Article

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Distal anterior interosseous nerve transfer to the deep ulnar nerve and end-to-side suture of the superficial ulnar nerve to the third common palmar digital nerve for treatment of high ulnar nerve injuries

Experience in five cases

Leandro Pretto Flores

ABSTRACT

Objective: To demonstrate the results of a double nerve transfer at the level of the hand for recovery of the motor and sensory function of the hand in cases of high ulnar nerve injuries. **Method:** Five patients underwent a transfer of the distal branch of the anterior interosseous nerve to the deep ulnar nerve, and an end-to-side suture of the superficial ulnar nerve to the third common palmar digital nerve. **Results:** Two patients recovered strength M3 and three cases were graded as M4; recovery of protective sensation (S3+ in three patients and S4 in two) was observed in the fourth and fifth fingers, and at the hypothenar region. The monofilament test showed values of 3.61 or less in all cases and the two-point discrimination test demonstrated values of 7 mm in three cases and 5 mm in two. **Conclusion:** This technique of double nerve transfer is effective for motor and sensory recovery of the distal ulnar-innervated side of the hand.

Key words: anterior interosseous nerve, end-to-side suture, peripheral nerve surgery, ulnar nerve.

Transferência do nervo interósseo anterior distal para o ramo profundo do nervo ulnar e sutura término-lateral do nervo ulnar superficial ao terceiro nervo digital comum para tratamento de lesões altas do nervo ulnar: experiência em cinco casos

RESUMO

Objetivo: Demonstrar os resultados obtidos com uma dupla transferência nervosa ao nível da mão para tratamento de lesões do nervo ulnar localizadas acima do cotovelo. **Método:** Cinco pacientes foram submetidos à transferência do nervo interósseo anterior para o ramo profundo do nervo ulnar, associado à sutura término-lateral do nervo ulnar superficial ao terceiro nervo digital comum. **Resultados:** Dois pacientes recuperaram força M3 e os outros três casos foram graduados como M4. Recuperação de sensibilidade protetora (S3+ em três pacientes e S4 em dois) foi observada nos quarto e quinto dedos, além da região hipotenar. O teste de monofilamentos demonstrou valores iguais ou menores do que 3,61 em todos os casos e o teste de discriminação de dois pontos apresentou valores de 7 mm em três casos e 5 mm em dois. **Conclusão:** A técnica de dupla transferência nervosa é eficaz como modalidade de tratamento para lesões altas do nervo ulnar.

Palavras-chave: cirurgia de nervos periféricos, nervo interósseo anterior, nervo ulnar, sutura término-lateral.

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The ulnar nerve takes the first place among the traumatic palsies of peripheral nerves. For instance, 390 of the 2037 cases of peripheral nerve injuries in a series reported by Seletz[1] were ulnar nerve palsies; and 32.1% of 7050 operated cases in the American Army during the Second Word War involved this nerve[2]. A complete ulnar nerve injury results in dennervation of the intrinsic musculature of the hand and severe functional deficit, including weak grip and key pinch. The patient also develops sensory deficits at the level of the hypothenar side of the hand, the ring and the small fingers.

Despite meticulous microsurgical repair, the prognosis of an injury of the ulnar nerve at a level above the elbow is usually considered poor in terms of potential for motor recovery of the distal muscles of the hand[3]. Most of the series report results of only 20% of M4 or M5 when the repair is performed in a position above the level of the elbow, irrespective of the use of grafts[4-7]. Given the limited results obtained with the nerve repair, it has been recommended that distal tendon transfers should be offered as the first-choice surgical intervention for such cases[8,9], discouraging the nerve surgery.

A special nerve transfer technique was developed as a surgical alternative for these cases, aiming to approximate the donor axons to the recipient muscles of the hand: the transfer of a terminal motor branch of the anterior interosseous nerve to the deep ulnar nerve. Novack and Mackinnon[10], Haase and Chung[11], and Battiston and Lanzetta[12] initially reported this technique, and good outcomes in terms of motor recovery were demonstrated. However, another distal nerve transfer should complement this technique in order to provide sensory protection for the hypothenar side of the hand, the ring and the small fingers. For this purpose some nerves have been described as a potential source of sensory axons, including examples such as the transfer of the sensory palmar branch of the median nerve[12] or the third webspace contribution of the median nerve to the superficial ulnar nerve[13].

The aim of this study is to describe the surgical results obtained with the transfer of the motor branch of the anterior interosseous nerve destined to *pronator quadratus* muscle to the motor division of the ulnar nerve (the deep ulnar nerve). It also aims to present the results of a new surgical technique developed for the sensory reinnervation of the fourth and fifth fingers, i.e., an end-to-side suture of the superficial ulnar nerve to the third common palmar digital nerve.

METHOD

Since 2007, five patients sustaining injuries of the ulnar nerve at or proximal to level of the elbow were treated by distal anterior interosseous nerve transfer to the deep ulnar nerve, combined with the third common palmar digital to superficial ulnar nerve transfer via an end-to-side suture, for reinnervation of both the motor and the sensory components of the hand (Fig 1). The age of the patients ranged from eight to 40 years old (mean 25.2 years-old). There was one female and four males. The mechanism of trauma involved gunshot wound in two cases, knife or glass wound in two cases and a complex humeral fracture in one case (Table). Written informed consent was obtained from each participant and the study was carried out in accordance with the Declaration of Helsinki II.

The procedure was performed under general anesthesia, without a tourniquet inflation of the affected upper limb. In order to ascertain the absence of nerve function at the level of the wrist, electrical stimulation (Aesculap®, Tutlingen, Germany) of the ulnar nerve was performed before any intraneural dissection, and thus avoiding that neuropraxia would provide false negative results. Considering that the proximal border of the *pronator quadratus* muscle is usually positioned four fingers tips proximally from the wrist, the incision incorporated the distal third of the forearm and the region of the Guyon's canal. Firstly, the deep and superficial divisions of the ulnar nerve at the level of the Guyon's canal were identified. Then, the motor division of the ulnar nerve

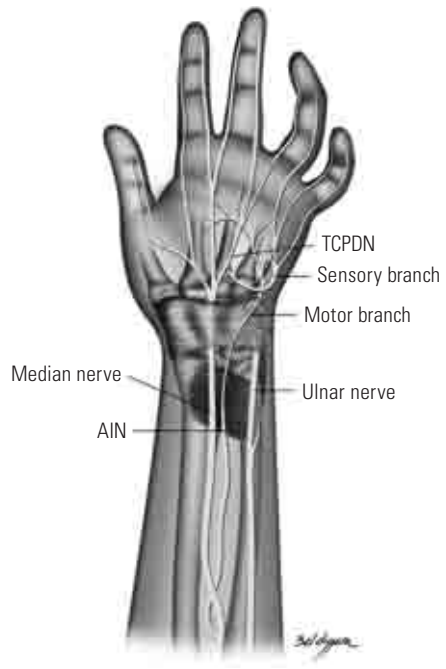

Fig 1. Schematic illustration demonstrating the surgical technique employed: the terminal branch of the anterior interosseous nerve (AIN) was sectioned and sutured to the motor branch of the ulnar nerve (deep ulnar nerve); the sensory branch (superficial ulnar nerve) was transected and sutured to the third common palmar digital nerve (TCPDN) via an end-to-side suture.

was isolated and traced proximally to the level of the proximal border of the *pronator quadratus* muscle, by means of an internal neurolysis of the ulnar nerve (Fig 2). The anterior interosseous nerve (AIN) was approached by sweeping all of the flexor tendons laterally, followed by the identification of the proximal border of the *pronator quadratus* muscle. The AIN runs over the interosseous membrane and enters the muscle centrally together with the vessel. The nerve was followed to the point where it began to branch out - which usually occurred at the midportion of the muscle - and mobilized proximally, in order to obtain a longer segment to be transposed to the ulnar nerve (Fig 3). The motor fascicle of the ulnar nerve was divided as proximally as possible and the AIN was divided at its distal-most segment into the muscle. A tension-free direct suture between both nerves was performed using two 10.0 stitches and fibrin glue. Next, the median nerve was identified at the level of the distal border of the carpal tunnel and the third common palmar digital nerve was isolated. The sensory fascicle of the ulnar nerve was divided and sutured to the third common palmar digital nerve in an end-to-side manner, using two 10.0 stitches and fibrin glue (Fig 4). An epineural window was not created on the donor nerve. The incision was sutured and the wrist was immobilized for three weeks. Following this period, sensory and motor rehabilitation was initiated immediately. Motor rehabilitation included passively movements of the fingers and wrist, active finger movements, electrical stimulation of the dennervated musculature, and pinching exercises during resisted forearm pronation. The standard sensory rehabilitation program was employed.

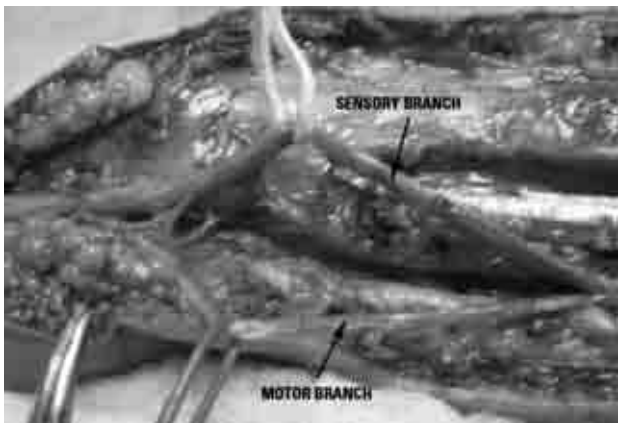

Fig 2. Operative photograph to the level of the distal forearm: the motor fascicle (motor branch) of the ulnar nerve was isolated from the sensory fascicle (sensory branch). The distal segment of the forearm is to the left side.

Fig 3. Operative photograph to the level of the distal forearm: by sweeping the flexor tendons apart, the distal segment of the anterior interosseous nerve was isolated at its point of entry at the *pronator quadratus* muscle.

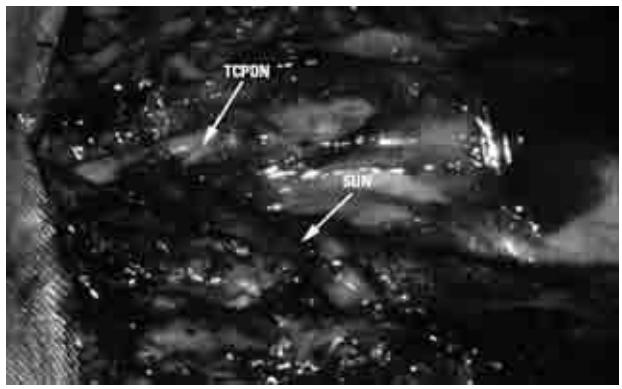

Fig 4. Operative photograph to the level of the hand: the sensory branch (Superficial Ulnar Nerve - SUN) was rotated laterally and sutured to the third common palmar digital nerve (TCPDN) by an end-to-side cooptation. The distal segment of the hand is to the left side.

Table. Summary of the characteristics of five patients submitted to surgery.

Patient	Age (years)	Local	Interval* (months)	Follow-up (months)	M.R[1]	S.R.[2]	2PD[3] (mm)	SW[4]
1	8	Axila	4	30	M4	S4	5	2.83
2	31	Infraclavicular	6	20	M4	S3	7	3.61
3	40	Elbow	10	15	M3	S3+	7	3.61
4	25	Arm	8	15	M4	S3+	7	3.61
5	22	Arm	9	18	M3	S4	5	2.83

*Interval of time between trauma and surgery; [1]Motor result; [2]Sensory result; [3]Two-point discrimination testing; [4]Semmes-Weinstein testing.

The final results were graded using the Highet-Zachary scheme (excellent: M5, S4 and Froment's sign negative; good: M3 or M4, S3+, Froment's sign negative; or poor: M3 or less, S3 or less, Froment's sign positive), in order to evaluate the surgical results regarding motor and sensory recovery. The strength of the following muscles was assessed: *abductor digiti minimi*, *opponens digiti minimi,* palmar and dorsal *interossei*, and *adutor pollicis*. Sensory recovery was measured by the Semmes-Weinstein test in order to analyze the cutaneous pressure threshold; and the Weber test, using the Dellon´s Disk-Criminator® device, was used for evaluation of the static two-point discrimination.

RESULTS

The mean time interval from injury to surgery was 7.4 months (range 4 to 10 months) and the mean postoperative follow-up time was 20 months (ranging from 15 to 30 months).

All patients demonstrated complete ulnar palsy before surgery (muscles M0 and sensory S0). All cases showed good outcomes according to the Highet-Zachary scheme, but none were classified as an excellent result because they did not demonstrated strength M5 after the follow-up period. Nonetheless, two patients were graded as S4 at the pulp of the distal phalange of the fifth finger as their final sensory result. No patient obtained a muscular power score less than MRC M3, hence no case was graded as a poor result. All patients regained good protective sensation of the fourth and fifth fingers, the middle and the distal area of the hypothenar region. Three cases were classified as S3+ and two as S4 at the end of the follow-up period. The monofilament test demonstrated values equal or less than 3.61 in all cases. The static two-point discrimination test demonstrated values of 7 mm in three cases and 5 mm in two (Table). Four patients were able to recognize a cold probe and three a warm probe head on the pulp of the involved digits.

None of the patients reported any functional deficit in performing tasks in pronation. No painful neuroma formation nor any sensory deficit at the autonomic region supplied by the third common palmar digital nerve (the medial border of the third finger and the lateral border of the fourth finger) was noted. No patient reported crossed sensory reinnervation. One subject referred light dysesthesia in the third web space two months after the procedure, but it did not required specific treatment and the symptoms disappeared in few weeks.

DISCUSSION

There are a number of different studies demonstrating that the direct repair of injuries in the ulnar nerve occurring above the level of the elbow usually result in a bad functional outcome, with minimal recovery of intrinsic muscle function and claw hand deformity[8,9]. This is especially true for injuries in adults (children usually have better prognosis) and if grafts are necessary to repair the nerve[14]. Secer et al.[7] demonstrated good outcomes (M3 or better) in only 15% of the cases sustaining gunshot injuries of the ulnar nerve at the level of the arm. A meta-analysis comparing the outcomes of proximal injuries of the ulnar and median nerve by Ruijs et al.[15] showed that ulnar nerve injuries demonstrated 71% less chance of motor recovery than the same type of injury occurring on the median nerve. Pfaeffle et al.[8] observed that all patients sustaining ulnar nerve lesions above the level of the elbow required some posterior tendon transfer for complete recovery, and Taha et al.[9] performed tendon surgery in 72% of the cases. It is usually considered that these poor outcomes occur due to the long distance between the site of the injury and the distal dennervated muscles of the hand, consequently the regenerating axons cannot provide a timely reinnervation. However, it must also be taken in account the fact that the delicate distal muscles of the hand have a small number of motor units, and that a fine central control is hard to restore.

The technique of transfer the anterior interosseous nerve to rehabilitate the motor component of the ulnar nerve has changed dramatically the prognosis of such lesions. The use of tendon transfer as the first option of treatment can be replaced by nerve surgery, aiming to obtain reinnervation of the full range of muscles supplied by the ulnar nerve at the level of the hand. Previous anatomical studies illustrated that the branch to the *pronator quadratus* is suitable for the transfer to the motor fascicle of the ulnar nerve: Wang and Zu[16] demonstrated that the number of fibers in this branch is 912±88, compared to 1216±108 in the deep motor branch of the ulnar nerve, also the diameter of these nerves is similar. Clinical studies reported good results (M4 or better) in about 85% of the cases, however the number of cases in each individual study is limited[10,12,16]. We observed good results employing this technique either: our patients recovered the strength for the grip and key pinch, in association with good opposition of the fifth finger.

The technique has many potential advantages: it is simple to perform; it does not require nerve grafts; and it approximates the nerve suture to the target muscles, decreasing the distance traveled by the axons in order to reach the muscle's end-plates. In terms of the surgical technique standpoint, we preferred to physically neurolyse the motor and sensory fascicles of the ulnar nerve (i.e., initially identifying the fascicles at the level of the Guyon's canal and then moving the intraneural dissection to the level of the distal forearm), opposed to the "visual neurolysis" proposed by Brown et al.[13] (which con-

sist in the identification of the motor fascicle by means of visual and tactile maneuvers, at the level of the takeoff of the dorsal cutaneous branch of the ulnar nerve), in order to guide the sutures to the proper targets. It is usually possible to carry out the intraneural dissection of the ulnar nerve - separating the motor and the sensory fascicles - up to the level of the distal third of the forearm, observing few interconnections between them. Employing this method, the suture to the AIN was considered tension-free in four cases, and in one patient it was necessary to slightly flex the wrist to achieve the same result.

Sensory recovery of the fourth and fifth fingers is not essential for fine manipulation of objects. Nonetheless, repeated ulcerations of the skin and all their consequences may occur if these areas are left anesthetized. Thus, sensory protection of the hypothenar area, the ring and the small fingers is an essential component of the planning for reinnervation of the hand, and it must necessarily complement the motor repair. Other authors have proposed alternative methods: Battiston and Lanzetta[12] described the transfer of the palmar branch of the median nerve to the superficial ulnar nerve. They obtained S3+ in all of their cases, but forfeited the sensory protection of the thenar region. Brown et al.[13] suggested an intraneural neurolysis of the median nerve and an end-to-end suture between a fascicle corresponding to the third webspace contribution of this nerve and the superficial ulnar nerve. This technique limits the region with sensory loss, but it still implies in the sacrifice of additional sensory protection in the affected hand. Additionally, there is the risk of generating pain of neural origin due the manipulation and section of a sensory fascicle from the healthy median nerve. The proposed transfer of the third common palmar digital nerve to the superficial ulnar nerve by an end-to-side suture proved to be as effective as the techniques previously described in terms of sensory recovery and, in our opinion, can provide advantages such as: [a] both nerves can be approached by the same incision, at the level of the palm of the hand; [b] since these nerves are very close, the distance traveled by the axons is shorter, and the time for recovery can be reduced; [c] risks associated with a painful neuroma in the suture line or pain from intraneural manipulation of a healthy nerve (complex regional pain syndrome type 1) are decreased; [d] no additional areas of anesthesia are created, nor are the pre-existing ones enlarged; this is an important factor considering that the hand already has an important sensory deficit due the ulnar nerve injury itself.

End-to-side neurorrhaphy, or terminolateral neurorrhaphy, consists of connecting the distal stump of a transected nerve to the side of an intact adjacent nerve. This technique is regarded as an extreme form of nerve transfer, which aims to minimize the functional deficit in the donor nerve. The clinical outcomes of this technique are very contradictory. Some studies reported acceptable results for selected cases (as for repair of digital nerves[17], sensory nerves[18], or small distal motor nerves[19]), while others reported no reinnervation when the technique is used in an attempt to reconstruct large mixed nerves[20,21]. The main criticism about this method - which has motivated a large number of experimental studies - lies in the fact that the functional motor recovery following the end-to-side suture is not predictable, and most authors agree that it should be reserved for cases in which sensory reinnervation is the main function to be restored. The technique proposed in the present study was designed to make the most of the main advantages offered by a terminolateral repair: relatively predictable results (as the suture was performed using two small and "sensory" nerves) and preservation of the donor nerve function. This is not the first description of the end-to-side technique in combination with the AIN-ulnar nerve transfer addressed in the literature. Brown et al.[13] described the suture of the dorsal cutaneous branch of the ulnar nerve to the lateral side of the median nerve as a method for sensory reinnervation of the dorsum of the hand. Nevertheless, the end-to-side suture of the entire superficial ulnar nerve to an adjacent digital nerve has not been reported before. From the technical standpoint, we did not perform any type of connective tissue (epineurium or perineurium) window; in fact, only an external neurolysis of the digital nerve was performed. Indeed, it is claimed that an epineural window in the donor nerve should be done in order to allow the regenerating axons to reach the recipient nerve[22]. However, experimental studies demonstrated that the end-to-side neurorrhaphy leads to sensory reinnervation of peripheral nerves territories also in cases where no window in the epineurium is performed[23]. In our cases, we observed that the connective tissues of the digital nerves were very thin and, in our opinion, the external neurolysis in combination with injuries of the epineurium caused by the sutures themselves, may cause sufficient disruption to the connective tissues so as to enable a functional regenerative process to take place.

In conclusion, this small series of five cases demonstrated that the distal nerve transfer of the anterior interosseous nerve to the deep ulnar nerve can provide good reinnervation of the intrinsic muscles of the hand, confirming the results previously reported in the literature. Moreover, the end-to side suture of the superficial ulnar nerve to the third common palmar digital nerve seems to be an effective complementary method to restore sensation of the ulnar nerve-innervated side of the hand for cases of high ulnar nerve injuries.

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