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Literature review

# Upper limb nerve transfers: A review

## *Transferts nerveux au membre supérieur : mise au point*

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A B S T R A C T

While upper limb nerve transfers were first described and performed several years ago, they have seen expanded use in the past 20 years. Initially indicated for surgical repair of brachial plexus injuries with nerve root avulsion, the indications have been extended to post-ganglionic lesions because of the excellent results of certain intraplexus nerve transfers. The traditional nerve repair techniques – primary suture and nerve grafting – form the basis of nerve surgery. Although nerve transfer does not replace them, they are a useful supplement as they provide a targeted approach to reinnervation and recovery of key functions of the upper limb. The goal of this review is to provide an overview of the various possible transfers by the function being restored and the quality of the outcomes.


R É S U M É

Décrits et pratiqués depuis plusieurs années, les transferts nerveux au membre supérieur ont pris un essor considérable depuis les deux dernières décennies. Initialement indiqués pour la chirurgie réparatrice du plexus brachial avec avulsion(s) radiculaire(s), les indications ont été étendues aux lésions post-ganglionnaires du fait d'excellents résultats obtenus avec certains transferts intraplexiques. Si les techniques traditionnelles de réparation nerveuse, de suture primaire et de greffe nerveuse restent la base de la chirurgie nerveuse, sans les remplacer, les transferts nerveux permettent de les compléter grâce à une approche plus ciblée de la réinnervation et de la récupération de fonctions primordiales du membre supérieur. Cette mise au point a pour objectif de donner un aperçu des différents transferts envisageables selon la fonction à réanimer et de la qualité de leurs résultats.


## 1. Introduction

Nerve transfer (NT) consists of partially or completely transecting a healthy nerve and transferring it onto the distal part of a nerve or nerve fascicle to restore deficient function. Other than for brachial plexus (BP) nerve root avulsion injuries where NT is the only possibility for nerve repair, one of the main advantages of NT relative to traditional methods is that it transforms a proximal nerve lesion into a more distal one, near the muscle that needs to be reinnervated. This helps reduce the denervation time of the motor end plates and potentiates the axonal load on a single high-priority function, ensuring a better recovery. Although NT is usually reserved for BP nerve root avulsions, it is being increasingly used to treat post-ganglionic BP nerve lesions or proximal peripheral nerve lesions.

Over the past 20 years, several motor and sensory NTs have been described in the upper limb; some are reliable and widely accepted while other have more unpredictable outcomes. Our goal is not to describe every NT techniques but to review the current knowledge about their indications, characteristics and outcomes. This review is organized anatomically from proximal to distal, instead of functional restoration priorities. Since this is a broad topic, we will not review NTs done for obstetrical brachial plexus palsy, quadriplegic patients or reinnervation of free muscle

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**Table 1**
Abbreviations used throughout the manuscript.

| Abbreviation | Nerve or muscle |
|---|---|
| ADM | Abductor digit minimi |
| AIN | Anterior interosseous nerve |
| BB | Biceps brachii muscle |
| BP | Brachial plexus |
| cC7 | Contralateral C7 root |
| DeBUN | Deep branch of the ulnar nerve |
| DeBRN | Deep branch of the radial nerve |
| DoBUN | Dorsal branch of the ulnar nerve |
| EBAN | External branch of the accessory nerve |
| ECRB | Extensor carpi radialis brevis |
| ECRL | Extensor carpi radialis longus |
| ECD | Extensor digitorum communis |
| ETE | End-to-end |
| ETS | End-to-side |
| FCR | Flexor carpi radialis |
| FCU | Flexor carpi ulnaris |
| FDP | Flexor digitorum profundus |
| FDS | Flexor digitorum superficialis |
| FPL | Flexor pollicis longus |
| IC, ICs | Intercostal |
| iC7 | Ipsilateral C7 root |
| LHTB | Long head of triceps brachii |
| MC | Musculocutaneous |
| NT | Nerve transfer |
| PIN | Posterior interosseous nerve |
| PL | Palmaris longus |
| PQ | Pronator quadratus |
| PT | Pronator teres |
| RETS | Reversed end-to-side |
| SBRN | Superficial branch of the radial nerve |
| SBUN | Superficial branch of the ulnar nerve |
| SETS | Supercharged end-to-side |
| SS | Suprascapular nerve |
| TB | Triceps brachii muscle |

transfers. The abbreviations used in this review are gathered in Table 1.

## 2. History

As early as 1828, Flourens [1] experimented with cross-suturing of two primary mixed nerves in the wing of roosters. Wing function had recovered within a few months. A few years later, Philipeaux and Vulpian [2] observed nerve regrowth in dogs when sensory nerve fibers were joined with motor nerve fibers (lingual nerve to hypoglossal nerve). In clinical practice, Letievant [3] described a few surgical procedures and the benefits of nerve repair in the third part of his "Treatise on Nerve Injuries". He described direct repair for more recent nerve injuries and a "nerve autoplasty with flap" procedure for nerve defects. For older injuries with defects, he recommended, under the umbrella of "nerve grafting", to join the ends of a nerve "cut by injury" to another nerve that was also "cut by injury" but that was "lower and had a less important function than the recipient end". He likely performed one of the first instances of coapting of the inferior end of the median nerve on the superior end of the musculocutaneous (MC) nerve. He even referred to the concept of end-to-side suturing of the inferior end of the median nerve on the "non-damaged" MC nerve.

The first clinical results from NT were reported in maxillofacial surgery [4,5] for the treatment of facial palsy: anastomosis was performed between the external branch of the accessory nerve (EBAN) and the facial nerve [6]. In 1903, Harris and Low [7] reported end-to-side transfer of part of the distal C5 root on the intact C6 root in three cases of C5 palsy. In 1921, Harris [8] reported one case of NT of the superficial branch of the radial nerve (SBRN) on the median nerve to restore sensibility in the median territory. In 1948, Lurje reported transferring the nerve of the brachialis muscle on the distal part of the radial nerve in the arm in the context of a high lesion of the radial nerve [9] and used several NTs for upper BP lesions (C5-C6): fascicles from the triceps brachii (TB) muscle on the axillary nerve, long thoracic nerve on the suprascapular (SS) nerve and pectoral nerve on the MC nerve [10].

Later, one of the advances was the use of extraplexus donor nerves. In 1961, Seddon reported one case of NT of the 3rd and 4th intercostal (IC) nerves on the MC nerve by interposition of a nerve graft (ulnar nerve) [11]. Several years later, the technique was modified by Tsuyama and Hara who directly sutured the IC nerves on the MC nerve [12]. From then on, several teams described new NTs that mainly involved extraplexus donor nerves: EBAN (wrongly called the "spinal accessory nerve"), ipsilateral cervical plexus, contralateral pectoral nerve, phrenic nerve and contralateral C7 root.

In 1980, the work of Jabaley's team [13] became the basis for the description of NTs in future years. While a nerve has a plexiform structure (Sunderland) in the proximal portion of the limbs, its fascicles are individualized into motor and sensory elements in the distal portion (selective distal fasciculation). Nerve mapping information is essential for performing certain NT procedures.

The 1990s were a turning point when Oberlin et al. [14] described a technique to restore elbow flexion. There was renewed interest in NT and several techniques were described, some of which have been widely adopted, such as the double transfer [15,16] and transfer of a motor branch of the TB on the axillary nerve [17–19]. The common thread between these latest advances was to locate the coapting as distally as possible, which improved the functional outcomes.

## 3. Nerve transfer principles

### 3.1. Benefits of motor nerve transfer

Motor NT supplies healthy nerve fibers to an injured nerve with a key function, as close as possible to the muscle being reinnervated. The reinnervation time is reduced by locating the suture site more distally, near the neuromuscular junction. For motor NT, using a pure motor nerve or motor fascicles provides freedom from the sensory axonal environment, thereby improving the quality of nerve regrowth and functional recovery. The surgery is performed within a non-scared zone, which facilitates dissection and reduces the operative time.

### 3.2. Timing of surgery

The potential for nerve regrowth is correlated with the time elapsed before surgery and the patient's age. Denervation time alters both the nerve fibers and the muscle fibers [20]. In adults, degeneration of the motor end plate becomes irreversible after 12 to 18 months [21,22]. Thus, it is important to intervene as early as possible to take into account the nerve regrowth time, which varies depending on the NT location relative to the muscle being reinnervated. The time required for nerve regrowth plus the delay before surgery must be less than 18 months ("18-month rule" proposed by Nath and Mackinnon [21]). It is recommended that surgery be performed within 6 month of the accident, ideally between 3 and 6 months [22,23].

### 3.3. Indications and contraindications

NTs were first described for treating BP nerve root avulsions. Because of convincing results, NT indications have been extended [20,22,24] and can be considered for: