter relevant studies on SETS nerve transfer impacts.

**Extraction and Charting the Data**

A data extraction form was developed to collect information on the authors, year of publication, country of origin, type of surgery, patient demographics, study design, significant factors impacting patient recovery, and any elements influencing these outcomes. Two reviewers (TJ and MF) extracted publication year, surgery type, article source, and methodological details to describe the population and surgical approach alongside factors affecting patient satisfaction and recovery to synthesize the data. An in-depth analysis of selected articles allowed for the extracting critical recovery-related factors, which were organized through regular discussions, ensuring a unified understanding of factors affecting surgical recovery. The team reviewed the extracted data, resolving disagreements with the senior author's (JM) input. The analysis adopted a systematic approach for identifying and categorizing information, directly employing and synthesizing extracted data.

**Experts' Consultation**

To ensure a comprehensive understanding of non-published data related to SETS AIN to ulnar nerve transfer outcomes, we presented our findings to leading experts in the field, which included hand and orthopedic surgeons specializing in nerve transfer techniques with an average of over 30 years of experience in hand surgery, identified from prominent institutions. Their insights on additional recovery factors and patient outcomes were meticulously gathered, enriching our review with expert knowledge beyond the published literature; see Appendix for the detailed expert panel.

**Results**

Our comprehensive search identified 296 articles, supplemented by four records from additional searches, totalling 300. After removing 106 duplicates, 194 records were screened for title and abstract, excluding 152. Subsequently, 38 full texts were screened, of which 13 articles met the eligibility criteria.

In addition, four more articles were identified from reference checking and included in this review. The PRISMA flowchart provides a detailed overview of the literature review process, including the reasons for exclusion at each step. The included studies ranged from cohorts (1 prospective and 8 retrospective) (9, 53%)[(13-21)] to case reports (5, 29%)[(22-26)], one case series[(8)], one RCT[(27)], and one systematic review[(28)]. Table 1 provides the general characteristics.

The studies provided several insights into the efficacy and application of supercharge nerve transfer. The reverse end-to-side transfer technique is promising for augmenting ulnar nerve axon regeneration, potentially boosting local nerve factors in the ulnar nerve's distal stump. It could also babysit motor endplates until native axons regenerate to the targeted muscle.[(19,22-24,29)] Later, SETS was increasingly recognized as a valuable adjuvant technique, especially in revision surgeries for cubital tunnel syndrome, which showed improved recovery in intrinsic muscles.[(14,16,20,27,28,30-33)] Additionally, many surgeons surveyed would opt for an AIN-SETS transfer in treating high ulnar nerve injuries and severe cubital tunnel syndrome, indicating a growing acceptance of this technique within the clinical community.[(34,35)]

Quantitative findings from the reviewed studies reveal significant outcomes in several areas. Postoperatively, there were notable improvements in first dorsal interosseous

(FDI) strength, with more than 75% of patients achieving the Medical Research Council (MRC) grade of ≥ 3.[16,18,19,21] Despite minor complications reported, such as manageable infection, allergic reactions, and postoperative fungal rashes, these did not significantly diminish the overall positive outcomes.[15,16,27] Long-term follow-up data indicate encouraging trends, with over three-quarters of patients experiencing partial or complete resolution of clawing and intrinsic muscle wasting. Moreover, 73% regained an MRC grade of ≥ 3, and 47% achieved an MRC grade of ≥ 4.[16]

**Patient characteristics**

A total of 300 patients with a mean age of 52 with SETS AIN to ulnar motor nerve transfers were included in this review, with males comprising 70% of the participants. (Table 1)

The timing from injury to treatment is critical in determining the treatment's success, with a notable cut-point of 8 weeks for isolated and high ulnar nerve injuries to decide between early or delayed intervention strategies.[14] For severe cases, such as those with intrinsic weakness or atrophy, immediate surgical intervention is implied to prevent permanent disability.

The results of our scoping review, which included 17 studies, displayed a broad range of focus areas and diagnostic criteria concerning the application of supercharged end-to-side (SETS) anterior interosseous nerve (AIN) to ulnar nerve transfers. Specifically, eight studies, comprising 47% of the review, focused on cubital tunnel syndrome.[15-17,21,23,25-27] The primary outcomes in these studies were typically assessed using the Medical Research Council (MRC) scale for muscle strength in the First Dorsal Interosseous (FDI) and Abductor Digiti Minimi (ADM), alongside the Disabilities of the Arm, Shoulder, and Hand (DASH) score [17,26]. Secondary outcomes included electrodiagnosis[16,21,25,26,27], recovery time[15], clawing deformity restoration[16], pinch and grip strength measures[17,23,26,27], pain[17], hand abduction[26], and therapy adherence[26]. In terms of results, the MRC FDI scores showed considerable improvement within the first three months following surgery.[15] Subsequent follow-ups indicated that 73% of patients achieved an MRC score greater than 3, 47% exceeded a score of 4, and 7% reached the maximum score of 5[16]. Moreover, DASH and Quick DASH scores improved by an average of 11 points. Long-term follow-ups revealed an average increase of 19 lbs in pinch strength and 42 lbs in grip strength.[17,23]

Experts unanimously recognize the significance of conducting recovery evaluations at various time points due to the dynamic nature of nerve regeneration and functional recovery, which unfolds over time. Although there was a consensus on the necessity of medium-term evaluations, experts differ in their opinions on the most appropriate timing within the 12-24-month range. This variability often reflects differences in clinical practices and the unique recovery trajectories influenced by individual patient characteristics. Some experts prioritized earlier assessments within this range to adjust rehabilitation strategies promptly, while others favoured later evaluations to observe substantial functional gains better.

Three other studies included mixed diagnoses involving proximal compression or traumatic injuries[19,20,28] The primary outcomes in these cases focused on the return of intrinsic muscle function and the MRC score of the FDI muscle. Secondary outcomes included measures of pinch and grip strength and restoration of claw deformity. These studies noted that 69% of patients regained function between three and 12 months post-operation, with 23% experiencing rapid recovery within the first three months. The proportion of patients with an MRC score of FDI strength at grades 0 and 1 decreased over time, while those with a grade equal to or greater than 3 increased. A comparative analysis showed that 84% of SETS patients achieved the return of intrinsic function, significantly outperforming the 38% in the non-SETS group.

Additionally, a case report involving a traumatic nerve injury at the elbow documented the successful use of the SETS procedure and the consequent restoration of ulnar intrinsic function.[24] Further studies on severe ulnar neuropathy assessed outcomes primarily through MRC and Quick DASH scores. Notable findings included a 22% improvement in MRC scores post-surgery, with early SETS procedures performed within

12 months of diagnosis yielding significantly higher MRC scores at the last follow-up than delayed procedures. Moreover, Quick DASH scores showed an improvement of approximately 13 points post-operatively.[8,18,22] Lastly, two studies addressed high ulnar nerve injuries proximal to the elbow, utilizing Rosen scores and pinch strength as primary outcomes and grip strength, MRC scores, EMG, and Quick DASH as secondary outcomes. These studies indicated that early SETS AIN transfers resulted in statistically significant improvements in pinch strength by six months, with both early and delayed transfers showing improvements by 12 months. However, the total Rosen score showed significant improvement only at the one-year mark, and the Quick DASH score significantly improved at long-term follow-ups between one and two years post-treatment. Nonetheless, only one of nine patients showed neurophysiological signs of improvement detectable by the SETS procedure, suggesting that the role of this technique in clinical practice might still be uncertain[13,14]; see Table 2 for the detailed outcomes in each study.

The outcomes from the scoping review of studies on SETS transfers for ulnar nerve entrapment can be categorized into primary and secondary measures, with certain variations observed across different diagnoses:

**Primary Outcome Measures:**

- *Medical Research Council (MRC) Scale for Muscle Strength*: This scale assesses the strength of the First Dorsal Interosseous (FDI) and Abductor Digiti Minimi (ADM) muscles.
- *Disabilities of the Arm, Shoulder, and Hand (DASH) and Quick DASH Score*
- *Rosen Score*: Applied mainly in studies dealing with high ulnar nerve injuries proximal to the elbow to assess overall nerve function and recovery.
- *Return of Intrinsic Muscle Function*: Assessed the restoration of intrinsic muscle functionality, particularly in studies involving mixed diagnoses of proximal compression or traumatic injuries.

The experts unanimously agreed with the primary outcomes identified in the abovementioned evidence. They suggested three more important issues that should be considered as the primary outcomes in the evaluation of recovery after the SETS procedure, including:

- *Consideration of Forearm Posture in Assessing Intrinsic Muscle Function*: The experts highlighted the importance of assessing intrinsic muscle strength in different postures. They noted that demonstrating strength during pronation could indicate that the recovery can be attributed to the AIN nerve, specifically, an aspect not fully covered in the existing literature.
- *Evaluation of Dorsal Web Space Intrinsic Muscle Atrophy (FDI muscle)*
- *The Use of Tinel's Sign for Short-term Assessment*: Unlike traditional use solely for sensory nerves, the experts utilize Tinel's sign for motor nerves, tracking recovery from the anastomosis site to the wrist. This method provides a valuable, early indicator of nerve regeneration and recovery progression.

**Secondary Outcome Measures:**

- *Electrodiagnosis*: NCS and EMG were included to assess nerve and muscle response.
- *Recovery Time*: The duration required for observable clinical improvement or recovery post-surgery, noted in studies of cubital tunnel syndrome.
- *Restoration of Clawing Deformity*: Focused on the effectiveness of the surgery in correcting specific deformities associated with ulnar nerve damage, especially in studies with mixed diagnoses.
- *Pinch and Grip Strength Measures* to evaluate the functional recovery of hand strength, which is standard across all types of ulnar nerve injuries.
- *Pain Assessment* to evaluate changes in pain levels post-surgery, especially in studies of cubital tunnel syndrome and severe ulnar neuropathy.
- *Hand Abduction and Therapy Adherence* to evaluate patient compliance with therapeutic protocols, mostly noted in cubital tunnel syndrome studies.

- *Sensation and Physical Examination*: Egawa's and Froment's signs detect specific neurological impairments or improvements, particularly in studies of severe ulnar neuropathy.

The experts strongly agreed on the significance of integrating these outcomes into the post-operative assessment framework.

**Variation Across Different Diagnoses**

The selection and focus of primary and secondary outcomes varied depending on the specific type of ulnar nerve injury being studied. For instance: Studies on **cubital tunnel syndrome** often emphasized functional recovery metrics like the DASH score and MRC scale alongside measures of physical rehabilitation and pain. Research on **severe ulnar neuropathy** focused more on quality of life and detailed functional assessments, such as Quick DASH scores and sensation testing. In cases of **high ulnar nerve injuries proximal to the elbow**, the Rosen score was uniquely utilized to provide a comprehensive assessment of nerve recovery over an extended period.

This differentiation in outcome measures reflects the tailored approaches needed to address ulnar nerve entrapment's varying complexities and presentations, which suggests that outcome measures may need to be specific and sensitive to the type of ulnar nerve pathology being treated. Such insights emphasize the importance of selecting appropriate and targeted outcome measures to evaluate and compare the efficacy of SETS transfers in clinical practice effectively.

**Donor Site Morbidity and Complications**

Two studies(15,19) reported no deficits in pronation ROM (range of motion) or strength, while several other studies(14,16,18,26,27) also specifically mentioned no donor site morbidity.

Three studies reported no complications after surgery[14,26,28]; however, two studies[16,27] reported minor complications, such as infection managed with antibiotics, seroma, hematoma, wound breakdown, keloid, hypersensitive scar, and allergic reactions. These complications were generally manageable and did not significantly impact the overall success of the procedure. Specific complications were noted in some cases, including persistent elbow pain, fungal rash, and postoperative hematoma requiring evacuation. However, these were isolated incidents and not indicative of widespread issues with the surgical approach.[15] Significant complications were notably absent in the cohort studies reviewed, with no patients suffering from complications that significantly altered the outcome or necessitated further surgical intervention.

Experts unanimously affirm that donor site morbidity following nerve transfer surgeries generally poses a minimal concern, with pronation force and range of motion typically remaining optimal, leading to high patient satisfaction. Minor complications are comparable to those seen in other surgical contexts and are typically manageable with standard care, thus not significantly impacting overall patient outcomes. However, the expert discussions contributed additional insights to the existing body of knowledge, particularly regarding the potential risks associated with surgical precision. A specific concern raised was the risk of incorrect recipient nerve fascicle identification, where the ulnar sensory fascicle could accidentally get selected to receive the AIN end-to-side coaptation if intraoperative stimulation is not feasible or if known nerve topography is not carefully followed.

**Factors Associated with Recovery**

Our scoping review showed that various factors affected the recovery outcomes following supercharged nerve transfer. Notably, the duration of preoperative dysfunction was mentioned in six studies (35%), indicating that longer periods before intervention correlate with diminished recovery prospects.[15,16,18,26,34,35] Similarly, patient-specific variables play a critical role in recovery, with factors such as age, anatomical differences, medical comorbidities, posture, and occupation being highlighted across several papers.

Particularly, older age and extended muscle atrophy before treatment, mentioned in six studies (35%), emerged as adverse predictors of outcomes.[14,15,24,26,28,29]

The severity and anatomical level of the nerve lesion were also noted to affect recovery significantly. Findings suggest that the greater the severity or, the more extensive the gap in the lesion, the more challenging the recovery. Additionally, lesions located closer to their target destination generally demonstrated better regeneration capabilities and functional outcomes, a detail cited in six (35%) reviewed studies.[14,16,19,20,23,31]

Four (24%) of the studies emphasized surgical technique as another crucial determinant of success. The precise placement of the nerve transfer and the incorporation of supplementary procedures, such as Guyon's canal release, were pivotal for enhancing nerve recovery.[25,32,34,36]

Lastly, adherence to rehabilitation significantly influences recovery, as detailed in three (18%) studies. When paired with thorough patient education and sustained motivation, a robust rehabilitation regimen was essential for maximizing surgical benefits and fostering functional recovery. This comprehensive approach addresses the physical aspects of recovery and the psychological components, ensuring a holistic treatment protocol.[19,25,26]

Despite the broad consensus on extracted factors from evidence, experts provided additional insights that enhance the existing understanding of factors associated with recovery:

- *Location of the Nerve Transfer*: It is recommended that the nerve transfer be located 9 centimetres proximal to the wrist crease to avoid tension during the repair. They noted that positioning the transfer distally could increase tension, hindering nerve regeneration and adversely affecting functional outcomes.
- *Decompression at Ulnar Guyon's Canal*: Failure to alleviate compression at this site could impede functional recovery. This step is crucial as it addresses a common

compression point that, if unmanaged, could negate the benefits of nerve transfer procedures like SETS.

- *The Use of Microscopic Surgery and Delicate Suture*: The utilization of microscopic techniques during surgery was advocated for enhancing visualization, which is essential for precise dissection and accurate identification of nerve structures. This approach minimizes damage to surrounding tissues and ensures optimal nerve coaptation. Additionally, delicate sutures were recommended to facilitate finer, more precise suturing of nerves, reducing trauma to nerve fibres and enhancing the prospects for successful nerve regeneration.
- *End-to-end nerve Transfer For the Most Severe Cases*: It is particularly endorsed for the most severe cases of nerve injury, where there is an absence of ulnar motor nerve electrodiagnostic response and a significant demand for functional recovery. This method is preferred for its direct reinnervation capabilities, essential in severe scenarios to achieve optimal functional recovery.

**Indication for Surgery**

This scoping review identified several key clinical conditions that frequently prompt using this surgical technique. High ulnar nerve injuries, particularly when the lesion is located proximal to the motor branch of the flexor carpi ulnaris (FCU) muscle, emerged as a standard indication cited in three (18%) studies.[13,14,24] This specific injury often necessitates targeted nerve transfers to restore essential motor functions.

Severe Cubital Tunnel Syndrome is characterized by significant intrinsic atrophy and functional impairment, including weakness, reduced CMAP amplitude, and slowed conduction velocity across the elbow. The presence of spontaneous activities (fibrillations or positive sharp waves) in ulnar muscle EMG was another major indication. This condition, often a result of failed previous interventions, was highlighted across eight (47%) studies, underscoring its prevalence and the complexity of its management through nerve transfer.[15-17,21,23,25-27]

Additionally, the presence of a normal PQ muscle, evaluated either by palpation of muscle contraction or by EMG to confirm insertional activities, was frequently noted as a critical indicator for proceeding with nerve transfers. Two (12%) studies specifically mentioned this, pointing to its importance in assessing the viability of nerve transfer and the potential for successful functional recovery.[15,19]

While there is substantial agreement on the primary indicators, experts provided further insights that enhance the understanding of surgical planning:

- *Assessing Pronator Quadratus Muscle Function*: Although clinically challenging, assessing the PQ muscle's functionality is crucial and best achieved through EMG. Experts emphasize the importance of evaluating PQ muscle function preoperatively, using EMG to confirm its normal activity before proceeding with nerve transfers. This practice is vital for ensuring the muscle's viability as a donor in nerve transfer procedures, significantly impacting the surgical outcome.
- *Electrodiagnostic Protocol*: Experts emphasize the importance of an electrodiagnostic protocol to identify suitable candidates for ulnar nerve surgery techniques.

**Discussion**

Our comprehensive scoping review analyzed 17 studies, contributing to a robust understanding of the demographic characteristics and primary diagnoses within the targeted 300-patient population. The participants across these studies boasted a mean age of approximately 52 years, showcasing a research focus that spans the middle to older adult populations. Notably, the male demographic was prominently represented, constituting 70% of the participants. This gender distribution underscores a significant inclination towards male subjects in the existing literature, possibly reflecting this demographic's prevalence or interest in the condition. Overall, the scoping review highlights the diversity in outcome measures and the surgical rationale of SETS transfers in treating various forms of ulnar nerve pathology. The variations in outcome measures and the timing of intervention significantly influence the recovery trajectories and functional outcomes. The findings emphasize the need for standardized outcome measures to facilitate robust comparisons and enhance the generalizability of results across different studies. Establishing such standards could significantly improve clinical outcomes and guide future research in this evolving field.

The primary diagnoses reported in these studies were diverse, yet several conditions emerged more frequently than others, indicating focal points of interest within the research community. While the investigations predominantly focused on cubital tunnel syndrome, they also delved into traumatic and other causes of ulnar neuropathies. Such findings point to a concerted effort within the scientific community to address and understand prevalent conditions and their impact on quality of life.

Based on the results, our scoping review's primary outcomes of interest predominantly centred around functional and neurological recovery following surgery. The top focus of primary outcomes of MRC and DASH score underscores the importance of quantifiable metrics in evaluating the success of nerve transfer surgeries.(13,14) Assessing the return to intrinsic muscle function also offers valuable insight into both functional improvement and the extent of muscle strength recovery.(19,20) These metrics offer valuable information for clinicians and patients regarding the expected recovery trajectory.

Experts suggest that forearm posture, particularly in pronation, may influence the accurate assessment of intrinsic hand muscles due to “Donor dominance”.(15) This phenomenon implies that when the forearm is pronated or resisted in pronation with reinnervation from the AIN, stronger intrinsic motor function is expected compared to supination. The alignment of muscle fibers varies with forearm position, with pronation facilitating more efficient alignment of intrinsic hand muscles, thus enhancing force generation. This optimized alignment may improve neural signal transmission and muscle contraction strength along the AIN pathway. Over time, the nervous system adapts to pronation, leading to enhanced coordination and motor control.(37) Experts now utilize Tinel's sign not only for sensory nerves but also for assessing motor nerve recovery, monitoring progress from the anastomosis site to the wrist. This expanded use reflects the need to monitor motor function recovery after nerve repair, enabling early detection of nerve regeneration and assessment of functional restoration progress. Additionally, experts recommend observing FDI atrophy as a visual indicator of post-procedural progress.

Secondary outcomes offered a comprehensive view of nerve transfer surgery efficacy, with electrodiagnosis providing insights into neurological improvements post-surgery.[15] Recovery time sheds light on the timeline for functional improvement and muscle strength recovery.[20] Besides monitoring rehabilitation protocol adherence, routine physical examinations, including range of motion assessment for claw recovery, pinch and grip strength measurement, ulnar nerve special tests, and pain and sensation assessment, are crucial for evaluating recovery effectively. Recently, assessing total hand abduction distance[26] and finger tracing has emerged as an accurate and flexible method for evaluating hand functionality, aiding in understanding how different conditions or therapies impact hand and finger coordination. This review emphasizes the significance of both objective and subjective measures in assessing surgical interventions' full scope for ulnar neuropathy.

Assessment timing post SETS AIN to ulnar motor nerve transfer shows initial improvement within 2-3 months due to remyelination. Axonal regeneration begins at 4-5 months, with supercharge nerve transfer yielding results at 6-7 months.[25] Nascent units appear around 8.5 months[16], and recovery continues at 12 and 24 months due to reinnervation, neuroplasticity, and endplate changes.[32,38] Early assessments focus on immediate recovery and reinnervation onset, while medium-term follow-up observes ongoing axonal regeneration and neuroplasticity benefits. Longer-term assessments gauge intervention durability and nerve function recovery. Timing varies across studies based on patient characteristics, emphasizing surgical interventions' efficacy in enhancing short and long-term outcomes post SETS procedure.

The AIN PQ branch serves as an excellent donor for the ulnar nerve due to several anatomical advantages: both nerves are similar in size, situated closely to each other, eliminating the need for grafts, and work together for motor retraining. Additionally, the expendability of the PQ branch, supported by the stronger forearm pronation function of the pronator teres, enhances its suitability for donation.[29,39] Concerns regarding donor site morbidity were addressed in reviewed studies, with minimal to no reported adverse effects, indicating negligible impact and refined surgical techniques.

Most studies report low rates of serious complications associated with supercharge nerve transfer, indicating its overall safety.[16,27] The scoping review and expert opinions align, highlighting favorable outcomes, minimal donor site morbidity, and low complication rates for ulnar neuropathy treatment. The only concern raised by experts involves the risk of misidentifying nerves during sensory branch side-to-side anastomosis of the AIN, potentially transferring the sensory branch of the ulnar nerve instead of the motor branch.

Several factors significantly influence recovery outcomes. Longer preoperative dysfunction durations consistently correlate with poorer outcomes.[34] Patient-specific factors such as age, anatomical considerations, medical comorbidities, and duration of muscle denervation impact recovery, with older age and prolonged atrophy serving as adverse predictors. The level and severity of the nerve lesion also affect recovery, with greater severity posing greater challenges.[23] For severe cases, experts prefer the end-to-end method for optimal functional recovery. Surgical technique recommendations include performing the transfer approximately 9 cm above the wrist crease to prevent tension on the repair and avoiding distal placement, which may hinder nerve regeneration or compress the motor branch around the hamate.[25] Comprehensive rehabilitation, supported by patient education and motivation, is vital for maximizing surgical intervention benefits and promoting functional recovery.[26] These findings underscore the complex interplay of factors shaping the success of supercharge nerve transfer procedures for ulnar neuropathy.

Our scoping review highlights primary indications for supercharge nerve transfer, including high ulnar nerve injury, severe cubital tunnel syndrome resistant to previous interventions, and a normal pronator quadratus muscle.[14,15] Understanding these indications aids clinicians in selecting appropriate candidates and improving treatment outcomes for ulnar neuropathy. Experts recommend an electrodiagnostic protocol for cubital tunnel syndrome diagnosis, including NCV tests across the elbow, intrinsic muscle weakness assessments, and EMG to detect spontaneous activities in recipient muscles. Positive results, coupled with normal activity in the PQ muscle (donor), indicate readiness for a mixed surgical technique, combining ulnar nerve transposition, Guyon's canal release, and SETS AIN to ulnar motor nerve transfer for comprehensive nerve injury management.[25]

The study's limitations include the possibility of publication bias resulting from the dependence on published literature and the heterogeneity of the data brought about by the inclusion of various study designs. Other problems include insufficient outcome reporting, limited demographic data, and inconsistent study quality. Notwithstanding these drawbacks, the review's objective is to present a thorough analysis of the literature on SETS AIN to ulnar nerve transfer, emphasising outcomes and potential research directions.

In summary, our scoping review has unveiled a varied and deep research landscape, with a notable emphasis on certain conditions deemed critical within the community. We meticulously examined the literature to identify studies that evaluated the efficacy of SETS AIN to ulnar motor nerve transfer for addressing ulnar neuropathy. Our review yielded diverse studies that explored both primary and secondary outcomes associated with this surgical intervention; see Table 3 for the brief conclusion by interventional mapping table of SETS scoping review with expert insights.

## Conclusion

The synthesis of expert feedback with findings from the scoping review has led to developing a more robust set of primary and secondary outcomes for assessing functional and neurological recovery following SETS surgery. By incorporating expert opinions, the body of knowledge is enriched, highlighting the recovery aspects that are most tangible and impactful for patients. This updated framework is grounded in solid evidence and enhanced by real-world clinical insights, reflecting a balance between empirical data and practical application. Drawing from firsthand clinical experiences and patient interactions, experts tend to emphasize immediately observable outcomes that significantly affect patients' daily lives and overall satisfaction. This focus aligns with the growing emphasis on patient-centred care in healthcare, ensuring that treatment outcomes resonate with the needs and experiences of patients, thereby optimizing clinical practice and patient care.

Figure 1: Selection studies on outcomes and influential factors following Supercharged End-to-Side Anterior Interosseous Nerve (SETS) to Ulnar Nerve Transfer

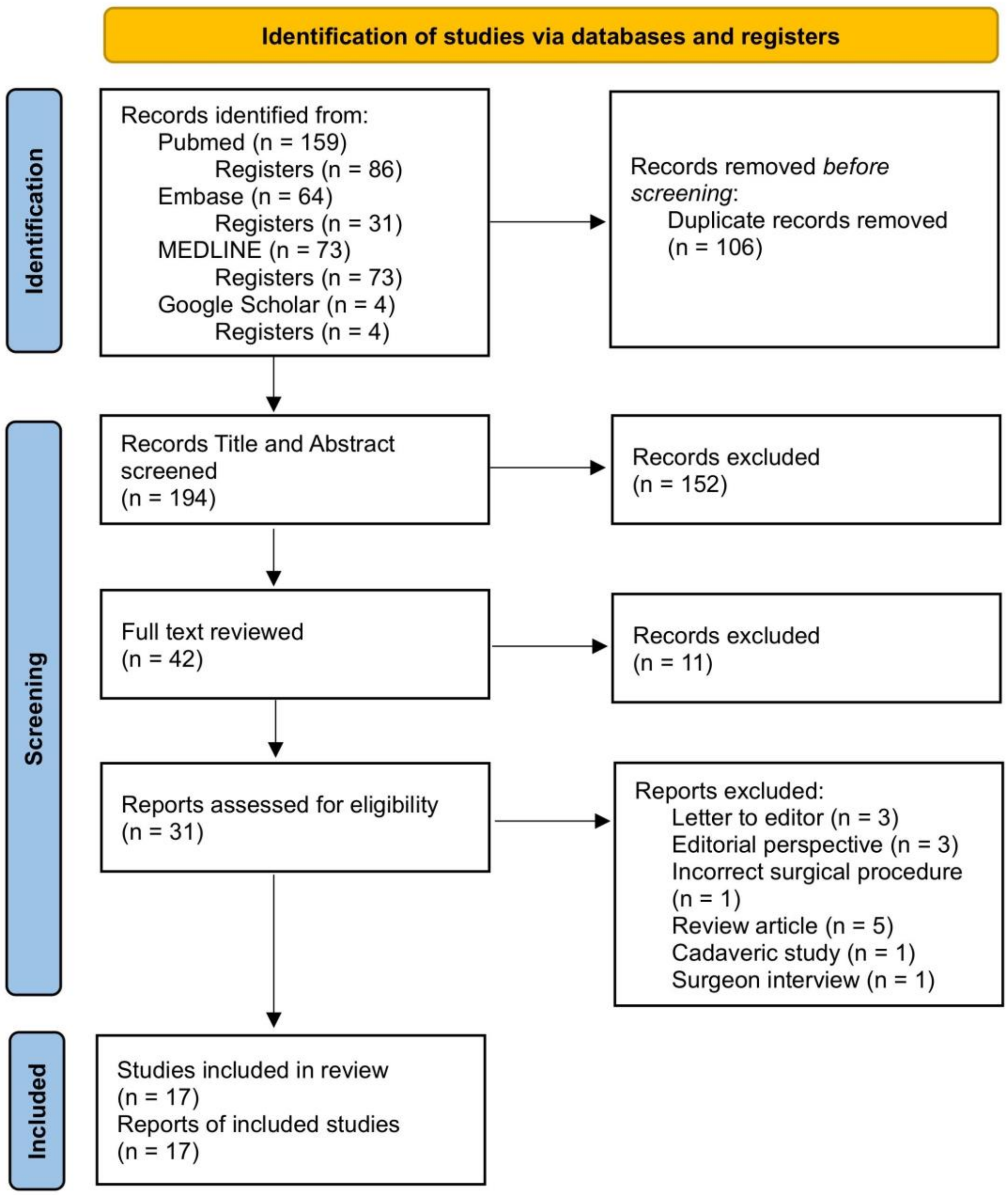

Table 1: Articles reporting outcomes from SETS procedure

| Authors | Years of publication | Study design/Level of evidence[40] | Sample size | Mean age | Male (%) |
|---|---|---|---|---|---|
| 1. Thorkildsen et al.[13] | 2024 | Prospective cohort study (level 2) | 9 | 40 | 6 (67) |
| 2. Chen et al.[14] | 2021 | Retrospective cohort study (level 3) | 13 | 38 | 9 (69) |
| 3. Dengler et al.[15] | 2020 | Retrospective cohort study (level 3) | 42 | 48 | 33 (79) |
| 4. Doherty et al.[16] | 2020 | Retrospective cohort study (level 3) | 30 | 53 | 21 (70) |
| 5. Dunn et al.[28] | 2019 | Systematic review (level 1) | 78* | 46 | 45 (58) |
| 6. Evans et al.[17] | 2021 | Retrospective cohorts study (level 3) | 30 | 57 | 22 (73) |
| 7. Jarvie et al.[22] | 2018 | Case report (level 5) | 2 | 57 | 1 (50) |

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|---|---|---|---|---|---|
| 8. Kale et al.[23] | 2011 | Case report (level 5) | 1 | 65 | 1 (100) |
| 9. Knight et al.[8] | 2023 | Case series (level 4) | 9 | 68 | 7 (78) |
| 10. McLeod et al.[18] | 2020 | Retrospective cohort study (level 3) | 17 | 48 | - |
| 11. Pathiyil et al.[24] | 2023 | Case report (level 5) | 1 | 36 | 0 (0) |
| 12. Power et al.[25] | 2020 | Case report (level5) | 3 | 50 | 3 (100) |
| 13. Tsang et al.[26] | 2021 | Case report (level 5) | 3 | 77 | 3 (100) |
| 14. Xie et al.[27] | 2022 | Randomized control trial (level 1) | 45 | 56 | 34 (75) |
| 15. Davidge et al.[19] | 2015 | Retrospective cohort study (level 3) | 55 | 50 | 38 (61) |
| 16. Baltzer et al.[20] | 2016 | Retrospective cohort study (level 3) | 13 | 35 | - |

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|---|---|---|---|---|---|
| 17. Head et al.[21] | 2020 | Retrospective cohort study (level 3) | 17 | 57 | 11 (65) |

* 68 duplications in Davidge[19] and Baltzer[20] studies

Table 2: Details of the selected articles

| Authors, year (type) | Diagnosis | Objective | Outcomes | Follow-up time (after surgery) | Result |
|---|---|---|---|---|---|
| Thorkildsen et al., 2024 (Prospective cohort)[13] | Complete ulnar nerve injuries at or proximal to the elbow | To use detailed clinical and neurophysiological examinations to strengthen outcome assessment after SETS for ulnar nerve injury | 1. Rosen score<br>2. Grip strength<br>3. Key pinch<br>4. Tripod pinch<br>5. Tip pinch<br>6. EMG<br>7. Quick DASH | - 9 months<br>- 1 year<br>- 2 years | - The total Rosen score was only significantly better than baseline at 1 year (p=0.04)<br>- The Quick DASH significantly improved from baseline at 1 and 2 years<br>- Neurophysiological signs (EMG) of function via the SETS were only seen for one out of nine patients |
| Chen et al., 2021 (Retrospective cohort)[14] | Isolated and high ulnar nerve injuries | To compare motor recovery after early or delayed ETS AIN transfer versus conventional procedures | 1. Pinch strength<br>2. Grip strength<br>3. MRC | - 6 months<br>- 12 months | - Early AIN transfer was found to have statistical significance at 6 months, but not for delayed transfer<br>- At 12 months, both early and delayed transfers were seen to show improvements in pinch strength |
| Dengler et al., 2020 (Retrospective cohort)[15] | Severe cubital tunnel syndrome | To provide an update on their clinical experience in the setting of | 1. MRC of FDI | - Less than 1 month<br>- 1-3 months | - 5% improved FDI in less than 1 month,<br>- 49% improved FDI between 1 and 3 months |

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| | | severe cubital tunnel syndrome | 2. Time to reinnervation | - 3-15 months | - 46% improved FDI between 3 and 15 months |
| Doherty et al., 2020 (Retrospective cohort)[16] | Severe cubital tunnel syndrome | To prove the hypothesis that the addition of SETS transfer to subcutaneous transposition will demonstrate early reinnervation of intrinsic musculature and improved functional recovery | 1. MRC of FDI&ADM<br><br>2. EMG<br><br>3. Resolution of clawing | - 6 months<br><br>- > 12 months<br><br>(Average follow-up was 18.6 months) | - 73% MRC grade ≥ 3<br>- 47% MRC grade ≥ 4<br>- 7% MRC grade 5 |
| Dunn et al., 2019 (Systematic review)[28] | All types (transection, compression, lesion-in-continuity, motor neuropathy, neuritis) | To review the demographics, outcomes, and complications following SETS for proximal ulnar nerve injuries | 1. Total number of patients who had a return of intrinsic muscle function<br><br>2. Time to intrinsic muscle function<br><br>3. grip and key pinch strengths | - 1-3 months<br><br>- 3-12 months | - 9 patients (23%) had rapid recovery between 1 and 3 months<br><br>- 27 of 39 patients (69%) regained function between 3 and 12 months |
| Evans et al., 2021 | Cubital tunnel syndrome | To evaluate the impact of adjunctive | 1. DASH | - 3 months<br><br>- 6 months | - Patients who received adjunctive procedures had an 11-point greater |

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| (Retrospective cohort)[17] | | procedures including SETS and electrical stimulation on patient outcomes | 2. Pinch strength<br>3. VAS | | improvement in DASH scores than their matched pairs |
| Jarvie et al., 2018 (Case report)[22] | Rapidly severe progressive ulnar neuropathy (no trauma) | To describe two cases with electromyographic findings where SETS was performed to successfully treat rapidly progressive ulnar neuropathy | 1. Quick DASH<br>2. SF-12<br>3. VAS | - 6 months<br>- 12 months | - 1st patient: Quick DASH 16 (6m) → 9 (12m)<br>- 2nd patient: Quick DASH 30 (6m) → 11 (12m) |
| Kale et al., 2011 (Case report)[23] | Cubital tunnel syndrome | To report successful recovered ulnar intrinsic function after SETS procedure | 1. Pinch strength<br>2. Grip strength | - 12 months | - Pre-op → Post-op pinch strength: 3 lbs → 22 lbs<br>- Pre-op → Post-op grip strength: 58 lbs → 100 lbs |
| Knight et al., 2023 (Case series)[8] | Severe compressive ulnar neuropathy | To extensively explore hand therapy and rehabilitation outcomes after SETS nerve transfers | 1. MRC of FDI&ADM<br>2. Pinch and grip strengths<br>3. 2 point discrimination<br>4. DASH<br>5. Egawa sign<br>6. Froment's sign | - 18 months after surgery | - FDI MRC strength from initial to 18 months after surgery: 22% → 44% |

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| | | | 7. Cross finger test | | |
| McLeod et al., 2020 (Retrospective cohort)[18] | Severe chronic ulnar neuropathy (McGowan grade III ulnar neuropathy) | To evaluate intrinsic muscle recovery in patients who have undergone both a proximal ulnar nerve decompression at the elbow and an AIN-to-UMN transfer (both ETE and ETS) | 1. MRC<br>2. EMG | - ≥ 6 months<br>- > 12 months | - Early SETS transfer demonstrated better MRC scores with statistically significant (<12m = 3.7, >12m = 2.2) |
| Pathiyil et al., 2023 (Case report)[24] | Severe traumatic ulnar neuropathy at elbow | To report the SETS procedural technique | NA | NA | NA |
| Power et al., 2020 (Case report)[25] | Cubital tunnel syndrome | To present guidelines for patient selection after diagnosis of cubital tunnel syndrome | EMG | NA | NA |
| Tsang et al., 2021 (Case report)[26] | Cubital tunnel syndrome | To evaluate the SETS AIN to ulnar nerve technique for cubital tunnel syndrome in comparison with a standard ulnar nerve transposition | 1. Quick DASH<br>2. EMG<br>3. Grip, key, and tripod pinch strength | - > 6 months<br>- > 12 months<br>- > 23 months | - Quick DASH (>23 months) was improved but depended on patient specific factors |

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| | | | 4. Hand abduction<br><br>5. Rehabilitation adherence | | |
| Xie et al., 2022 (RCT)[27] | Severe cubital tunnel syndrome based on the modified McGowan classification | To compare ulnar nerve decompression and anterior subfascial transposition with versus without SETS AIN to ulnar motor<br><br>nerve transfer for advanced cubital tunnel syndrome | 1. Key pinch strength<br><br>2. Grip strength<br><br>3. Tripod grip<br><br>4. EMG | - 3 months<br><br>- 6 months<br><br>- 12 months<br><br>- 18 months<br><br>- > 24 months | - The results of the study group were superior to those of the control group with regard to postoperative pinch strength at 24 months follow-up (significant superior at 6, 12, 18, and > 24 months follow-up) |
| Davidge et al., 2015 (Retrospective cohort)[19] | Both compression and high ulnar nerve injuries | To review clinical experience after SETS | 1. MRC FDI<br><br>2. Key pinch strength<br><br>3. Grip strength<br><br>4. DASH | - 1-3 months<br><br>- 3-6 months<br><br>- 6-12 months | - The proportion of patients with MRC 0,1 FDI strength declined over time, whereas the proportion with grade ≥ 3 strength increased |
| Baltzer et al., 2016 (Retrospective cohort)[20] | Proximal ulnar nerve injuries (either traumatic or compressive) | To prove that patients with a SETS AIN to ulnar motor nerve transfer would demonstrate superior return of | 1. Return of intrinsic function<br><br>2. Reduced claw | - At least 1 year follow-up or demonstrated return of ulnar intrinsic | - Follow-up was shorter in the SETS group compared with the standard treatment group<br><br>- Return of intrinsic function 84% SETS vs 38% non-SETS |

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| | | intrinsic function compared with conventional treatment only | 3. Grip and pinch strength | function within 1 year | |
| Head et al., 2020 (Retrospective cohort)[21] | Severe cubital tunnel syndrome | To evaluate the clinical and electrodiagnostic pattern of reinnervation of intrinsic hand musculature following SETS AIN to ulnar motor nerve transfer | 1. MRC of FDI<br>2. MRC of ADM<br><br>3. EMG | - > 6 months<br><br>(mean follow-up of 16.7 ± 8.5 months) | - The median MRC grade for the FDI increased from 1 to 4,<br><br>with 12 patients (71 %) achieving MRC ≥ 3 |

Table 3: Interventional mapping table of SETS scoping review with expert insights

| Category | Results | Expert insights |
|---|---|---|
| Primary outcomes | Subjectives:<br>- Patient-reported outcomes (DASH, quick DASH)<br>- Return of function (patient's perception)<br>Objectives:<br>- The MRC of FDI and ADM muscles<br>- Rosen score<br>- Return of intrinsic muscle function (clinician assessment) | - Assess intrinsic function in forearm pronation<br>- FDI evaluation<br>- Tinel's sign in short-term assessment |
| Secondary outcomes | Subjectives:<br>- Restoration of clawing deformity (patient's perception)<br>- Pain assessment<br>- Therapy adherence<br>Objectives:<br>- Electrodiagnosis<br>- Recovery time | |

| | | |
|---|---|---|
| | - Pinch and grip strength<br>- Hand abduction<br>- Neurological examination | |
| Timing of assessment | - Short-term<br>- Medium-term<br>- Long-term | - Dependent on individual patient characteristics |
| Donor site morbidity and complications | - No donor site morbidity and complications<br>- Minor complications<br>- Specific complications which are not indicative issue with the SETS | - The potential risks associated with surgical precision (incorrect nerve detection) |
| Factors associated with recovery | - The preoperative dysfunction duration<br>- Patient-specific variables<br>- The severity and anatomical level of the nerve lesion<br>- The surgical techniques<br>- Rehabilitation adherence | - Location of the nerve transfer (proximal to the wrist crease to avoid tension during the repair)<br>- Concurrent decompression at ulnar Guyon's canal<br>- Microscopic surgery and delicate suture preference<br>- End-to-end technique for the most severe cases |

| | | |
|---|---|---|
| Indication for surgery | - Severe cubital tunnel syndrome<br><br>- High ulnar nerve surgery<br><br>- Normal PQ presence by EMG | - Intraoperative PQ assessment<br><br>- Electrodiagnostic protocol consideration |

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- **Amir R. Farhoud, MD**, Assistant Professor, Department of Orthopedic Surgery, Tehran University of Medical Sciences
- **Reza S. Kamrani, MD**, Department of Orthopedic Surgery, Tehran University of Medical Sciences

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# Chapter 3

## Forging Consensus: Establishing a Core Set of Outcome Measures in the Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer – A Delphi Study

Tachit Jiravichitchai, MD[a,b,c], Maryam Farzad, PhD[a,b,d], Joy MacDermid, PhD[a,b], Pulak Parikh[a], PhD, Stahs Pripotnev, MD[b]

[a] *Department of Health and Rehabilitation Sciences, Faculty of Health Sciences, University of Western Ontario, London, ON, Canada*

[b] *Roth | McFarlane Hand and Upper Limb Center, St. Joseph's Health Care, London, ON, Canada*

[c] *Department of Rehabilitation Medicine, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand*

[d] *Department of Occupational Therapy, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran*

**Abstract**

This Delphi study aimed to establish a consensus among experts in the field of ulnar nerve surgeries, focusing specifically on the supercharged end-to-side anterior interosseous nerve (SETS AIN) to ulnar nerve transfer procedure. Through iterative rounds of expert consultation, a comprehensive framework of outcome measures crucial for evaluating surgical efficacy was delineated, spanning motor function, functional performance, health-related quality of life, pain and sensory assessment, dexterity evaluation, and patient perspective. The study's findings provide valuable guidance for both research and clinical practice, offering insights into optimal outcome assessment tools and constructs relevant to SETS surgery. By synthesizing expert opinions and integrating diverse perspectives, this study contributes to standardizing outcome assessment, optimizing patient care, and driving advancements in the field of ulnar nerve surgery.

**Keyword:** Cubital tunnel syndrome; Ulnar neuropathy; Nerve transfer; Anterior Interosseous Nerve; Supercharged end to side; Delphi study; Hand Surgery

**Background and Rationale**

The ulnar nerve plays a vital role in hand function as it controls the majority of hand motor function through the intrinsic muscles and provides sensation to the ulnar side of the hand. When the ulnar nerve is disrupted, it can cause an imbalance between flexor and extensor muscles, resulting in a loss of lateral pinch strength and digital dexterity.[(1)] This can lead to a deformity known as claw hand, especially in cases of low ulnar nerve injury, where there is no loss of FDP function compared to high ulnar nerve injury.[(1)] Damage to the ulnar nerve can have severe consequences, particularly for adults, and often leads to poor functional recovery.[(2)] The motor endplates of the intrinsic muscles of the hand can irreversibly degenerate before being reinnervated by regenerating axons of the ulnar nerve from the injured site. This can occur because of a significant distance between the endplates and the nerve injury site, resulting in incomplete functional recovery.[(3)] The second most frequent type of compressive neuropathy is ulnar neuropathy at the elbow or cubital tunnel syndrome.[(4)] The management of cubital tunnel syndrome can be conservative or surgical. Mild cases of cubital tunnel syndrome can be successfully treated conservatively, aiming to reduce traction and compression on the nerve. Surgical management of cubital tunnel syndrome is increasing in frequency, with multiple surgical options available.[5] Severe cubital tunnel syndrome does not respond to nonoperative management, and functional outcomes decline as the disease becomes more severe. Although there is no preferred surgical technique for cubital tunnel syndrome, nerve transfers are employed to aid in the recuperation of severe cases of ulnar neuropathy.[6] Nerve transfers to the distal portion of the ulnar nerve have become increasingly popular as an adjunct procedure in severe cubital tunnel syndrome.[7]

Primary repairs may result in good recovery of sensation but may be poor in motor function, especially in cases where the injury is proximal.[8,9] To address this issue, distal nerve transfers were selected from the anterior interosseous nerve (AIN) to the motor branch of the ulnar nerve to bridge the significant gap that needs to be regenerated. In end-to-end fashion, the end targets were only innervated by the donor nerve (AIN) and not by the regenerating ulnar nerve.[10] The supercharged end-to-side (SETS) transfer procedure is done by connecting the donor nerve (AIN) to the motor branch of the ulnar nerve through a perineural window, allowing for quicker reinnervation of the distal endplate while the more proximal repair regenerates. This results in "double innervation". Barbour et al. were the first to describe this clinically.[11]

Due to the possibility of reinnervation from the proximal ulnar nerve, the supercharged end-to-side transfer (SETS) is believed to be a more favourable surgical technique than the traditional end-to-end transfer. However, the variability of outcome measures across different studies poses a challenge for standardization.[12] Therefore, this project aims to determine, by expert consensus, the items that make up the clinical history, clinical examination, prognosis of recovery, and the processes in developing outcome measures needed to establish a clinical reasoning process and pathway of care for patients after this procedure, with the objective of developing a standardized core set of outcome measures that can inform evaluations in both research and clinical settings.

## Methods

The Delphi process leverages expert opinion to achieve consensus, a methodology first introduced by the RAND Corporation in the early sixties. Since its inception, the Delphi method has been widely adopted across various fields to facilitate controlled interaction among respondents, fostering independent thought and expert judgment.(13) Through a series of iterative rounds of anonymous surveys and feedback; two to three rounds is typical, the Delphi process allows experts to share their insights, opinions, and expertise on complex and uncertain topics, ultimately leading to the convergence of viewpoints and the identification of areas of agreement. After subjectively analyzing the consensus measurement, it was concluded that proceeding with a third round of the study would not offer additional insights beyond those provided by the initial two rounds. Therefore, the study was concluded.(14,15) The Delphi process allows for a large group of respondents and the process is not restricted to a specific geographical region. Rather, it can expand over several areas; thus, access to a wide variety of experts is possible.(16) This structured approach to consensus-building empowers experts to contribute meaningfully to the collective knowledge and decision-making process, driving innovation, problem-solving, and evidence-based practice in diverse domains.(17)

## Survey Development

The initial round survey items were meticulously developed following a comprehensive review, which involved an exhaustive examination of existing literature on upper extremity musculoskeletal disorders and relevant surgical procedures. This review drew upon investigators' clinical expertise in upper extremity musculoskeletal disorders, ensuring that the survey items were grounded in both empirical evidence and practical clinical insights. Demographic information for each expert, including age, profession, years of experience, biological sex, race, country of practice, and research interests, was double-checked by the senior author (JM) to ensure accuracy and completeness. The constructs of outcomes related to general ulnar nerve surgery, including SETS AIN to ulnar nerve transfer, were identified through a synthesis of findings from peer-reviewed articles, clinical guidelines, and consensus statements. These constructs encompassed various domains, such as pain[18], sensation[19], function[6,20], strength[21,22], range of motion[23], patient satisfaction[24], change over time[25], and quality of life[18,26]. They were further categorized into two groups: those relevant to the clinical setting and those pertinent to research studies. Additionally, preferred outcome measures identified from the comprehensive review were listed to provide expert participants with a selection, ensuring that the survey captured the breadth of relevant outcomes and measures identified in the literature.

**Eligibility Criteria and Expert Participation**

The inclusion criteria for expert participants were carefully delineated by the investigators. Eligible individuals included registered healthcare professionals, such as physicians, surgeons, or therapists, recognized by their peers, professional associations, and/or research interests in the field of upper extremity nerve repair, with a specific focus on SETS AIN to ulnar nerve transfer. Each expert was required to have a minimum of 5 years of experience in hand surgery and therapy, as well as experience in managing SETS AIN to ulnar nerve transfer procedures. A letter of information was distributed to all identified upper extremity experts by the principal and co-investigators. Upon expressing agreement to participate, each expert received an individualized email containing a survey link to access the first-round Delphi survey. Specialists who did not specialize in nerve transfer procedures or did not perform the SETS AIN transfer to ulnar nerve in clinical practice were excluded from participation. Additionally, all participating experts were required to sign an electronic consent form and return it to the investigators. The electronic informed consent had been approved by the local ethics committee (WREM HSREB 123698).

**First Round Ranking**

In the first round of the Delphi study, participants were provided with a list of outcome measures and asked to rank them according to their perceived importance in evaluating surgical outcomes related to various ulnar nerve procedures, including transposition for decompression, nerve repair, and nerve transfer. They were instructed to classify the outcome measures separately based on their relevance in clinical settings and research studies.

**Consensus of the First Round**

After the completion of the first round, a predetermined threshold was set to establish consensus for each outcome measure. Consensus was deemed to be achieved if a certain percentage of participants ranked an outcome measure within a specified range. This report presents a hierarchy of outcomes meticulously ranked by the level of agreement, exclusively listing those that surpassed the 75% agreement threshold.[27] This process involved evaluating the rankings provided by experts to determine which outcome measures were considered most important across the board.

**Revise Survey for Second Round**

After analyzing the consensus from the first round, the survey was revised for the second round, incorporating the most highly ranked outcomes from the initial round. These revisions aimed to address any ambiguities or gaps identified in the first round and to refine the survey to focus specifically on outcome measures relevant to the SETS procedure.

**Second Round Ranking**

In the second round of the Delphi study, participants were presented with the revised survey and asked to rank the outcome measures related to the SETS procedure. Similar to the first round, they ranked the outcome measures based on their perceived importance in both clinical settings and research studies.

**Consensus of the Second Round**

After the completion of the second round, consensus among participants was analyzed once again to identify the outcome measures that met the predetermined threshold of agreement. This process ensured that the outcome measures deemed most important for evaluating the success of the SETS procedure were identified based on the collective input of experts.

**Determination of Study Conclusion and Report**

Following the completion of both rounds and the analysis of consensus, it was determined whether further rounds of the study were necessary to achieve additional insights. Given that the objectives of the Delphi study were achieved by the conclusion of the second round, the study was concluded at that stage. A comprehensive report summarizing the findings, including the hierarchy of outcome measures based on consensus, was then prepared for dissemination.

**Results**

*First Round*

The initial round of the Delphi study served as a comprehensive platform to query experts on pivotal outcomes, aiming to achieve consensus for ulnar nerve surgeries, including the specific subset of the SETS procedure. Our goal was to consolidate expert opinions on a core set of outcome measures for these surgeries. The unanimous agreement to participate among the 15 experts consulted indicated a strong commitment to the study's objective and a collective effort to advance the field.

The expert panel (15) was predominantly male (11, 73%), with a mean age ± standard deviation (SD) of 44.5 ± 10.31 years, and the mean years of practice stood at 8.66 ± 5.79 years. Specialties were diverse, encompassing hand therapists (2, 13%), occupational therapists (2, 13%), physiotherapists (2, 13%), hand and microsurgery surgeons (8, 53%), among whom 1 was a plastic surgeon and 7 were orthopedic surgeons, and a physiatrist (1, 7%). The racial composition of the panel was predominantly Asian (7, 46%) and White (6, 40%), with Middle Eastern and Latino representation as well (1, 7% each), reflecting a broad range of cultural and regional insights. The countries of practice were similarly varied, with the majority from Thailand (6, 40%) and Canada (7, 46%), followed by contributors from the USA and Iran (1, 7% each); see Table 1 for a brief summary of participant demographics.

The research interests of the panel members spanned a wide array of specializations within the domain of nerve surgery and rehabilitation, including but not limited to elbow surgery, nerve surgery, brachial plexus injury (BPI), hand surgery, tendon and nerve surgery, spasticity, nerve reconstruction, hand and wrist trauma, peripheral nerve conditions, neuropathic pain, neuroscience, rehabilitation, clinical research, upper limb outcomes, hand therapy, biologics, hand and upper extremity rehabilitation, and mesenchymal stem cell research about nerve conditions.

In the first round results, participants were presented with potential goals for the AIN transfer to the ulnar nerve. **Restoration of motor function** emerged as a top priority, indicating strong agreement among experts on its importance. Following closely as the next top priority was **improving functional performance**, reinforcing its significance in the context of ulnar nerve surgeries. In addition to ranking predefined outcomes, experts were also invited to suggest any additional outcomes they deemed crucial. Among the outcomes proposed by the experts were postoperative claw correction to address hand deformities and restoration of sensory function, including pain reduction. Other suggested strategies included measures to mitigate muscle atrophy and preserve motor units, assessments of muscle strength using the Medical Research Council (MRC) scale, patient-reported outcome measures such as the Patient-Rated Ulnar Nerve Evaluation (PRUNE) and Quick Disabilities of the Arm, Shoulder and Hand (DASH), as well as assessments of pinch strength and quantitative electromyography.

In our initial focus on defining optimal construct outcomes for **research study** following general ulnar nerve surgery, experts unanimously endorsed key outcome measures such as **health-related quality of life**, **self-reported functional ability**, **work limitations**, **grip strength**, and **patient satisfaction**. Broadly preferred measures included **lateral pinch strength**, **pain severity**, and **sensory threshold**. Additionally,

**performance-based tests of dexterity**, **finger abduction/adduction strength**, and **health status over time** received notable recognition.

In **clinical practice** post-ulnar nerve surgery, experts unanimously endorsed tools like **daily living self-assessment**, **work-related evaluation**, and **patient satisfaction**. Broadly supported tools included **lateral pinch**, **grip**, and **finger movement strength**, as well as **quality of life assessment**. Moderately supported tools included **pain intensity** assessment and evaluation of **sports and recreational activities**; see Table 2 for a consensus level of constructs for research and clinical purpose post-ulnar nerve surgery.

Experts also reached a consensus on the preferred methods for evaluating the most important outcomes of ulnar nerve surgeries. For assessing health status or health-related quality of life, experts favored established tools such as the short form-36 health survey (SF-36), the short form-12 health survey (SF-12), and the EuroQol-5 dimension (EQ-5D). Patient-rated outcome measures, including the patient-rated ulnar nerve evaluation (PRUNE) and the quick disabilities of the arm, shoulder, and hand (DASH), were identified as essential for capturing patients' perspectives on their surgical outcomes. Pain assessment methods included the numeric rating scale (NRS), the visual analog scale (VAS), and pain interference measures such as the pain interference subscale of the patient-reported outcomes measurement information system (PROMIS) questionnaire and the brief pain inventory (BPI). Sensation evaluation involved measures like two-point discrimination, localization of touch, the Tinel's sign, and the ten tests for sensation. For assessing dexterity, experts recommended the nine-hole peg test, the Purdue peg board test, and the Jebsen-Taylor hand function test. Additionally, both patient-rated and clinician-rated global rating of change (GRC) measures were endorsed to provide a comprehensive evaluation of the patient's overall status or change post-surgery.

*Second Round*

In the subsequent round, we retained 14 out of the 15 participants from the first round, resulting in a participation rate of 93%. Only one expert participant did not join the second round. We honed our focus on the SETS procedure, building upon the insights gleaned from the initial round.

From the outcomes constructed in general ulnar nerve surgery in the first round, experts reached a new consensus on the core outcome set for specific SETS procedures in the second round as in Table 3. In the research domain for SETS, **lateral pinch strength**, **finger abduction/adduction strength**, and **performance-based tests of dexterity** garnered significant attention. In the clinical setting, **daily living functions self-assessment** and **lateral pinch strength measurement** emerged as crucial outcomes.

Regarding the preferred methods for evaluating outcomes of ulnar nerve surgeries in the first round, experts agreed on the most preferred method in each category for evaluating outcomes of the specific SETS AIN to ulnar nerve transfer; see Table 4 for the round 2 rankings. The **SF-12** was favoured for evaluating health-related quality of life, while the **PRUNE** was selected as a valuable patient-reported specific outcome. Experts' consensus on pain evaluation using the **VAS** and the pain interference subscale of the **PROMIS** questionnaire. They also agreed on using the **two-point discrimination** to evaluate sensory problems and the **nine-hole peg test** to evaluate dexterity. They also indicated that using the patient-rated **GRC** provides a level of recovery from the patients' point of view. These methods form a robust toolkit for clinicians and researchers, enhancing patient care and decision-making.

**Discussion**

The findings of this Delphi study underscore the critical importance of establishing a consensus among experts in the field regarding outcome measures for ulnar nerve surgeries, with a specific focus on the SETS AIN to ulnar nerve transfer procedure. Through two iterative rounds of expert consultation, this study has yielded a comprehensive framework for evaluating surgical efficacy, encompassing both research and clinical practice domains.

The unanimous agreement among experts on the participation in this study reflects a strong commitment to advancing the understanding and standardization of outcomes in this surgery. The diverse composition of the expert panel, representing various specialties, demographics, and geographical regions, enriches the robustness and generalizability of the consensus reached.

In the first round, experts emphasized the paramount importance of restoring motor function and improving functional performance as primary goals in ulnar nerve surgeries. This consensus underscores the centrality of patient-centric outcomes in assessing surgical success. The delineation of outcome measures into unanimity, broad preference, and significant recognition categories provides a nuanced understanding of the metrics deemed essential by the expert panel.

The subsequent round aimed to refine outcome measures specific to the SETS procedure, focusing on gaining deeper insights into its multifaceted goals and assessment tools crucial for success. Experts highlighted additional goals beyond motor function improvement, including postoperative claw correction and restoration of sensory function. This emphasis on sensory outcomes underscores a holistic approach to addressing the diverse manifestations of ulnar nerve pathologies. It suggests that experts recognize the importance of comprehensive recovery, encompassing both motor and sensory functions, for optimal outcomes in SETS surgery. Patients benefiting from improved sensory function likely undergo simultaneous primary nerve repair and nerve decompression. Although SETS AIN transfer is associated with superior motor functional outcomes in some studies, ulnar and cubital tunnel releases are still commonly performed in most patients.[11,28-30] Additionally, experts emphasized strategies to mitigate muscle atrophy, indicating a comprehensive approach to preserving overall hand function and quality of life post-surgery.

In research studies, prioritizing outcomes like lateral pinch strength[20-22], finger abduction/adduction strength, and dexterity tests highlights the importance of assessing motor and dexterity function after SETS surgery. These metrics offer valuable insights into patients' hand function and skill levels post-surgery. Consistent inclusion of these measures in research protocols enhances comparability across studies and optimizes outcome assessment standardization. McLeod's 2020 study further supports this, emphasizing the need to prioritize motor and dexterity function assessments for comprehensive evaluation of SETS interventions' effectiveness.(31)

In the clinical setting, the identification of daily living functions self-assessment and lateral pinch strength measurement as crucial outcomes underscore the practical implications of SETS procedures in enhancing functional abilities and hand strength among patients. The emphasis on daily living functions self-assessment reflects the significance of evaluating patients' ability to perform activities of daily living, providing valuable insights into the real-world impact of SETS interventions on patients' functional independence and quality of life.(32) Moreover, the recognition of lateral pinch strength measurement highlights the importance of assessing hand strength, a fundamental aspect of hand function essential for various tasks and activities.(33,34) By prioritizing these outcomes in the clinical assessment of SETS patients, clinicians can effectively monitor postoperative progress, tailor rehabilitation strategies, and optimize treatment approaches to maximize functional recovery. Furthermore, the integration of patient-reported assessments alongside objective measures of hand strength offers a comprehensive evaluation of treatment outcomes, aligning with patient-centered care principles and facilitating shared decision-making between clinicians and patients.

The identification of preferred methods for measuring outcomes specific to SETS procedures underscores the importance of employing comprehensive assessment tools to capture various facets of patient experience and functional outcomes post-surgery. Among the preferred methods, the SF-12 emerged as a top choice for assessing health-related quality of life, reflecting its ability to provide a comprehensive overview of patients' physical and mental well-being.(18) The inclusion of patient-reported outcome measures which is the PRUNE(35), a reliable and valid measurement tool specifically tailored for patients with ulnar nerve pathology, highlights the importance of incorporating patients' perspectives into outcome assessment, enabling a more holistic understanding of treatment efficacy and patient satisfaction.

Furthermore, the recognition of pain assessment tools such as the VAS and the pain interference subscale of the PROMIS questionnaire[36] underscores the significance of quantifying pain intensity and its impact on daily life, essential considerations in evaluating treatment success and optimizing pain management strategies post-surgery. Sensory assessment through methods like Two-Point Discrimination is deemed essential for evaluating nerve function and recovery following surgery, providing valuable insights into sensory deficits and the effectiveness of nerve regeneration.

Moreover, the preference for functional assessment tools such which is the Nine-Hole Peg Test[37] highlights the importance of assessing dexterity and fine motor function, key components of hand function critical for patients' functional independence and quality of life post-surgery. Lastly, patient-rated global assessments of status or change, exemplified by the Patient-rated GRC[25], offer a comprehensive perspective on treatment outcomes, allowing clinicians and researchers to gauge the overall impact of the SETS AIN to ulnar nerve transfer procedure from the patient's viewpoint.

As far as we know, there has been only one systematic review conducted by Dunn et al. in 2021, which delved into the aspect of outcome measures for evaluating results following SETS surgery.[34] Also, there is the latest systematic review regarding the psychometric properties of the patient-rated outcome measures for people with the ulnar nerve entrapment at the elbow.[38] However, our Delphi study offers a more comprehensive overview by incorporating a wider range of outcome measures based on expert consensus, adding significant outcome results from these previous reviews in several fundamental aspects.

Dunn et al. (2021) highlighted postoperative improvements in grip and key pinch strength. Our surveys likely included various methods for assessing strength, such as pinch strength assessments, which align with the findings of improved grip and key pinch strength in their systematic review. Additionally, the authors noted a significant percentage of patients experiencing postoperative recovery of intrinsic function. Our surveys encompassed assessments related to motor function restoration, such as finger abduction/adduction strength, aligning with the reported recovery of intrinsic function. However, our Delphi results have encompassed a broader range of outcome measures beyond strength assessments. These measures, including pain intensity, sensation, and dexterity, were not explicitly mentioned in the excerpt from Dunn et al.'s systematic review. It's noteworthy that the SETS procedure, when combined with concurrent decompression of the ulnar nerve, may have implications not only for motor function but also for sensation and pain management. While the SETS procedure alone may not directly address sensation and pain, the overall surgery, which includes decompression or transposition at the elbow, could potentially impact these aspects.(34)

Comparing our findings to those of Dabbagh et al. (2022), both studies recognized the Patient-Rated Ulnar Nerve Evaluation (PRUNE) as a valuable tool for assessing outcomes in patients with ulnar nerve entrapment at the elbow. They highlighted PRUNE's reliability, correlation with other health-related measures, content validity, and responsiveness. Our study echoed these findings, with PRUNE emerging as the most preferred patient-reported outcome measure among experts. While Dabbagh et al. focused mainly on patient-rated outcome measures, our Delphi surveys broadened the scope by identifying additional outcome measures such as health-related quality of life, pain assessment, sensation evaluation, and dexterity assessment. Moreover, our study integrated potential goals and outcome constructs relevant to both research and clinical settings, determined through consensus among experts specializing in ulnar nerve surgery, including the SETS procedure.(38)

Although the Delphi study offered insightful information about desired outcome metrics and evaluation objectives for ulnar nerve surgeries including the specific SETS procedure, it is important to recognize some limitations. First off, because participant viewpoints may differ, the study's dependence on expert judgement may introduce bias. Furthermore, because the Delphi approach is intrinsically dependent on participant selection, even with the best of intentions to assemble a broad panel of experts, the sample may not accurately reflect all pertinent parties or viewpoints. Additionally, the Delphi method calls for several iterations of data collection and analysis, which can be resource- and time-intensive.

Consequently, there can be restrictions on the scope and depth of subjects covered or the quantity of participants. While our study involved a relatively small number of participants, comprising 15 experts, it's important to note that identifying individuals with significant experience and extensive involvement in the specific field of SETS surgery can be challenging. This limitation, however, underscores the depth of expertise and specialized knowledge represented in our research. By engaging experts with substantial experience, our study benefitted from insights and perspectives grounded in real-world practice and years of dedicated involvement in the field. Therefore, while the sample size may be modest, the expertise and depth of knowledge among participants enhance the credibility and relevance of our findings. Finally, even though the Delphi study sought to find expert consensus, it is important to understand that consensus does not always indicate accuracy. Future research may want to take into account other viewpoints or newly emerging information.

**Conclusion**

In culmination, the findings of our Delphi study represent a significant contribution to the field of ulnar nerve surgeries, particularly in the context of SETS procedures. Through iterative expert consultation, we have delineated a comprehensive framework of outcome measures crucial for evaluating surgical efficacy across various domains, including motor function, functional performance, health-related quality of life, pain management, sensory assessment, and dexterity evaluation. The broad consensus among experts underscores the importance of these metrics in assessing patient outcomes post-surgery and guiding both research and clinical practice. Moreover, our study bridges existing gaps in the literature by integrating insights from previous systematic reviews while expanding the scope to include additional outcome measures and crucial constructs relevant to the SETS procedure. By synthesizing expert opinions and incorporating diverse perspectives, our study offers a robust and nuanced understanding of outcome assessment in the SETS surgery, providing invaluable guidance for clinicians, researchers, and policymakers. Moving forward, this consensus-derived framework serves as a cornerstone for standardizing outcome assessment, optimizing patient care, and driving further advancements in the field of ulnar nerve surgery.

Table 4: Expert demographic for round 1 (n=15)

| **Demographics** | | **(n, %)** |
|---|---|---|
| Specialists | Physician (Physiatrist) | 1, 7% |
| | Hand and Microsurgery Surgeons (Orthopedic and Plastic) | 8, 53% |
| | Therapist (Hand, OT, and PT) | 6, 40% |
| Race | Asian | 7, 46% |
| | White | 6, 40% |
| | Middle Eastern | 1, 7% |
| | Latino | 1, 7% |
| Country of practice | Canada | 7, 46% |
| | Thailand | 6, 40% |
| | USA | 1, 7% |
| | Iran | 1, 7% |
| Sex (male) | | 11, 73% |
| | | **Mean ± SD** |
| Average years practicing in the SETS surgery | | 8.66 ± 5.79 |
| Mean age | | 44.5 ± 10.31 |

Table 5: A consensus level of optimal outcome for research study and clinical purpose after general ulnar nerve surgery in round 1

| Consensus Level: Strongly Endorsed (90-100%) | |
|---|---|
| **Research study** | **Clinical setting** |
| Health-Related Quality of Life | Daily Living Functions Self-Assessment |
| Self-Reported Functional Ability in Daily Life | Work-Related Functional Capacity Self-Assessment |
| Self-Reported Work Limitations | Patient Satisfaction Evaluation |
| Grip Strength Assessment | |
| Patient Satisfaction Evaluation | |
| **Consensus Level: Broadly Supported (75-89%)** | |
| Lateral Pinch Strength | Lateral Pinch Strength Measurement |
| Pain Severity | Grip Strength Assessment |
| Sensory Threshold | Finger Movement Strength Evaluation |
| | Health-Related Quality of Life Assessment |
| **Consensus Level: Moderately Supported (70-74%)** | |
| Performance-Based Tests of Dexterity | Pain Intensity Assessment |
| Finger Abduction/Adduction Strength | Sports and Recreational Activities Functional Self-Assessment |
| Health Status Over Time | |

Table 6: A core outcome set for research study and clinical purpose after the specific SETS surgery in round 2

| **Research study** | | **Clinical setting** | |
|---|---|---|---|
| **Core sets** | **Mean Rank (number of participants ranked)** | **Core sets** | **Mean Rank (number of participants ranked)** |
| Lateral Pinch Strength | 1.92 (13) | Daily Living Functions Self-Assessment | 2.23 (13) |
| Performance-Based Tests of Dexterity | 3.2 (10) | Lateral Pinch Strength Measurement | 2.79 (14) |
| Finger Abduction/Adduction Strength | 3.54 (13) | | |

Table 7: Preferred methods for measuring SETS AIN to ulnar nerve transfer outcomes ranking in round 2

| **Health status or health-related quality of life** | **Mean rank (number of participants ranked)** |
|---|---|
| The Short Form-36 Health Survey (SF-36) | 1.57 (7) |
| The Short Form-12 Health Survey (SF-12) | **1.125 (8)** |
| The EuroQol-5 Dimension (EQ-5D) | 1.83 (6) |
| **Patient-rated outcome measures** | |
| The Patient-Rated Ulnar Nerve Evaluation (PRUNE) | **1.25 (12)** |
| The Quick DASH | 1.58 (12) |
| **Pain intensity measures** | |
| The Numeric Rating Scale (NRS) | 1.625 (8) |
| The Visual Analog Scale (VAS) | **1.11 (9)** |
| **Pain interference measures** | |
| Pain interference subscale of the PROMIS questionnaire | **1 (9)** |
| The Brief Pain Inventory (BPI) | 2 (4) |
| **Sensation** | |
| Two-point discrimination | **1.125 (12)** |
| Localization of touch | 2.5 (4) |

| | |
|---|---|
| Tinel's sign | 3.67 (3) |
| The ten tests for sensation | 1.57 (7) |
| **Dexterity** | |
| The Nine-Hole Peg Test (NHPT) | **1.2 (10)** |
| Purdue Peg Board Test | 2 (4) |
| The Jebsen-Taylor Hand Function Test | 1.7 (10) |
| **The patient's global rating of status or change** | |
| Patient-rated Global Rating of Change (GRC) | **1 (11)** |
| Clinician-rated Global Rating of Change (GRC) | 2 (5) |

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# Chapter 4

## Grand Discussion: Synthesizing Insights from Scoping Review with Expert Insight and Delphi Study to Enhance Understanding and Evaluation of Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer

Tachit Jiravichitchai, MD

In this grand discussion, we amalgamate the findings from two distinct yet complementary research endeavors – a scoping review with expert insight and a Delphi study – aimed at advancing our understanding and evaluation of Supercharged End-to-Side (SETS) Anterior Interosseous Nerve (AIN) to Ulnar Nerve transfer.

The scoping review with expert perspective aims to systematically map the existing evidence regarding outcome measures utilized following SETS AIN to ulnar nerve transfers for treating ulnar nerve entrapment. It encompasses clinical, patient-reported, and electrodiagnostic measures in short-term and long-term follow-ups, while also integrating expert opinions and potentially unpublished data to assess consistency and relevance. Additionally, the review explores the surgical rationale behind SETS transfers, focusing on specific patient populations, diagnoses, and recovery trajectories to deepen understanding and guide future clinical practice and research. Together, these objectives provide a comprehensive overview of SETS surgery techniques, outcomes, and associated factors, identifying gaps, inconsistencies, and standardization opportunities to enhance patient care in nerve transfer surgeries.

Building upon this foundation, the Delphi study engages experts in the field to establish a standardized core set of outcome measures essential for evaluating the efficacy and impact of ulnar nerve surgeries including SETS surgery. By leveraging the collective wisdom and expertise of specific healthcare practitioners, we delineate a comprehensive framework encompassing motor function, functional performance, health-related quality of life, pain management, sensory assessment, and dexterity evaluation. Additionally, this project aims to determine, by expert consensus, the items that make up the clinical history, clinical examination, prognosis of recovery, and the processes in developing outcome measures needed to establish a clinical reasoning process and pathway of care for patients after this procedure. Through this holistic approach, the objective is to develop a standardized core set of outcome measures that can inform evaluations in both research and clinical settings, thereby enhancing the comparability and interpretability of study findings across diverse hand surgery and rehabilitation settings and patient populations.

Furthermore, our discussion emphasizes how important it is to use consensus-driven methods and expert insights to influence the direction of future ulnar nerve surgical research and clinical practice. We encourage cooperation and creativity among stakeholders from a variety of backgrounds, such as physicians, surgeons, physiotherapists, occupational therapists, and researchers, which advances the discipline and eventually improves patient results.

**Implications for Findings**

The results of the Delphi research and the scoping review with expert insights have significant implications. The scoping review's thorough summary gives important new information on the state of current knowledge when it comes to SETS surgery results, recovery times, and related variables. This review fills in gaps and discrepancies in the literature while also adding to our understanding of SETS surgical outcomes by combining the results of several research and expert viewpoints. Comparably, a core set of standardized outcome measures is established by the Delphi study, which is crucial for assessing the effectiveness and significance of ulnar nerve surgeries, including SETS procedures. This study offers an organized method for developing reliable outcome measures through consensus-building among experts, improving comparability and interpretability of study outcomes across healthcare settings and patient populations.

**Clinical Implications**

From a clinical perspective, the findings of both projects have significant implications for patient care and treatment decision-making in the context of ulnar nerve surgeries. The scoping review with expert insights offers healthcare practitioners valuable information on the multifaceted nature of SETS surgery outcomes and factors influencing patient recovery. This knowledge can inform clinical practice by guiding treatment strategies and rehabilitation interventions tailored to individual patient needs. Similarly, the standardized core set of outcome measures established by the Delphi study provides clinicians with standardized tools for assessing patient outcomes post-SETS surgery. By integrating these outcome measures into clinical practice, healthcare practitioners can effectively monitor postoperative progress, tailor rehabilitation strategies, and optimize treatment approaches to maximize functional recovery and enhance patient outcomes.

## Limitations

Both projects offer important contributions, but there are some limits that should be taken into account. The possibility of selection bias present in the literature search procedure is one of the scoping review's limitations, as it could affect how thorough the results are. The sample size and makeup of the expert panel, which might not accurately reflect all pertinent viewpoints in the field of ulnar nerve surgery, may also be a limitation of the Delphi study. Additionally, the quality and quantity of currently available evidence may place limitations on both projects, which may affect the findings' generalizability and dependability. These restrictions highlight the necessity of interpreting the data carefully and the significance of ongoing study to fill in knowledge gaps and improve techniques.

## Impact of Research

The impact of both projects on research in the field of ulnar nerve surgeries is considerable. The scoping review with expert insights synthesizes existing evidence and identifies key gaps in knowledge, thereby informing future research directions and priorities. By integrating expert perspectives and potentially unpublished data, this review contributes to a more comprehensive understanding of SETS surgery outcomes and factors influencing patient recovery. Similarly, the standardized core set of outcome measures established by the Delphi study enhances the comparability and interpretability of study findings across research settings, facilitating meta-analyses and systematic reviews. This standardized approach to outcome assessment promotes consistency in research methodologies and enhances the quality and reliability of evidence generated in the field of ulnar nerve surgery.

## Education for healthcare practitioners

It is essential to ensure optimal patient outcomes in the context of ulnar nerve surgeries, including SETS procedures. Future educational initiatives should aim to disseminate the findings of both the scoping review with expert insights and the Delphi study to healthcare providers involved in the management of ulnar nerve pathologies. This includes surgeons, therapists, and other allied healthcare professionals. Educational programs should emphasize the importance of standardized outcome assessment in evaluating surgical efficacy and guiding clinical decision-making. Additionally, training modules should be developed to enhance practitioners' understanding of the intricacies of ulnar nerve surgeries, including surgical techniques, postoperative rehabilitation protocols, and patient monitoring strategies. Moreover, integrating patient-centered care principles into educational curricula can foster a holistic approach to patient management, ensuring that healthcare practitioners prioritize patients' individual needs, preferences, and goals throughout the treatment journey. By investing in ongoing education and professional development opportunities, healthcare practitioners can stay abreast of the latest advancements in ulnar nerve surgery and provide high-quality, evidence-based care to patients, ultimately improving treatment outcomes and enhancing patient satisfaction.

**Future Direction**

Future research in the field of ulnar nerve surgeries should focus on addressing the limitations identified in both the scoping review with expert insights and the Delphi study. This includes conducting larger-scale studies with more diverse patient populations to enhance the generalizability of findings and mitigate selection bias. Additionally, future research should prioritize the development and validation of novel outcome measures that capture the full spectrum of patient outcomes and recovery trajectories following SETS surgery. Furthermore, there is a need for longitudinal studies to evaluate the long-term efficacy and durability of SETS procedures and assess their impact on patients' quality of life. Moreover, initiating a qualitative study to assess the patient perspective after the SETS procedure can provide valuable insights into patient experiences, preferences, and suggestions. By incorporating patient perspectives, future research can ensure that outcomes measures are patient-centered and address the holistic needs of individuals undergoing ulnar nerve surgeries. By addressing these priorities, future research can continue to advance the understanding and standardization of outcome assessment in ulnar nerve surgeries, ultimately improving patient care and treatment outcomes.

**Conclusion**

The scoping review's findings combined with expert insight and the Delphi research provide a substantial addition to the corpus of knowledge about SETS surgery. Through the integration of data from extant literature and expert agreement, we offer a comprehensive framework that facilitates the assessment of surgical outcomes, informs clinical decision-making, and drives future research opportunities. Our results open the door for future cooperative initiatives to improve patient care, harmonize outcome evaluation, and advance ulnar nerve operations. We aim to achieve important improvements in surgical and rehabilitative practice as well as excellence in patient care via ongoing discourse, cooperation, and innovation.

# Appendices

## Appendix A: The First and Second Survey Structures

### The First-Round Qualtrics Survey

### Preamble

Given that the **Anterior Interosseous Nerve (AIN) to ulnar nerve transfer** is a relatively new procedure, our aim is **to establish outcome measures that everyone should be reporting**, so that we can share our data and learn about the effectiveness of this type of surgical treatment.

As an appreciation for your time filling out this survey, we also upload the pdf file of information about this surgical procedure:

Anterior Interosseous Nerve to Ulnar Nerve Transfer: A Systematic Review (optional).

### Consent

I have read and understood the information provided in the letter of information.

☐ I agree to voluntarily participate in this study

☐ I do not consent

Please provide your professional background and expertise related to AIN transfer to the ulnar nerve and ulnar nerve transposition.

Your specialty

____________________________________________

Your biological sex

☐ Male

☐ Female

☐ Prefer not to say

Your country of practice

______________________________________________________________________

Your race

______________________________________________________________________

Your partial date of birth (MM/YY)

______________________________________________________________________

Years of experiences for the procedure

______________________________________________________________________

Your research interests

______________________________________________________________________

Please rank the following potential goals for the AIN transfer to the ulnar nerve, with **1 being the most important**. (Randomized choices)

☐ Restoration of motor function

☐ Improvement in sensory function

☐ Reduction of pain

☐ Improving functional performance

☐ Enhancing quality of life

☐ Other (Please specify)_______________________________________________

How important is each of the following complications that can arise from ulnar nerve transposition?

| | Not important | Somewhat important | Very important |
|---|---|---|---|
| CRPS or other abnormal postoperative pain response | | | |
| Abnormal sensation (i.e. hyperalgesia) | | | |
| Infection | | | |
| Nerve regeneration issue | | | |
| Neuroma formation | | | |
| Hematoma formation | | | |
| Scar sensitivity | | | |
| Stiffness or joint contracture | | | |
| Other (Please specify) ________________________________ | | | |

How important is each of the following complications that can arise specifically from AIN to ulnar nerve transfer procedures?

| | Not important | Somewhat important | Very important |
|---|---|---|---|
| Decreased pronation strength | | | |

| | | | |
|---|---|---|---|
| Decreased thumb IP flexion strength | | | |
| Decreased DIP flexion strength of index and middle finger | | | |
| Other (Please specify) ________________________________ | | | |

This section is asking about **what constructs or topic outcomes are important** to measure or assess. Your expertise and insights are highly valued. Please carefully consider each question and provide your responses based on your professional knowledge and experience. Please respond separately for **research study** and **clinical practice**.

1. How important do you think the following outcomes of **<u>pain</u>** are as constructs to be included in a core outcome measure data set?

| | Pain severity | | Pain frequency | | Pain interference | | Pain distribution | | Pain quality/characteristic | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice |
| Not at all important | | | | | | | | | | |
| Slightly important | | | | | | | | | | |
| Moderately important | | | | | | | | | | |
| Very important | | | | | | | | | | |
| Extremely important | | | | | | | | | | |

2. How important do you think the following outcomes of **function** are as constructs to be included in a core outcome measure data set?

| | Self-reported functional ability in tasks of daily life | | Self-reported functional ability in work/work limitations | | Self-reported functional ability in sports/recreation | | Performance-based tests of dexterity | | Performance-based tests of hand function | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice |
| Not at all important | | | | | | | | | | |
| Slightly important | | | | | | | | | | |
| Moderately important | | | | | | | | | | |
| Very important | | | | | | | | | | |
| Extremely important | | | | | | | | | | |

3. How important do you think the following outcomes of **strength** are as constructs to be included in a core outcome measure data set?

| | Grip strength | | Lateral pinch strength | | Tip pinch strength | | Tripod pinch strength | | Finger abduction/adduction strength | | Thumb abduction strength | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice |
| Not at all important | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slightly important | | | | | | | | | | | | |
| Moderately important | | | | | | | | | | | | |
| Very important | | | | | | | | | | | | |
| Extremely important | | | | | | | | | | | | |

4. How important do you think the following outcomes of **motion** are as constructs to be included in a core outcome measure data set?

| | ROM elbow flexion/extension | | ROM forearm pronation/supination | | ROM wrist flexion/extension | | ROM wrist radial/ulnar deviation | |
|---|---|---|---|---|---|---|---|---|
| | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice | Research study | Clinical practice |
| Not at all important | | | | | | | | |
| Slightly important | | | | | | | | |
| Moderately important | | | | | | | | |
| Very important | | | | | | | | |
| Extremely important | | | | | | | | |

5. How important do you think the following outcomes of **<u>sensation</u>** are as constructs to be included in a core outcome measure data set?

| | Sensory threshold testing | | Sensory discrimination testing | | Sensory distribution testing | | Vibration | | Proprioception | | Pressure | | Temperature (hot/cold) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R | C | R | C | R | C | R | C | R | C | R | C | R | C |
| Not at all important | | | | | | | | | | | | | | |
| Slightly important | | | | | | | | | | | | | | |
| Moderately important | | | | | | | | | | | | | | |
| Very important | | | | | | | | | | | | | | |
| Extremely important | | | | | | | | | | | | | | |

6. How important do you think the following outcomes of **<u>patient satisfaction</u>** are as constructs to be included in a core outcome measure data set?

| | Patient satisfaction | |
|---|---|---|
| | Research study | Clinical practice |
| Not at all important | | |
| Slightly important | | |

| | | |
|---|---|---|
| Moderately important | | |
| Very important | | |
| Extremely important | | |

7. How important do you think the following outcomes of quality of life are as constructs to be included in a core outcome measure data set?

| | Health-related quality of life | |
|---|---|---|
| | Research study | Clinical practice |
| Not at all important | | |
| Slightly important | | |
| Moderately important | | |
| Very important | | |
| Extremely important | | |

8. How important do you think the following outcomes of perceived global rating of change are as constructs to be included in a core outcome measure data set?

| | Change over time | |
|---|---|---|
| | Research study | Clinical practice |
| Not at all important | | |

| | | |
|---|---|---|
| Slightly important | | |
| Moderately important | | |
| Very important | | |
| Extremely important | | |

For the following constructs which require patient-reported outcome measures, we would ask you to rank your preference (rank up to 3 of the outcome measures) with **1 being your most preferred choice** for the following instruments considering quality and relevance.

**Patient-reported hand function**

☐ The Patient-Rated Ulnar Nerve Evaluation (PRUNE)

☐ The Disabilities of the Arm, Shoulder, and Hand (DASH)

☐ The QuickDASH

☐ The Upper Extremity Functional Index (UEFI)

☐ The Michigan Hand Outcome Questionnaire (MHQ)

☐ The Upper Limb Functional Index (ULFI)

☐ The Patient-Specific Functional Scale (PSFS)

☐ Hand function subscale of the PROMIS questionnaire

☐ Other (please specify)________________________________________________

**Dexterity**

☐ The Nine-Hole Peg Test (NHPT)

☐ The Purdue Peg Board Test

☐ The O'Connor Finger Dexterity Test

☐ The Box and Block Test

☐ The Jebsen-Taylor Hand Function Test

☐ The Sollerman Hand Function Test

☐ The Functional Dexterity Test

☐ The Minnesota Manual Dexterity Test

☐ Other (please specify)______________________________________________

**Pain severity**

☐ The Numeric Rating Scale (NRS)

☐ The Visual Analog Scale (VAS)

☐ The Verbal Rating Scale (VRS)

☐ The Brief Pain Inventory (BPI)

☐ The McGill Pain Questionnaire (MPQ)

☐ Pain Subscale of The Michigan Hand Outcome Questionnaire (MHQ)

☐ Pain Subscale of The Patient-Rated Ulnar Nerve Evaluation (PRUNE)

☐ Other (please specify)______________________________________________

**Pain interference**

☐ Pain interference subscale of the PROMIS questionnaire

☐ Brief Pain Inventory (BPI)

☐ Multidimensional Pain Inventory (MPI)

☐ West Haven-Yale Multidimensional Pain Inventory (WHYMPI)

☐ Pain Disability Index (PDI)

☐ Chronic Pain Grade (CPG)

☐ Other (please specify)_______________________________________________

**Health status or Health-related quality of life**

☐ The EuroQol-5 Dimension (EQ-5D)

☐ The World Health Organization Quality of Life (WHOQOL)

☐ The Short Form-36 Health Survey (SF-36)

☐ The Short Form-12 Health Survey (SF-12)

☐ Other (please specify)_______________________________________________

**The patient's global rating of status or change**

☐ Single Alphanumeric Evaluation (SANE)

☐ Patient-rated Global Rating of Change (GRC)

☐ Clinician-rated Global Rating of Change (GRC)

☐ Change in Health Status (CHS)

☐ Other (please specify) ______________________________________________

**Sensation**

☐ Two-point discrimination

☐ Localization of touch

☐ Tactile recognition

☐ Pressure

☐ Vibration threshold

☐ Joint position sense

☐ Thermal threshold

☐ Perception threshold

☐ Moberg pick up test

☐ Functional sensory test

☐ Tinel's sign

☐ The ten test for sensation

☐ Other (please specify) ____________________________________________________

**End**

Is there anything else you would like to tell us about measuring outcome for this procedure? (Optional)

___________________________________________________________________________

___________________________________________________________________________

**The Second-Round Qualtrics Survey**

**Preamble**

In the initial round for the Anterior Interosseous Nerve (AIN) to Ulnar Nerve Transfer with Ulnar Nerve Transposition, 15 diverse experts achieved consensus on core outcome measures. **Only outcomes with over 75% agreement were included**, signifying collective endorsement by a diverse panel of predominantly male experts with a mean age of 44.5 years and an average of 8.66 years of practice. The panel's racial and geographic diversity, including backgrounds from Asia, White, Middle Eastern, to Latino.

This second round focuses exclusively on refining outcome measures for the specific **Supercharged End-To-Side (SETS)** AIN to Ulnar Nerve Transfer, aiming for precision and applicability in **research** and **clinical** settings. Through iterative collaboration, this study seeks to establish a comprehensive framework aligning with the latest consensus among specialists.

Thank you for your previous response. This second round survey will be much shorter, just for the final few issues, and **should only take 5-10 minutes**.

Please indicate your occupation and country of practice

Occupation_______________________________________________________________

Country of practice_______________________________________________________

These 2 potential **goals** for the **SETS** procedure were extracted from the first round of Delphi. Please review any additional outcomes you, as experts, consider vital for its success.

1. Restoration of Motor Function

2. Improving Functional Performance

Would you like to add others (that you think are also very important but not listed)?

---

How would you measure the goal?

---

which outcome measure would you use to measure?

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In the initial round of our Delphi study, which focused on various types of ulnar nerve surgery, experts identified critical outcomes for both clinical practice and research purposes. This round produced two key sets of outcomes:

- **Clinically Important Outcomes**: These are the measures that clinicians highlighted as crucial for evaluating the success and patient recovery in a practical, clinical setting. These outcomes are vital for day-to-day patient care and management, especially in environments where quick and effective decision-making is paramount due to high patient volumes.
- **Research-Focused Outcomes**: This set consists of consensus-based outcomes that experts considered most suitable for in-depth research. These outcomes are essential for generating valuable data that contribute to our understanding and advancement of ulnar nerve surgery techniques, including the SETS procedure.

Please review the outcomes from the first round and rank them based on their importance for the SETS procedure. Select (by filling "Y") the methods you believe are most relevant for assessing outcomes, specifically after the SETS procedure. Once selected, please rank them in order of importance.

| **Important Outcomes in the clinical setting** | | |
|---|---|---|
| | Selection | Ranking |
| Daily Living Functions Self-Assessment | | |

| | | |
|---|---|---|
| Work-Related Functional Capacity Self-Assessment | | |
| Patient Satisfaction Evaluation | | |
| Grip Strength Assessment | | |
| Lateral Pinch Strength Measurement | | |
| Finger Movement Strength Evaluation | | |
| Overall Health-Related Quality of Life Assessment | | |
| Pain Intensity Assessment | | |
| Sports and Recreational Activities Functional Self-Assessment | | |
| Others (that you think are also very important but not listed here)______________________________ | | |
| **Important Outcomes in the research** | | |
| Health-Related Quality of Life | | |
| Self-Reported Functional Ability in Daily Life | | |
| Self-Reported Work Limitations | | |
| Grip Strength | | |
| Patient Satisfaction Evaluation | | |

| | | |
|---|---|---|
| Pain Intensity Assessment | | |
| Lateral Pinch Strength | | |
| Sensory threshold | | |
| Performance-Based Tests of Dexterity | | |
| Finger Abduction/Adduction Strength | | |
| Health Status Over Time | | |
| Others (that you think are also very important but not listed here)______________________________ | | |

**Preferred Methods for Measuring Ulnar Nerve Surgery Outcomes**

This section presents the most agreed-upon methods for evaluating key outcomes of ulnar nerve surgery. These methods have been selected based on the consensus of our expert panel. Please review the listed outcomes and their associated measurement methods. For this part, we ask you to select (by filling "Y") the methods you believe are most relevant for assessing outcomes, specifically after the SETS procedure. Once selected, please rank them in order of importance.

| **Health status or Health-related quality of life** | | |
|---|---|---|
| | Selection | Ranking |
| The Short Form-36 Health Survey (SF-36) | | |
| The Short Form-12 Health Survey (SF-12) | | |
| The EuroQol-5 Dimension (EQ-5D) | | |

| | | |
|---|---|---|
| **Patient-Rated Outcome Measures** | | |
| The Patient-Rated Ulnar Nerve Evaluation (PRUNE) | | |
| The Quick DASH | | |
| **Pain** | | |
| *Pain Severity Measures:* | | |
| The Numeric Rating Scale (NRS) | | |
| The Visual Analog Scale (VAS) | | |
| *Pain Interference Measures:* | | |
| Pain interference subscale of the PROMIS questionnaire | | |
| **Sensation** | | |
| Two-point discrimination | | |
| Localization of touch | | |
| Tinel's sign | | |
| The ten tests for sensation | | |
| **Dexterity** | | |
| The Nine-Hole Peg Test (NHPT) | | |
| Purdue Peg Board Test | | |

| | | |
|---|---|---|
| The Jebsen-Taylor Hand Function Test | | |
| **The patient's global rating of status or change** | | |
| Patient-rated Global Rating of Change (GRC) | | |
| **Others** | | |
| Others (that you think are also very important but not listed here)___________________________________ | | |

**Appendix B: Letter of Information**

**Protect Title: A Core Set of Outcome Measures in the Anterior Interosseous Nerve to Ulnar Nerve Transfer with Ulnar Nerve Transposition: A DELPHI Study**

**Principal Investigator: Dr. Joy MacDermid, PT, PhD**
**Co-Investigators: Dr. Tachit Jiravichitchai, MD, MSc(c)**

**Introduction**

Patients with hand and wrist dysfunction resulting from severe nerve compression are often faced with poor functional outcomes. The supercharged end-to-side anterior interosseous nerve (SETS AIN) to ulnar motor nerve transfer provides a treatment for helping to regain function. However, the variability of outcome measures across different studies poses a challenge for standardization. Therefore, the purpose of this project is to determine, by expert consensus, the processes for developing outcome measures needed to establish a research and clinical reasoning process and pathway of care for patients after this procedure.

**Purpose**

You are invited to participate because you are an expert in caring for patients who have undergone a SETS AIN to ulnar motor nerve transfer. Your expertise in this procedure makes you a valuable contributor to this study. The objective is to establish consensus on the criteria used by healthcare practitioners and create a core set of outcome measures to guide future assessments and management options. Researchers will be conducting this study to fulfill the requirements for part of Tachit Jiravichitchai's master of science degree at Western University.

**Study Procedures**

The DELPHI process is a research methodology that leverages expert opinion to achieve consensus among experts. To initiate this process, the principal investigator and co-investigators will commence by gathering relevant items and questions related to AIN transfer to the ulnar nerve. This information will be drawn from their extensive clinical expertise in upper extremity musculoskeletal disorders and a comprehensive review of relevant literature.

Recruitment efforts will target an international cohort of healthcare practitioners, including physicians, surgeons, and therapists, who specialize in assessing and managing upper extremity nerve transfers, particularly for AIN to ulnar nerve cases. Contact with these experts will be established via email by the principal investigator and co-investigators. All interested experts who, after reviewing the provided information and consenting to participate, will be included in the first round of the questionnaire process.

The DELPHI process is flexible, accommodating a diverse group of respondents, and not confined to specific geographic regions. It offers accessibility to a wide array of experts worldwide. Utilizing the Qualtrics online platform, a questionnaire will be administered to collect data on a core set of outcome measures related to AIN transfer to ulnar nerve procedures. The DELPHI process will encompass 2-3 rounds of reviews, with rounds concluding upon consensus achievement, such as a Kappa Statistic exceeding 0.61, signifying "substantial agreement," or after three rounds of reviews.

Following the initial round, comprehensive feedback, including individual remarks, will be provided to all participants. A refined rating scale will be presented in the subsequent round for further review. This iterative process will continue until the predetermined termination criteria are met. Importantly, participants may adjust their opinions in subsequent rounds based on prior responses. If consensus is not reached after three rounds, a smaller group of experts may be convened to establish a consensus on the final core set of outcome measures, ensuring their effective assembly and dissemination for knowledge translation purposes.

**Participation to the Study**

An initial contact email will be dispatched to all identified upper extremity experts by the principal and co-investigators of this project. Thus, a letter of information and consent form will be sent to the clinicians who accept the offer of the initial contact email. Upon their agreement and consent to participate, these experts will be sent individual emails containing a survey link for accessing the DELPHI questionnaire. The investigators will specifically recognize each expert as a registered healthcare professional, including physicians, orthopedic surgeons, and therapists. These experts are acknowledged within their field of upper extremity nerve repair by their peers, professional associations, and/or research interests. All participating experts must possess a minimum of 5 years of experience in assessing and managing AIN transfer to the ulnar nerve. Demographic information for each expert, including their profession, age, years of experience, biological sex, country of practice, and research interest, will be collected.

Participation in this study is entirely voluntary and is part of a student project. Upon acceptance, you will receive a copy of the letter of information and a consent form for your records. Signing the consent form does not waive any legal rights. You can refuse to participate, decline to answer specific questions, or withdraw from the study at any point. You can withdraw from this study by contacting either the principal investigator, Dr. Joy MacDermid, or the co-investigator, Dr. Tachit Jiravichitchai, directly. If you choose to withdraw, no further data will be collected after your withdrawal from the study. If concerns arise or if you wish to withdraw, you can contact the principal investigator, Dr. Joy MacDermid, or co-investigator, Dr. Tachit Jiravichitchai.

**Potential benefits of participating in this study**

There is no direct benefit from participating in the study.

**Potential risk or discomforts associated with this study**

There are no risks to this study, however if participants feel uncomfortable at any time during the survey, they may stop the survey or chose not to respond to the questions. While there are no physical risks or harms to the participants in this study, results will be stored on the Western University's server; and while we try our best to keep all personal information secure, potential privacy breech can occur.

**Compensation**

There will not be any compensation provided for participating in the study.

**How many people will be in this study?**

We will be conducting the DELPHI study with approximately 30 experts.

**Confidentiality**

The overall results of the study will be available to you upon request. Your individual results will be treated with utmost confidentiality, and your study-related records will not be accessible to anyone other than the study team without your explicit permission. Personal identifying information will be either removed or coded to ensure the de-identification of the study database. Our study utilizes the Qualtrics platform, renowned for its strong data protection, including robust encryption, secure data storage, and stringent access controls. Your study data will be securely stored on Western Qualtrics servers, housed within a highly secure data center in Ireland, providing a reliable defense against breaches. The primary list is securely stored electronically on Western's One Drive, with exclusive access granted to the study team. You will also receive a copy of this letter for your records. Representatives from the Western University Health Sciences Research Ethics Board may need access to your study-related records or may conduct follow-up inquiries to monitor the research's integrity. In accordance to UWO policy, your information and study data will be retained by the study investigators for 7 years.

**Alternatives**

It's important to note that your decision to withdraw or decline participation will not impact your professional or academic standing.

**Study contacts**

You will be given a copy of this letter and the signed consent form. If you have questions about taking part in this study, you can directly contact:

Dr. Joy MacDermid
Dr. Tachit Jiravichitchai

If you have questions about your rights as a research participant or about the conduct of the study you may contact The Office of Human Research Ethics

## Appendix C: Letter of Initial and Second Contacts

### LETTER OF INITIAL CONTACT

Subject: Invitation to Participate in **A Core Set of Outcome Measures in the Anterior Interosseous Nerve to Ulnar Nerve Transfer with Ulnar Nerve Transposition: A DELPHI Study**

Dear (name),

I hope this email finds you well. We are excited to invite you to participate as an expert panelist in a Delphi study focused on identifying and achieving consensus on outcome measures for anterior interosseous nerve (AIN) to ulnar nerve transfer with ulnar nerve transposition procedures.

Your expertise in the field of this procedure makes you a valuable contributor to this study. As a panelist, your insights will help shape the selection of outcome measures that are vital for evaluating the success and effectiveness of these surgical interventions.

The Delphi study will involve multiple rounds of surveys and feedback, providing you with the opportunity to collaborate with fellow experts and collectively arrive at a consensus on the most relevant and meaningful outcome measures for AIN to ulnar nerve transfer with ulnar nerve transposition.

Participation in this study will require approximately 20-30 minutes of your time over the course of approximate 3 rounds. Your input will be crucial in advancing our understanding of the best practices and standards for assessing patient outcomes in these surgical procedures.

If you are interested in joining this important research effort, please confirm your participation by 2 weeks. Upon confirmation, you will receive further instructions on how to access the study materials and participate in the Delphi rounds.

We highly value your expertise and insights, and we believe that your contribution to this Delphi study will significantly impact the field. Should you have any questions or require additional information, please feel free to reach out to us.

Thank you for considering this invitation. We look forward to your potential participation and to collectively advancing the knowledge and practice in the area of AIN to ulnar nerve transfer with ulnar nerve transposition.

Sincerely,

Dr. Joy MacDermid (Principal investigator)
University of Western Ontario
Dr. Tachit Jiravichitchai (Co-investigator)
University of Western Ontario

**LETTER OF SECOND CONTACT**

Subject: Round 2: **AIN to Ulnar Nerve Transfer DELPHI Study**

Dear (name),

We hope this message finds you well. We greatly appreciate your participation as an expert panelist in our DELPHI study, which aims to establish consensus on outcome measures for anterior interosseous nerve (AIN) to ulnar nerve transfer with ulnar nerve transposition procedures.

Round 2 Overview:

We are excited to inform you that we have successfully completed Round 1 of the Delphi study, thanks to your valuable contributions. Round 2 represents the next step in our collaborative effort to identify the most relevant outcome measures for these surgical interventions.

Your Insights Matter:

Your insights and expertise have already proven to be instrumental in shaping the study's direction. In this round, we will present you with the aggregated responses from Round 1 and ask you to provide further feedback and rate the importance of each proposed outcome measure. Your input will be critical in reaching a consensus among our panel of experts.

Time Commitment:

We understand the demands on your time and are committed to making the process as efficient as possible. Round 2 should take approximately 5-10 minutes of your time. Your ongoing commitment to this study is greatly appreciated.

Accessing Round 2:

To participate in Round 2, please follow the link provided below, which will take you to the survey platform:

LINK

Deadline for Round 2:

We kindly request that you complete Round 2 by (Deadline Date), allowing us to maintain the study's timeline and momentum.

Questions or Concerns:

Should you have any questions or encounter any issues during Round 2, please do not hesitate to reach out to us. Your feedback is invaluable, and we are here to support you throughout the process.

Thank you once again for your dedication to this DELPHI study. Your continued involvement brings us closer to improving the standards of care in AIN to ulnar nerve transfer with ulnar nerve transposition procedures.

We look forward to receiving your insights in Round 2 and advancing our collective understanding of this important field.

Sincerely,
Dr. Joy MacDermid (Principal investigator)
University of Western Ontario
Dr. Tachit Jiravichitchai (Co-investigator)
University of Western Ontario

**Appendix D: Consent form**

**Consent Form**

**<u>Consent To Participate In:</u>**

**A Core Set of Outcome Measures in the Anterior Interosseous Nerve to Ulnar Nerve Transfer with Ulnar Nerve Transposition: A DELPHI Study**

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

| | | |
|---|---|---|
| ______________________ | ______________________ | ______________________ |
| Signature of Participant | Print Name | Date |

| | | |
|---|---|---|
| ______________________ | ______________________ | ______________________ |
| Signature of person obtaining consent | Print Name of person obtaining consent | Date |

# Curriculum Vitae

| | |
|---|---|
| **Name:** | Tachit Jiravichitchai |
| **Post-secondary Education and Degrees:** | Faculty of Medicine Ramathibodi Hospital<br>Mahidol University, Bangkok, Thailand<br>2008-2014 Doctor of Medicine (M.D.)<br><br>Department of Rehabilitation Medicine<br>Faculty of Medicine Ramathibodi Hospital<br>Mahidol University, Bangkok, Thailand<br>2015-2018 Diploma of Rehabilitation Medicine (FRCPhysiatrT)<br><br>Health and Rehabilitation Sciences<br>Faculty of Health Sciences<br>The University of Western Ontario<br>London, Ontario, Canada<br>2022-2024 Master of Science (M.Sc.) |
| **Honours and Awards:** | FHS Graduate Student Conference Travel Award<br>Summer 2023 |
| **Related Work Experience** | Assistant Professor and Medical Instructor<br>Department of Rehabilitation Medicine, Faculty of Medicine<br>Ramathibodi Hospital, Mahidol University, Thailand<br>2018-present<br><br>Graduate Teaching Assistant<br>The University of Western Ontario<br>London, Ontario, Canada<br>2022-2024 |
| **Conference Presentation:** | June 4-8, 2023 at 17th World Congress of the International Society of Physical and Rehabilitation Medicine (ISPRM) on the topic of "Efficacy of Repetitive Peripheral Magnetic Stimulation for Pain Alleviation in Patients with Chronic Low Back Pain" at Cartagena, Colombia |
| **Publications:** | **First and Corresponding Author**<br>Jiravichitchai, T., Chira-Adisai, W., Panuwannakorn, M., & Kiertiburanakul, S. (2021). Claw hand deformity: a rare complication of herpes zoster. *Orthopedic research and reviews*, 209-214. |