Outcome following Nerve Repair of High Isolated Clean Sharp Injuries of the Ulnar Nerve

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Abstract

Objective: The detailed outcome of surgical repair of high isolated clean sharp (HICS) ulnar nerve lesions has become relevant in view of the recent development of distal nerve transfer. Our goal was to determine the outcome of HICS ulnar nerve repair in order to create a basis for the optimal management of these lesions.

Methods: High ulnar nerve lesions are defined as localized in the area ranging from the proximal forearm to the axilla just distal to the branching of the medial cord of the brachial plexus. A meta-analysis of the literature concerning high ulnar nerve injuries was performed. Additionally, a retrospective study of the outcome of nerve repair of HICS ulnar nerve injuries at our institution was performed. The Rotterdam Intrinsic Hand Myometer and the Rosén-Lundborg protocol were used.

Results: The literature review identified 46 papers. Many articles presented outcomes of mixed lesion groups consisting of combined ulnar and median nerves, or the outcome of high and low level injuries was pooled. In addition, outcome was expressed using different scoring systems. 40 patients with HICS ulnar nerve lesions were found with sufficient data for further analysis. In our institution, 15 patients had nerve repair with a median interval between trauma and reconstruction of 17 days (range 0–516). The mean score of the motor and sensory domain of the Rosen’s Scale instrument was 58% and 38% of the unaffected arm, respectively. Two-point discrimination never reached less than 12 mm.

Conclusion: From the literature, it was not possible to draw a definitive conclusion on outcome of surgical repair of HICS ulnar nerve lesions. Detailed neurological function assessment of our own patients showed that some ulnar nerve function returned. Intrinsic muscle strength recovery was generally poor. Based on this study, one might cautiously argue that repair strategies of HICS ulnar nerve lesions need to be improved.

Introduction

Traumatic isolated ulnar nerve injuries result in function loss of ulnar wrist, dig IV and V flexion, sophisticated complex hand movements and sensory loss in the hypothenar, half of dig IV and V. It is generally held that surgical repair of ulnar nerve lesions do relatively poor as compared to, for instance, the radial and median nerve. The level of injury can roughly be divided into high or low, referring to the distance of the lesion to the sensory and motor end organs. Surgical repair of high lesions results generally in poorer outcome than in low lesions [1], [2], [3], [4], [5]. In high lesions, axons have to bridge a larger distance to the end organ than in the lower lesion. In the time needed to reach the end organ, multiple irreversible changes take place, which negatively affect outcome. For a proper interpretation of nerve surgical outcome, it is of eminent importance to group patients with similar type and level of lesion. Most articles on traumatic ulnar nerve lesions have primarily focused on wrist-level or forearm injuries [6], [7], [8], [9]. There are some papers with reference to high lesions [4], [10], [11], [12], [13], however, these papers report only mixed data (i.e. high and low injuries grouped together) and use different kinds of outcome measurements like the Rosen Score [9], percentage of good hand (Woodhall method) [2], MRC-score [10], LSUIHSC criteria [13] and the Seddon score [14]. In this study we focus on high isolated clean sharp (HICS) ulnar nerve lesions defined as lesions localized in the area ranging from the proximal forearm to the axilla just distal to the branching of the medial cord of the brachial plexus. Recently, the distal nerve transfer technique was introduced in which the anterior interosseus nerve is connected to the deep ulnar nerve motor branch for the surgical repair of ulnar nerve lesions [15], [16]. This technique can potentially be used to optimize outcomes of HICS ulnar nerve lesions. To our knowledge, 32 cases have been reported in five different papers and the results of this transfer seems promising [17], [18], [15], [19], [20]. Ideally, a distal nerve transfer should be performed as soon as possible preferably at the same time of repair of the ulnar nerve lesion in order to reduce the deleterious effects of prolonged denervation [21]. It than becomes relevant to know what the outcome can be expected from HICS ulnar nerve repair. We therefore performed a meta-analysis of the current literature of outcome following HICS ulnar nerve repair. Furthermore,
a detailed analysis of our results of microsurgically repaired traumatic high isolated ulnar nerve injuries is presented. Based on our surgical results and those identified in the literature we present a rational for the treatment of HICS ulnar nerve lesions.

Methods

Search strategy

Medline (1966–8th June 2011) was searched for published papers using both key (MeSH-terms) and text words (Table S1). Additionally a similar search was performed on Web of Science (Science Citation Index Expanded) and EMBASE (1974–8th June 2011). Articles were initially first screened by title, abstract and key words. If reference was made to clinical outcome data and ulnar nerve repair, the article was selected for further reading, Articles, whose baseline were not clear enough nor had an abstract available or could not be rejected by its key words, were selected for further reading. Reviews were also selected for further reading. Finally, reference lists of the selected articles were studied and articles that were not initially found by the search strategy were added if they had appeared after 1965.

Studies were included if they met the following inclusion criteria. (1) Ulnar nerve injury was caused by traumatic injuries resulting in clean-cut wounds or lacerations. (2) The ulnar nerve was conventionally repaired by either direct coaptation or autologous nerve grafting. (3) The injury was located in the area ranging from the proximal 1/3 part of the forearm to the axilla just distal to the branching of the medial cord of the brachial plexus. (4) Follow-up was at least two years long. (5) Injuries were isolated ulnar nerves.

The results of individual patients that met our inclusion criteria were converted from the description in the literature into the ulnar function score according to Birch [22] in order to present the data in a uniform fashion (Appendix S1). The converting algorithm was as follows: the motor outcome of each individual case was compared to the motor criteria specified in the Birch grading table. If neither of the criteria met the outcome, the next (lower) grade was compared, until finally all criteria were in accordance with the extracted outcome.

Study population

A retrospective study was performed of patients who had suffered a traumatic ulnar nerve injury between 1992 and 2009. Patients were selected from the peripheral nerve lesions database of the Department of Neurosurgery, which contains around 450 patients.

Inclusion criteria. Patients were included in our study if they had Sunderland [21] grades IV, V or Seddon’s [23] neurotmesis intra operatively determined and respectively (1) one isolated clean, sharp injury that caused transection of the ulnar nerve (2) the injury was located in the area ranging from the proximal 1/3 part of the forearm above or just below the branch of the flexor digitorum profundus III & IV to the axilla just distal to the branching of the medial cord of the brachial plexus (3) the nerve was microsurgical repaired by immediately primary suture or after an interval usually with nerve grafting to bridge a residing gap following medial transposition of the nerve (4) follow up was longer than at least 2 years.

Exclusion criteria. Patients were excluded from the study if (1) the trauma was inflicted by any form of tumor growth or (2) damage occurred due to compression, (3) contusions and (4) root avulsions.

All patients that met our inclusion criteria were invited to visit our department for extensive and detailed neurological assessment of the affected upper limb.

Classification of level of injury

HICS ulnar nerve lesions were classified according to the level of injury into three parts as follows: (a) If the lesion was located above the Flexor Carpi Ulnaris (FCU) branch the level of injury was defined as a type I. (b) When the nerve was lacerated between the FCU and the Flexor Digitorum Profundus (FDP) III & IV branch the level of injury was defined as a type II lesion. (c) When the nerve was damaged below the FDP (III & IV) branch and no more than 10 centimeter distal from the elbow crease, the injury was defined as a type III HICS lesion (Figure 1).

Ulnar nerve function-assessment

The motor function of the following muscles was assessed: FCU, FDP III and IV, Abductor Digitii Quinti (ADQ) and MRC graded according to Seddon [24] and the ulnar function score according to Birch [22]. Sensory function of digit V and the ulnar half of digit IV were graded according to the Hight Scale modified by Dellon [25], [24].

In addition, the Rosen’s Scale instrument was used as described by Rosén and Lundborg [26] and the Rotterdam Intrinsic Hand Myometer (RIHM) as described by Schreuders [27], [28], [29] for strength measurement of the intrinsic hand muscles was used.

The Rosen’s Scale instrument

The Rosen’s Scale instrument contains three domains: sensory, motor and pain/discomfort. For each of the three domains a maximum of one point can be scored. The sensory domain consists of four separate tests, both the motor and pain/discomfort domains consist of two tests each. The total score was calculated as described by Rosén. In short, in each test, points are given from zero to different maximum scores. Because the three domains consist of a different number of tests, the results are summarized and the quotient is calculated by dividing the obtained results from each domain with the unaffected hand score.

Motor domain. The motor domain consists of muscle strength which was assessed using MRC muscle power grading [30] and grip strength test (Jamar Dynamometer) [31], [32]. For

Figure 1. Classification of the type of HICS ulnar nerve injury according to the level of transection.

doi:10.1371/journal.pone.0047928.g001
the muscle power grading, the index finger abduction, as the little finger abduction and addition were examined. Grip strength was scored using the Jamar Dynamometer (set at the second handle position). The patients were instructed to flex their elbow in an angle of approximately 90 degrees and to keep their shoulder adducted during the task.

Sensory domain. Sensory function was assessed with the pocket version of the Semmes-Weinstein monofilaments (Touch Test sensory Evaluator, North Coast Medical Inc) containing five probes (score 0–5) as described by Bell-Krotoski [33]. Tactile gnosis was assessed using static two-point discrimination (s2PD) according to Moberg [34] and the shape texture identification (STI) test described by Rosén and Lundborg [35]. Three different shapes and three simple textures with increasing difficulty needed to be identified with the distal phalanx of the fifth finger. To measure finger dexterity, patients performed three tasks selected according to Moberg [34] and the shape texture identification test was repeated three times on both hands and the averages were reported on the RIHM device is expressed in Newton (N). Each resistance could be given and in these cases a “0” score was recorded.

Results

Literature search

The Medline and EMBASE search strategies identified a total of 412 articles. After removing duplicates 299 articles remained. No additional articles were found using the Science Citation Index. The screening on title, abstract and key words resulted in 47 articles for further analysis. Of these 47 articles, three papers were categorized as review without original patient series, and thus excluded [39], [40], [5]. Screening the reference lists of the 47 articles resulted in two additional articles [14], [41]. So, finally 46 articles were read in detail. Of the 46 articles, we excluded based on type of injury [42], [10], [13], [11], [4], [12], [43], [44], method of repair [45], [46], [47], [19], [18], [15], [18], level of injury [49], [50], [7], [51], [25], [9], [8], [6], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], not isolated ulnar nerve injuries [65], [41].

Ultimately eight papers did meet all our criteria and could be used for further analysis (Table 1). Seven papers presented individual patient data [66], [3], [67], [68], [14], [2], [69]. In one paper results of individual patients were not given, but were grouped by outcome [70].

From the included studies, we were able to extract 40 patients and the available data were used for transformation to the Birch score for uniformity [22] (Table 2). A good result, according to Birch was achieved in 29 of the 40 patients (72.5%). A poor result was found in six (15%) and a fair in two (5%) and three other outcomes were scored between fair and poor (7%). The mean interval between surgery and repair was 3.9 months (SD±3.67 range 0–13). Twenty-two lesions (53%) were at a high level and eighteen (45%) at intermediate level.

Results of Leiden population

Out of 280 patients surgically treated for nerve trauma, a total of 15 patients met our inclusion criteria. The average age was 30 years (range 8–62; SD±17). Patients were followed for an average of 73.3 months (range 24–146; SD±44.4) and the median delay from trauma to the surgery was 17 days (range 0–516) (Table 3). Eight of these 15 patients (53.33%) had a type I injury and seven (46.67%) had a type II or type III lesion.

| Authors & Year | No. hUN(*) | Techniques | Motor grading scale | Sensory grading scale | Motor (sensory)# |
|----------------|------------|------------|---------------------|----------------------|-----------------|
| Milli et al., 1972 | 1 (32)     | NG         | Highet              | 2PD, PTT (Protective) | M2              |
| Milli et al., 1976 | 1 (12)     | NG         | BMRC (1954)         | BMRC (1954)           | M2              |
| Morel, 1981     | 1 (10)     | NG         | Seddon (1973)       | Seddon (1973)         | M3 (32)         |
| Pluchino et al., 1981 | 1 (20) | NG         | BMRC (1954)         | BMRC (1954)           | M2              |
| Gaul, 1982      | 6 (41)     | ES         | % of normal power (WH) |                      |                 |
| Barrios et al., 1989 | 8 (44) | NG/FS/ES   | BMRC (1954)         | BMRC (1954)           |                 |
| Barrios et al., 1991 | 2 (19)  | FS         | BMRC (1954)         | BMRC (1954)           | M3 (53)         |
| Kalomiri et al., 1995 | 20 (115) | NG         | Seddon (1972)       | Seddon (1972)         |                 |

*Total Ulnar Nerves in manuscript, # Cut-off point of successful outcome in manuscript hUN High Ulnar nerve, NG Nerve grafting, FS fascicular suture, ES epineural suture, WH Woodhall Method, 2PD Two-point discrimination, PTT pain touch temperature.

doi:10.1371/journal.pone.0047928.0001

Table 1. Results of review.
Ulnar nerve function-assessment

Nine patients were willing to come for additional extra detailed neurological examination. The main reason for the remaining six patients to abstain from further detailed neurological assessment was that they themselves could not benefit from this study. Therefore, these six patients were evaluated based on the available data in their medical records.

Results of MRC motor and sensory recovery. According to the MRC scoring system five out of eight (62.5%) type I lesions, of which four patients had a detailed exam, gained a full (MRC grade 5) recovery for the FCU muscle. The best of the muscles FDP III/IV gained a full recovery in 50%. No patients regained full strength in the ADQ muscle and two patients had no recovery (MRC grade 0) at all. In the type II level group, the ADQ muscle recovered to MRC grade 4 in one patient and the other had no recovery in this muscle. The type III level group consisted of five patients of which three had a detailed exam. One patient regained strength MRC grade 4 in the ADQ muscle.

In the analysis according to the MRC score of sensory recovery in digit V four patients attained level S3/S3+, of which only one patient out of the type I level group. Four only gained sensory recovery of S1. One of them had a type II lesion and had a very long delay of more than one year before she was grafted. Sensory recovery in the ulnar part of digit IV showed a S4 result in only one patient with a type II lesion and young age. Level S3+ was gained in four patients. Two patients gained as little recovery as S1 in all three groups (Table 4).

Birch scoring system. In the analysis of motor recovery according to Birch 10 patients gained a good result (66.67%) and 5 patients (33.33%) gained a fair result. Four patients out of 8 in the type I level group, regained a good result. Of the type III level

| Authors & Year | Case (*) | A | B | C | D | E | F | G |
|---------------|---------|---|---|---|---|---|---|---|
| Milesi et al., 1972 | 1 (nr. 3) | 4 (30) | 63 (M) | 13 | 48 | Good | 4–5 | SwT – PS+ |
| Milesi et al., 1976 | 2 (nr. 36) | 3 (100) | 12 (F) | 3 | 24 | Fair | ADQ =0 | SwT – PS+ |
| Moneim, 1981 | 3 (J) | 5 (20) | 20 | 1 | 33 | Good | Proximal 5/Distal 3 | 3 |
| Pluchino et al., 1981 | 4 (1) | (90) | 16 (F) | 9 | 2 years | Poor | 2 | - |
| Gaul, 1982 | 5 (CAE) | 14 (M) | 16 | Good | AP = 84%, INT1 = 67%, | ADQ = 100% |
| | 6 (TH) | 8 (M) | 36 | Good | AP = 60% | - |
| | 7 (TH) | 7 (M) | 61 | Good | AP = 71%, INT1 = 56%, | ADQ = 95% |
| | 8 (JH) | 30 (M) | 50 | Fair/ Poor | AP = 38%, INT1 = 50%, | ADQ = 10% |
| | 9 (DG) | 54 (M) | 60+ | Fair/ Poor | AP = 35%, INT1 = 30%, | ADQ = 35% |
| | 10 (JLC) | 30 (M) | 60+ | Fair/ Poor | AP = 25%, INT1 = 26%, | ADQ = 30% |
| Barrios et al., 1989 | 11 (15) | 3 (50) | 6 (F) | 2 | 15 | Good (1–4) | 4 (0) 3 |
| | 12 (20) | 4 (40) | 19 (M) | 10 | 55 | Good (1–4) | 4 (1) 4 |
| | 13 (22) | 4 (40) | 30 (M) | 11 | 100 | Poor (2) 2+ | (1) 2+ |
| | 14 (27) | 3 (20) | 6 (F) | 3 | 21 | Good (1–4) | 4 (0) 4 |
| | 15 (28) | 4 (20) | 31 (M) | 5 | 13 | Good (1–4) | 4 (0) 4 |
| | 16 (29) | 3 (30) | 62 (M) | 5 | 3 | Good (2) 4 | (2) 3 |
| | 17 (30) | 4 (30) | 30 (M) | 0 | 47 | Good (1) 3 | (0) 3 |
| | 18 (34) | 0 (0) | 21 (M) | 1 | 31 | Poor (1) 1 | (0) 3 |
| Barrios et al., 1991 | 19 (5) | 12 (M) | 1 | Mean 2 years (1–5) | Fair | (2) 3 | 4 (0) 3 |
| | 20 (7) | 8 (F) | 1 | Mean 2 years (1–5) | Good | (0) 4 | (0) 3 |
| Kalomiri et al., 1995 | 4 cases | (55–80) | 13–28 | 4 | >2 years | Good | 4–5 | 3+-4 |
| | 6 cases | (4–13) | 7–29 | 4 | >2 years | Good | 4–5 | 3 |
| | 4 cases | (4–9) | 7–23 | 5.5 | >2 years | Good | 3 | 3+–4 |
| | 3 cases | (6–10) | 17–35 | 4 | >2 years | Good | 3 | 3 |
| | 1 case | 75 | 40 | 6 | >2 years | Poor | 2+ | 2 |
| | 1 case | 50 | 39 | 8 | >2 years | Poor | 2 | 2 |
| | 1 case | 45 | 8 | >2 years | Poor | 1 | 2 |

Column A = Gap (distance in mm), B = Age (gender), C = Delay (Months), D = Follow-up (Months), E = Birch Score, F = Motor function: (Before) After surgery, G = Sensory function: (Before) After surgery AP = adductor pollicis, INT1 = first interosseus, ADQ = Abductor digiti quinti, SwT = Sweat test negative, PS+ = Protective sensation, *identification in manuscript.

doi:10.1371/journal.pone.0047928.t002

Table 2. Details of patients after ulnar nerve repair following HICS as identified in literature review.
injuries all patients (100%) achieved a good result. So, lower location of lesion gave better results of repair (Table 4).

Rosen’s Scale instrument

The average results of the total group showed a Rosen score of 1.7 on a maximum of 3. A detailed overview of the results per domain using the Rosen’s Scale instrument can be found in Table 5.

Motor domain. In the motor domain the average of the total group showed a score of 0.58 (range 0.08–0.81; SD±0.22) on a maximum of 1. Jamar grip strength showed a mean score of 0.68 (range 0.09–0.85; SD±0.23) in the total group.

Sensory domain. With the sensory domain analysis, an average sensibility score of 0.38 (range 0.19–0.68; SD±0.14) was found. Semmes-Weinstein monofilaments test showed a mean score of 0.53 (range 0.21–0.87; SD±0.19) in the total group. For the two-point discrimination those mean was 0.04 (range 0–0.33; SD±0.11) for the total group. Type I lesions scored zero with the two-point discrimination test. Shape texture identification showed averages of 0.17 (range 0–0.67; SD±0.24) in the total group and in the type I lesions zero. Dexterity measured with three tasks from Sollerman procedure showed means of 0.77 (range 0.42–1.00; SD±0.17) in the total group.

Pain/discomfort domain. The total group of nine patients scored an average of 0.74 (range 0.33–1.00; SD±0.25) for both Cold intolerance and Hyperaesthesia. Two of the nine patients had (0.33) severe/pronounced discomforts (Table 6).

Rotterdam Intrinsic Hand Myometer

The RIHM analysis showed on average a strength (percentage of good hand) for the abduction of the index finger of 24.80 (range 0–71.76; SD±29.73) percent of the unaffected hand in the total group. The adduction of the little finger showed on average strength of 7.97 (range 0–65.12; SD±21.54) in the total group. There was zero recovery for type I lesions for the adduction of the little finger. The average regained abduction strength of the little finger was 26.4 (range 0–55.76; SD±22.59) percent for the total group (Tables 4 and 5).

Table 3. Characteristics of Leiden study group.

| Patients (N = 15) | No. of patients (%) |
|-------------------|---------------------|
| Men               | 12 (80)             |
| Women             | 3 (20)              |
| Total             |                     |
| Mean age at time of repair (range) | 29.72 years (8–62) |
| Median delay between injury and surgery (range) | 17 days (0–516) |
| Mean follow-up after surgery (range) | 75.3 months (24–146) |

Table 4. Ulnar nerve function-assessment with different scoring systems.

| Case | Level | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|------|-------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1    | Type I | + (−) | 0 (5) | 0 (4) | 0 (4) | | | | | | | | | | 3 |
| 2    | Type I | + (+) | 0 (4) | 0 (4) | 0 (0) | | | | | | | | | | 2 |
| 3    | Type I | + (+) | 0 (3) | 0 (4) | 0 (0) | | | | | | | | | | 2 |
| 4    | Type I | + (+) | 0 (5) | 0 (5) | 0 (4) | 4 | 3 | 3 | 3+ | 3 | 3 | 0 | 49.48 | 0 | 0.60 |
| 5    | Type I | + (+) | 0 (5) | 0 (5) | 0 (4) | 4 | 3 | 3 | 3+ | 3 | 3 | 71.76 | 55.76 | 0 | 0.78 |
| 6    | Type I | + (+) | 0 (5) | 0 (5) | 0 (1) | 1 | 1 | 1 | 1+ | 1 | 1 | 2 | 0 | 0 | 0.45 |
| 7    | Type I | + (+) | 0 (5) | 0 (5) | 0 (1) | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 0.53 |
| 8    | Type I | + (+) | 0 (4) | 3 (4) | 0 (3) | | | | | | | | | | 3 |
| 9    | Type II | + (+) | 2 (5) | 0 (4) | 5 | 4 | 3+ | 4 | 4 | 3 | 70.58 | 45.66 | 65.12 | 0.81 |
| 10   | Type II | + (+) | 0 (4) | 0 (0) | 1 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0.08 | 0.19 |
| 11   | Type III | + (+) | 0 (3) | 4 | 3 | 2+ | 3 | 3+ | 3 | 15.19 | 17.40 | 0 | 0.71 | 0.36 |
| 12   | Type III | + (+) | 0 (3) | 4 | 3 | 3 | 3+ | 3 | 26.14 | 35.39 | 6.59 | 0.68 | 0.48 |
| 13   | Type III | + (+) | 0 (0) | | | | | | | | | | | | 3 |
| 14   | Type III | + (+) | 3 (3) | | | | | | | | | | | | 3 |
| 15   | Type III | + (+) | 0 (4) | 4 | 0 | 3 | 3 | 3 | 3 | 39.47 | 34.26 | 0 | 0.61 | 0.41 |

Column A = Froment’s Sign, B = Flexor Carpi Ulnaris, C = Best of Flexor Digitorum Profundus III or IV, D = Abductor Digiti Quinti, E = Abduction Index finger – first dorsal interosseous muscle, F = Abduction Little finger – third palmar interosseous muscle, G = Little finger, H = Ulnar half of ring finger, I = Birch Score (Good = 3, Fair = 2), J = Abduction of index finger, K = Abduction of little finger, L = Abduction of little finger, M = Motor domain, N = Sensory domain.

*Percentage of normal hand.

doi:10.1371/journal.pone.0047928.t003

doi:10.1371/journal.pone.0047928.t004
Several clinical factors which affect peripheral nerve function recovery after nerve repair have been identified over the last decades. These are: interval between trauma and reconstruction, level of injury, type of lesion and repair and age of the patient [21].

In addition, it is well recognized that the functional outcome following repair of different individual nerves, in otherwise comparable circumstances, are not the same. In fact: “each nerve has its own story”. A widely accepted explanation for this phenomenon has not yet been provided. The intrinsic complexity of the function of the nerve seems to play a role. In order to put outcomes of treatment in perspective, it is important to document the aforementioned factors. This is especially so to correctly

**Table 5.** Leiden detailed ulnar nerve function-assessment of ulnar nerve function after repair following HICS grouped by measurement score.

| Measurement                      | Type I (N = 4) | Type II (N = 2) | Type III (N = 3) | Total (N = 9) |
|----------------------------------|---------------|----------------|-----------------|--------------|
| **Rosen’s Scale instrument**     |               |                |                 |              |
| Total score (0–3)                | 1.74 ± 0.24 (1.40–1.95) | 1.54 ± 1.33 (0.60–2.49) | 1.75 ± 0.35 (1.35–1.99) | 1.70          |
| Sensory domain (0–1)             | 0.32 ± 0.05 (0.26–0.38) | 0.43 ± 0.34 (0.19–0.68) | 0.41 ± 0.06 (0.36–0.48) | 0.38          |
| Semmes-Weinstein                 | 0.43 ± 0.16 (0.21–0.58) | 0.60 ± 0.38 (0.33–0.87) | 0.60 ± 0.06 (0.54–0.67) | 0.53          |
| 2PD                              | 0.00          | 0.17 ± 0.24 (0.00–0.33) | 0.00             | 0.04          |
| STI                              | 0.00          | 0.33 ± 0.47 (0.00–0.67) | 0.28 ± 0.10 (0.17–0.33) | 0.17          |
| Sollerman                        | 0.83 ± 0.12 (0.75–1.00) | 0.63 ± 0.29 (0.42–0.83) | 0.78 ± 0.13 (0.67–0.92) | 0.77          |
| **Motor domain (0–1)**           | 0.59 ± 0.14 (0.45–0.78) | 0.44 ± 0.52 (0.08–0.81) | 0.67 ± 0.05 (0.61–0.71) | 0.58          |
| Manual Muscle Strength Test      | 0.40 ± 0.25 (0.20–0.73) | 0.47 ± 0.57 (0.07–0.87) | 0.62 ± 0.08 (0.53–0.67) | 0.49          |
| JAMAR                            | 0.76 ± 0.07 (0.70–0.85) | 0.42 ± 0.47 (0.09–0.75) | 0.71 ± 0.04 (0.69–0.76) | 0.68          |
| Discomfort/pain domain (0–1)     | 0.83 ± 0.14 (0.67–1.00) | 0.67 ± 0.47 (0.33–1.00) | 0.67 ± 0.29 (0.33–0.83) | 0.74          |
| Cold intolerance                 | 0.83 ± 0.19 (0.67–1.00) | 0.67 ± 0.47 (0.33–1.00) | 0.67 ± 0.58 (0.00–1.00) | 0.74          |
| Hyperesthesia                    | 0.83 ± 0.19 (0.67–1.00) | 0.67 ± 0.47 (0.33–1.00) | 0.67             | 0.74          |
| **RIHM (% of good hand)**        |               |                |                 |              |
| Abduction index finger           | 17.94 ± 35.88 (0.00–71.76) | 35.29 ± 49.91 (0.00–70.58) | 26.93 ± 12.16 (15.19–39.47) | 24.80         |
| Adduction little finger          | 0.00          | 32.56 ± 46.05 (0.00–65.12) | 2.20 ± 3.80 (0.00–6.59) | 7.97          |
| Abduction little finger          | 26.31 ± 30.49 (0.00–55.76) | 22.83 ± 32.29 (0.00–45.66) | 29.01 ± 10.08 (17.40–35.39) | 26.4          |

Values in table presented as Mean ± Standard Deviation (Range).

doi:10.1371/journal.pone.0047928.t005

**Discussion**

Several clinical factors which affect peripheral nerve function recovery after nerve repair have been identified over the last decades. These are: interval between trauma and reconstruction, level of injury, type of lesion and repair and age of the patient [21]. In addition, it is well recognized that the functional outcome following repair of different individual nerves, in otherwise comparable circumstances, are not the same. In fact: “each nerve has its own story”. A widely accepted explanation for this phenomenon has not yet been provided. The intrinsic complexity of the function of the nerve seems to play a role. In order to put outcomes of treatment in perspective, it is important to document the aforementioned factors. This is especially so to correctly

**Table 6.** Ulnar nerve function-assessment of 15 patients and detailed ulnar nerve function-assessment of nine cases.

| Case | Level | A | B | C | D | E | F | G |
|------|-------|---|---|---|---|---|---|---|
| 1    | Type I | 8 (M) | L (R) | DG(55) | 201 | 92 |
| 2    | Type I | 12 (M) | R (R) | PS | 0 | 24 |
| 3    | Type I | 20 (M) | R (R) | DPS | 396 | 27 |
| 4    | Type I | 23(M) | R (R) | PS | 0 | 146 | 0.83 | 1.82 |
| 5    | Type I | 26(M) | R (R) | PS | 0 | 104 | 0.83 | 1.95 |
| 6    | Type I | 36(M) | R (R) | PS | 0 | 88 | 0.67 | 1.40 |
| 7    | Type I | 56(M) | R (R) | DPS | 68 | 74 | 1.00 | 1.79 |
| 8    | Type I | 62 (F) | L (R) | DPS | 17 | 24 |
| 9    | Type II | 11(M) | L (R) | PS | 0 | 62 | 1.00 | 2.49 |
| 10   | Type II | 49(F) | L (R) | DG(15) | 516 | 95 | 0.33 | 0.60 |
| 11   | Type III | 15(M) | L (R) | DPS | 6 | 134 | 0.83 | 1.90 |
| 12   | Type III | 18(M) | L (R) | DPS | 47 | 146 | 0.83 | 1.99 |
| 13   | Type III | 29 (F) | L (R) | DPS | 77 | 24 |
| 14   | Type III | 38 (M) | R (R) | DPS | 293 | 36 |
| 15   | Type III | 42(M) | L (R) | PS | 0 | 53 | 0.33 | 1.35 |

Column A = Age (Gender), B = Side Injured (Dominant Hand), C = Surgical Technique, D = Delay in days, E = Follow-up in months, F = Rosen Score: Pain/discomfort domain (0–1), G = Total Rosen Score (0–3).

PS Primary suture, DPS Delayed primary suture, DG Delayed graft (graft in millimeter).

doi:10.1371/journal.pone.0047928.t006
interpret and evaluate the results of specific treatment paradigms and optimize treatment strategies.

In this study we focused solely on outcome of surgical repair of isolated clean sharp injuries of the ulnar nerve located in the area ranging from the proximal forearm to the axilla just distal to the branching of the medial cord of the brachial plexus. We performed a systematic literature search and analyzed our own data. Interestingly, in the literature only forty patients could be found that met appropriate criteria for correct interpretation of outcome. Our own series consists of fifteen patients.

Unfortunately, from the literature search, we could not draw any conclusions regarding the outcome. The data in most of the articles did not allow any comprehensive analysis for which several factors were accountable. Firstly, outcomes were given in groups consisting of combined ulnar and median nerve lesions with high or low level injuries. Secondly, lesions had different causes and were either sharp or blunt or resulted from gunshot wounds. Thirdly, some papers defined high injuries as injuries above the elbow whereas others defined these levels above and around the elbow. In addition, different definitions of intermediate and low levels were applied. Fourthly, levels of injury were not explicitly stated in all of the studies. Fifthly, most of the time, outcome was only presented in general terms and recoveries of strength of the proximal and distal muscles were not stated individually. Sixthly, different motor and sensory scoring systems were used to assess pre- and post-operative severity of the symptoms and, therefore, accurate grouping of the outcome data was not possible. Finally, as a seventh factor, outcomes were not always clearly defined. All factors taken together, made it impossible to get a clear picture of ulnar nerve function outcome following HICS nerve lesion repair.

For the analysis of our own series, we defined three types of ulnar nerve injuries based on nerve anatomical levels: Type I level lesion was defined as a nerve laceration above the first segreagating FCU branch; Type II: between the FCU and the FDP branch: Type III just below the FDP branch. We used four different outcome assessments namely, MRC motor score, Birch Score, Rosen Score and the RIHM, in order to get an analysis as completely as possible.

In general, outcome of nerve repair is better when performed directly after trauma and will decline with increasing interval. Unfortunately, from our series we cannot draw any definite conclusion on intrinsic hand muscle recovery after immediate repair. It seems, however, that functional recovery of intrinsics is modest even in the setting of immediate repair. This might in part be due to misrouting of axons, and because axonal outgrowth and elongation over a relatively long distance does not take place. The ulnar nerve contains axons connected to many individual muscles. The function of these muscles is highly specialized, especially of the intrinsics. Misrouting of axons will, therefore, have a profound negative effect on the coordinated and integrated control of intrinsic muscle contraction. The effect of misrouting of axons in ulnar nerve lesions is probably higher than in, for instance, comparable radial nerve lesion. Almost all radial nerve axons are involved in one type of movement, namely extension.

The analysis of our patients showed that in most of the type I level injuries the muscle function of the proximal muscles regained good strength even those with delayed repair. The Birch Score showed that a lower location of the lesion and repair resulted in a better outcome. The analysis of motor recovery with the Birch scoring system showed that more than two third of the patients gained a good result. Transformation of the available data from the forty patients found in the literature showed a slightly higher percentage of good results (72.5%). However, recovery of the intrinsic hand muscles for abduction and adduction of the fifth digit and abduction of the index finger in our series measured with RIHM was poor in most patients. The main reason of this difference is the importance of muscles noted by these two scoring systems. A good outcome with the Birch score is already reached when the FCU and the FDP of the little and ring finger regained a MRC score of 4 or better and the intrinsic muscles attained at least MRC score 2.

The RIHM was especially developed for quantification of the strength of the intrinsic muscles and provides an objective scoring. Manual muscle strength testing applying the MRC (grades 0–5) method [24] has, although clinically widely used, specific limitations for ulnar nerve function assessment [20]. The intrinsic hand muscles are difficult to score because side-to-side movements of the fingers are partly dependent on the extrinsic muscles. In addition, the ability to assess pressure as a parameter for muscle strength depends on experience of the examiner [27].

Regarding sensory recovery in our patient group there was some restoration of sensation especially in the ulnar half of digit IV, varying between fair and good. Some of the domains of the Rosen Score showed good recovery. In the motor domain, most of the patients had good grip strength. In the sensory domain, however, only a few patients could identify shape textured objects. None of our patients scored 2-point discrimination less than 12 mm. Moberg [34] defined a good result of nerve repair when the 2-point discrimination is less than 12 mm. In the pain domain, only two of the patients had severe discomforts.

The outcome of repair may differ depending on the presence of a Martin-Gru¨ber connection [71]. The presence of such a connection should in fact be documented prior to nerve surgery with detailed electromyographic (EMG) studies. Martin-Gru¨ber connections are present in around twenty five percent of normal individuals and in varying anatomical patterns. We have not performed EMG studies systematically focused on such connections in our patient series. Therefore, we do not know whether this factor does affect our major conclusions.

The question arises whether distal nerve transfer can improve useful intrinsic hand muscle function [72]. Favorable results based on this transfer have been reported [17], [18], [15], [19], [20]. Whether distal nerve transfers will optimize outcome following repair of HICS ulnar nerve lesions needs to be further assessed. The role of a transfer of a sensory branch to the distal nerve stump [73] or side-to-side [74], [75] or distal end-to-side nerve grafts [76] in order to slow down the process of degeneration of the distal targets in HICS ulnar nerve lesions remains to be established. Based on the results of our study one might cautiously argue that there is a basis to include distal nerve transfers at the same time as HICS ulnar nerve repair.

Conclusions

From the systematic literature review, no definite conclusions could be drawn concerning outcome of HICS ulnar nerve lesion and repair. From our own series we conclude that the proximal muscles generally regained useful strength of minimal MRC 4. Intrinsic muscle recovery was poor. Based on these results we conclude that complete recovery cannot be expected. Combining HICS ulnar nerve repair with distal nerve transfers at the same time might improve outcome.

Supporting Information

Appendix S1 Birch Score for grading results of high ulnar nerve repair.

(DOC)
# References

1. Sakellarides H (1962) A follow-up study of 172 peripheral nerve injuries in the upper extremity in civilians. J Bone Joint Surg Am 44-A: 140–148.

2. Gaul JS Jr (1982) Intrinsic motor recovery—a long-term study of ulnar nerve repair. J Hand Surg Am 7: 502–508.

3. Barrios C, Amillo S, De Pablos J, Canadell J (1990) Secondary repair of ulnar nerve injury. 44 Cases followed for 2 years. Acta Orthop Scand Feb;61(1):46–9.

4. Vastamaki M, Kallio PK, Solonen KA (1993) The results of secondary microsurgical repair of ulnar nerve injury. J Hand Surg Br 18: 325–326.

5. Ruijs ACJ, Jaquet JB, Kalmijn S, Giele H, Hovius SER (2005) Median and ulnar nerve injuries: A meta analysis of predictors of motor and sensory recovery after modern microsurgical nerve repair. Plast Reconstr Surg 116: 404–494.

6. Trail IA (1985) Delayed repair of the ulnar nerve. J Hand Surg Br 10: 345–346.

7. Leclercq DC, Carlier AJ, Kluce T, Depeurples L, Lejeune GN (1985) Improvement in the results in sixty-four ulnar nerve sections associated with arterial repair. J Hand Surg Am 10: 997–999.

8. Rosen B, Dahlin LB, Lundborg G (2000) Assessment of functional outcome after nerve repair in a longitudinal cohort. Scand J Plast Reconstr Hand Surg 34: 71–78.

9. Rosen B, Lundborg G (2001) The long term recovery curve in adults after median or ulnar nerve repair: a reference interval. J Hand Surg Br 26: 196–200.

10. Trumble TE, Kuhn U, Vanderhoof E, Bach AW (1995) A technique to quantitate motor outcome following nerve grafting. J Hand Surg Am 20: 367–372.

11. Trettveit MC, Tussen C, de Jager LT, Jonn JM (1995) The functional results of ulnar nerve repair. Defining the indications for tendon transfer. J Hand Surg Br 20: 444–446.

12. Matejcik V (2002) Peripheral nerve reconstruction by autograft. Injury 33: 607–613.

13. Kim DH, Han K, Tiel RL, Murovic JA, Kline DG (2003) Surgical outcomes of 634 ulnar nerve outcomes. J Neurosurg 98: 993–1000.

14. Moneim MS (1982) Interfascicular nerve grafting. Clin Orthop Relat Res: 65–74.

15. Batiston B, Lanzetta M (1999) Reconstruction of high ulnar nerve lesions by distal double median to ulnar nerve transfer. J Hand Surg Am 24: 1185–1191.

16. Brown JM, Yee A, Mackinnon SE (2009) Distal median to ulnar nerve transfers to restore ulnar nerve power and sensory function within the hand: technical nuances. Neurosurgery 65: 966–977.

17. DeSmet L (2006) Anterior intersosseous nerve transfer to the motor branch of the ulnar nerve: a case report. Eur J Plast Surg 29: 525–529.

18. Haase SC, Chung KC (2002) Anterior intersosseous nerve transfer to the motor branch of the ulnar nerve for high ulnar nerve injuries. Ann Plast Surg 49: 283–290.

19. Novak CB, Mackinnon SE (2002) Distal anterior intersosseous nerve transfer to the deep motor branch of the ulnar nerve for reconstruction of high ulnar nerve injuries. J Reconstr Microsurg 18: 459–464.

20. Wang Y, Zhu S (1997) Transfer of a branch of the anterior interosseus nerve to the median nerve in the forearm. J Hand Surg Am 22: 390–397.

21. Dellon AL, Curtis RM, Edgerton MT (1974) Reeducation of Sensation in Hand Injuries. JAMA 224: 444–446.

22. Novak CB, Mackinnon SE (2002) Distal anterior interosseous nerve transfer for high ulnar nerve injuries. Ann Plast Surg 49: 285–290.

23. Mathiowetz V, Weber K, Volland G, Kashman N (1984) Reliability and Validity of Grip and Pinch Strength Evaluations. J Hand Surg Am 9A: 222–226.

24. Bell-Krotoski JA (2009) Sensitivity testing: current concepts. In: Hunter JM (Ed) JCA, editor. Rehabilitation of the hand: surgery and therapy 4th ed St Louis: Mosby. 1995:109–128.

25. Moebreg E (1998) Two-point discrimination test. A valuable part of hand surgical rehabilitation, e.g. in tetraplegia. Scand J Rehabil Med 22: 127–134.

26. Rosen B, Lundborg G (1998) A new tactile gnosis instrument in sensibility testing. J Hand Ther 11: 251–257.

27. Schreuders TA, Selles RW, Roebroeck ME, Stam HJ (2006) Strength Comparing manual muscle strength testing, grip and pinch strength dynam- et al. measurement of the intrinsic hand muscles: a review of the development and measurement of outcomes for nerve repair. J Hand Surg Am 25A: 535–543.

28. Schreuders TA, Selles RW, Roebroeck ME, Stam HJ (2006) Strength measurements of the intrinsic hand muscles: a review of the development and evaluation of the Rotterdam intrinsic hand myometer. J Hand Ther 19: 393–401.

29. Schreuders TAR, Roebroeck ME, Jaquet JB, Hovius SER, Stam HJ (2004) Long-term outcome of muscle strength in ulnar and median nerve injury: Comparing manual muscle strength testing, grip and pinch strength dynamometers and a new intrinsic muscle strength dynamometer. J Rehabil Med 36: 273–276.

30. Schreuders TAR, Roebroeck ME, Jaquet JB, Hovius SER, Stam HJ (2004) Measuring the strength of the intrinsic muscles of the hand in patients with ulnar and median nerve injuries. Reliability of the Rotterdam Intrinsic Hand Myometer (RIHM). J Hand Surg Am 29A: 318–324.

31. Seddon HJ (1954). Peripheral nerve injuries Medical Research Council Special Report Series 282: London: Her Majesty’s Stationery Office.

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**Table S1 Literature search strategy.**

**Author Contributions**

Conceived and designed the experiments: RP MM. Performed the experiments: RP. Analyzed the data: RP. Contributed reagents/materials/analysis tools: RP. Wrote the paper: RP KdB MM.
59. Bruyns CN, Jaquet JB, Schreuders TA, Kalmijn S, Knypers PD, et al. (2003) Predictors for return to work in patients with median and ulnar nerve injuries. J Hand Surg Am 28: 20–24.
60. Jazayeri M, Ghavanini MR, Rahimi HR, Raissi GR (2003) A study of the sympathetic skin response and sensory nerve action potential after median and ulnar nerve repair. Electromyogr Clin Neurophysiol 43: 277–279.
61. Mitz V, Meriaux JL, Vihain R (1984) Functional sequelae after ulnar nerve repair. Study of forty-nine cases. Ann Chir Main 3: 193–203.
62. Donzelli R (1998) Microsurgical nervous reconstruction using autografts: a two-year follow-up. J Neurosurg Sci 42: 79–83.
63. Bolitho DG, Boustred M, Hudson DA, Hodgetts K (1999) Primary epineural repair of the ulnar nerve in children. J Hand Surg Am 24: 16–20.
64. Galanakos SP, Zoubos AB, Ignatiadis I, Papakostas I, Gerostathopoulos NE, et al. (2011) Repair of complete nerve lacerations at the forearm: An outcome study using Rosen-Lundborg protocol. Microsurgery. 2011 May; 31(4): 253–262.
65. Hurst LC, Dowd A, Sampson SP, Badalamente MA (1994) Partial lacerations of median and ulnar nerves. J Hand Surg Am 16: 207–210.
66. Barrios C, de Pablos J (1991) Surgical management of nerve injuries of the upper extremity in children: a 15-year survey. J Pediatr Orthop 11: 641–645.
67. Millesi H, Meisel G, Berger A (1976) Further experience with interfascicular grafting of the median, ulnar, and radial nerves. J Bone Joint Surg Am 58: 209–218.
68. Millesi H, Meisel G, Berger A (1972) The interfascicular nerve-grafting of the median and ulnar nerves. J Bone Joint Surg Am 54: 727–750.
69. Pluchino F, Luccarelli G (1981) Interfascicular suture with nerve autografts for median, ulnar and radial nerve lesions. Ital J Neurol Sci 2: 139–146.
70. Kalomiri DE, Souacous PN, Beris AE (1995) Management of ulnar nerve injuries. Acta Orthop Scand Suppl 264:41–4: 41–44.
71. Rodriguez-Niedenfuhr M, Vazquez T, Parkin I, Logan B, Satudo JR (2002) Martin-Gruber anastomosis revisited. Clin Anat 15: 129–134.
72. Tung TH, Mackinnon SE (2010) Nerve transfers: indications, techniques, and outcomes. J Hand Surg Am 35: 332–341.
73. Elshemy A, Butler R, Bain JR, Fahnestock M (2009) Sensory protection of rat muscle spindles following peripheral nerve injury and reinnervation. Plast Reconstr Surg 124: 1060–1068.
74. Ladak A, Schembri P, Olson J, Udina E, Tyreman N, et al. (2011) Side-to-side nerve grafts sustain chronically denervated peripheral nerve pathways during axon regeneration and result in improved functional reinnervation. Neurosurgery 68: 1634–1645.
75. Zhang S, Ji F, Tong D, Li M (2012) Side-to-side neurorrhaphy for high-level peripheral nerve injuries. Acta Neurochir (Wien) 154: 527–532.
76. Kale SS, Glau SW, Yee A, Nicolson MC, Hunter DA, et al. (2011) Reverse end-to-side nerve transfer: from animal model to clinical use. J Hand Surg Am 36: 1631–1639.