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A Systematic Review of Outcomes of Contralateral C7 for the Treatment of Traumatic Brachial Plexus Injury: Part 2-Donor-site morbidity of contralateral C7 transfer for traumatic brachial plexus injury

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Abstract

Background—Although contralateral C7 (CC7) transfer has been widely used for treating traumatic brachial plexus injury, the procedure safety is questionable. We performed a systematic review to investigate the donor-site morbidity including sensory abnormality and motor deficit to guide clinical decision-making.

Methods—A systematic review on CC7 transfer for traumatic brachial plexus injury was performed for the original articles in PubMed and EMBASE databases. Patient demographic data and donor-site morbidity of CC7 transfer including incidence, recovery rate and time were extracted from the included studies. The sensory abnormality areas and muscles involved in motor weakness were also summarized.

Results—A total 904 patients from 27 studies were reviewed. Overall, 74% of patients (668/897) experienced sensory abnormalities, and 98% of patients (618/633) recovered to normal; the mean recovery time was 3 months. For motor function, 20% of patients (118/592) had motor deficit after CC7 transfer and 91% (107/117) regained normal motor functions; mean recovery time was 6 months. Sensory abnormality mainly happened in the median innervated area of the hand, whereas motor deficit most often involved radial nerve innervated muscles. There were 2% of patients (19/904) with long-term morbidity of donor site in the studies.

Conclusions—The incidence of donor-site morbidity after CC7 transfer was relatively high, and severe and long-term defects occurred occasionally. CC7 transfer should be indicated only when other donor nerves are not available, and with a comprehensive knowledge of the potential risks.

Level of evidence—Level III

Keywords

Traumatic Brachial Plexus Palsy; Contralateral C7 transfer

INTRODUCTION

Brachial plexus injury is a relatively frequent condition and is caused mainly by traumatic accidents resulting in complex functional impairment and disability of the upper limb.¹ Nerve transfer is a major advancement for treating this injury. Shoulder and elbow functions are the main priorities of nerve reconstruction, whereas hand and finger functions might not be addressed because of insufficient donor nerve resources, especially in total brachial plexus avulsion injuries. Thus, there is a great need to seek new transferable sources of nerve to restore the limb functions adequately.²

In the 1980s, some surgeons noticed that an isolated C7 nerve severance did not result in significant motor and sensory defects in the patients.^{2, 3} Based on this finding, Gu designed the healthy C7 as donor nerve to repair the injured nerves on the opposite side for treatment of traumatic brachial plexus avulsion injury.⁴ Contralateral C7 (CC7) has been widely applied for nerve transfer and functional free muscle neurotization, especially in some Asian countries.^{5, 6, 7} However, the safety of CC7 transfer still remains questionable. On the one side, abandoning this procedure because of fears for donor-site morbidity may lose a valuable donor nerve for useful function reconstruction. On the other side, transecting normal C7 nerve without a thorough understanding of risks may cause irreparable damage to the remaining useful limb. To provide the best evidence to guide clinical decision-making, we performed a systematic review based on the available data collected from the clinical reports to assess the donor-site morbidity of CC7 transfer for the treatment of traumatic brachial plexus injury.

MATERIALS AND METHODS

Literature Search

A systematic search of literature using PubMed and EMBASE databases from January 1986 to April 2014 was conducted to identify original articles related to CC7 transfer for traumatic brachial plexus injury following the PRISMA guideline⁸. PubMed and EMBASE cover over 24 million citations for biomedical literature including MEDLINE and life science journals with English abstracts for non-English articles. We chose these two databases to maximize our search. “C7” or “C-7” or “seventh cervical nerve” and “brachial plexus” were used as terms to search abstract and title. Among 759 articles identified from the first search, 464 were yielded after removal of duplicate articles. Two reviewers (G.Y. and K. W. C. C) who were trained in systematic review techniques screened the titles and abstracts according to the predetermined inclusion and exclusion criteria. For the articles showing insufficient information in the title and abstract for inclusion and exclusion, a full article review was performed to make a clear decision.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria are indicated in Table 1. We excluded studies from review if they met any of the following exclusion criteria: (1) review article, (2) without CC7 transfer report, (3) CC7 transfer without morbidity of donor-site report, (4) CC7 transfer for neonatal brachial plexus injuries, (5) data duplication from the same author, (6) lacking extractable data in the study.

Data Extraction and Summaries

After full-text review, two reviewers (G.Y. and K. W. C. C) independently extracted data from the included studies. The following study patient demographic data and descriptive statistics were extracted: study published year, location, patient number, gender, age at time of surgery, CC7 type, follow-up period, number of patients who had donor-site sensory abnormality and motor deficit after CC7 transfer. If the individual patient demographic information was not available, we used the reported overall mean value.

In this systematic review, we reported donor-site morbidities based on CC7 types: overall, whole CC7 and partial CC7. The studies that stated that the whole CC7 was transected were considered “whole”; partial CC7 such as anterior and posterior parts, posterosuperior and anteriosuperior halves, and motor rootlets of CC7 were all categorized as “partial.” We extracted the highest evidence available on incidences, recovery rates, and mean recovery time after initial sensory abnormality and motor deficit. Because most extractable studies reported 3 months as the cut-off point for recovery time we dichotomized the recovery from sensory abnormality into groups based on recovery within 3 months or abnormality persisting longer than 3 months. Sensory abnormality included patient-reported and/or physician-measured numbness, hyperalgesia, hypoalgesia, and abnormal two-point discrimination. Motor deficit recovery was likewise dichotomized into groups based recover within or longer than 6 months. Motor deficit included CC7-innervated motor weakness measured by physical examinations or instruments.

We also summarized the sensory abnormality areas and muscles involved in motor deficit to demonstrate common functional losses after CC7 transfer.

For long-term and severe donor-site morbidity, the number and clinical symptoms of the patients who did not recover at the final follow-up visit in the included studies were summarized.

RESULTS

Study and Patient Demographic Characteristics

Database search and number of studies retrieved and excluded are presented in Figure 1 and all the included articles are presented in Appendix I. Among 27 included studies, there was one prospective randomized control trial;⁹ all others were retrospective studies.^{7, 10–34} The studies were divided into whole CC7 (n=16) and partial CC7 (n=11). Three studies reported two CC7 types,^{9, 12, 25} and the CC7 type was not available in 3 studies^{10, 13, 33} that were only included in overall study (Table 2).

A total of 904 patients were included in this systematic review. Overall, 93% of patients (471/507) were male with mean age 25 years and the average follow-up period was 41 months (Table 3). For 378 patients in the whole CC7 group, 91% were male (221/243), mean age was 26 years, and mean follow-up period was 40 months. For 405 patients in the partial CC7 group, 98% of the patients were male (140/143), mean age was 24 years, and mean follow-up period was 38 months.

Summaries of Donor-Site Morbidity of CC7 Transfer

The summaries of donor-site morbidity are presented in Table 3. Regardless of CC7 types, 74% of patients (668/897) developed sensory abnormality after CC7 was harvested. Recovery rate was available for 633 patients and was 98%, and mean recovery time was 3 months. Recovery period was reported for 260 patients; 85% recovered within 3 months, whereas 15% were still experiencing sensory abnormalities at 3-month follow-up time point. Weakness at the donor site was experienced by 118 of 592 patients (20%) with 91% (107/117) recovery rate. Mean recovery time was 6 months, and 95% (61/64) recovered within 6 months.

The incidence of sensory abnormality in the whole CC7 group was 79% (293/371) with a recovery rate of 96% out of 258 patients. The mean recovery time was 3 months and 83% (137/166) recovered within 3 months. Motor deficit incidence was 29% (56/196) with an 89% (49/55) recovery rate. Mean recovery time was 6 months; 91% (10/11) patients recovered within 6 months.

The incidence of sensory abnormality in the partial CC7 transfer group was 67% (271/405), and 98% (266/271) recovered to normal. The mean recovery time was 3 months, the same as the whole CC7 group. Forty-one of 52 patients (79%) regained normal sensation within 3 months, whereas the remaining 21% required more than 3 months. Motor deficit incidence was 15% (58/375) with a recovery rate of 95% (55/58). Mean recovery time was 5 months, shorter than that of whole CC7 transfer. Within 6 months, 96% of patients had recovered.

Sensory Abnormality Area

The most frequent areas experiencing sensory abnormality were the median nerve area of the hand, especially in the thumb (25%), index finger (37%), middle finger (24%) and palm (7%) (Figure 2). Abnormal sensations in the radial side of forearm (1%), anterolateral aspect of upper arm (1%) and shoulder (1%) were also reported.

Involved Muscles of Motor Deficit

In 348 involved muscles, the most commonly affected by motor weakness was the triceps (36%), followed by hand grip (27%), extensor digitorum communis (16%) and wrist extensor (10%) (Figure 3). Less frequent motor weakness involved latissimus dorsi (4%), wrist flexor (3%), elbow flexor (1%) and finger flexor (3%) from some studies.

Donor-Site Long-term Morbidity

Among 904 included patients, 19 patients in 7 studies (2%) did not completely recover from functional loss within the follow-up period.^{9, 12, 13, 15, 16, 30, 34} Seven of them had both

sensory and motor function deficits. Fifteen patients in 3 studies did not have complete recovery from sensory abnormality.^{9, 15, 30} Eleven patients in 6 studies with motor weakness did not recover by the latest follow-up period.^{9, 12, 13, 16, 30, 34} Among them, 3 patients sustained severe motor deficits including loss of hand muscle functions; 2 patients required subsequent tendon transfer.^{9, 12, 30} Clinical symptoms of all 19 patients are presented in Table 4.

DISCUSSION

Reports of temporary donor site functional deficits after C7 transection were not uncommon in the current literature.^{7, 19, 23, 29, 31–33, 35, 36} In this systematic review, we demonstrated that the majority of patients (74%) suffered sensory abnormalities, and 98% of patients recovered, generally within 3 months. Compared to sensory abnormality, motor functional morbidity was experienced less frequently (20%). The recovery rate of motor deficit was 91% (107/117), and mean recovery time was 6 months. The high incidences of temporary donor limb functional deficits after CC7 transfer might be attributed to the complex anatomical characteristics of C7.^{2, 36} There is no terminal branch off from C7 root directly. Axons from C7 intertwine with other roots before coming into the terminal branches. Therefore, there is no absolute sensory dominance and single muscle innervated by C7 alone. Denervation of C7 could product reduced sensation and muscle weakness rather than complete loss of function, and, in theory, these deficits would be compensated by axons from other roots.

Our results showed whole CC7 section resulted in higher donor-site morbidity incidence and lower recovery rate than partial CC7 for both in sensory abnormality and motor deficit. Our results were similar to the prospective randomized control trial conducted by Tu in 2014.⁹ In their study, 15% of the patients (3/20) developed morbidity in the donor limb in the partial CC7 group, whereas 30% (6/20) patients in the whole CC7 group did. There was a significantly higher incidence of donor-site morbidity after whole CC7 transection. These coincident results imply that sectioning more fibers of CC7 will contribute to the higher risk of morbidity. In our results, mean recovery time for motor deficit in the whole CC7 group (6 months) was longer than that of the partial CC7 group (5 months). However, mean recovery time for sensory abnormality was the same (3 months) in both groups. This may be an artifact of small sample size and heterogeneity of the samples. There were more patients in the partial group (21%, 11/52) than the whole group (17%, 29/166) who required more than 3 months to recover. However, the 11 patients in the partial group were reported by one study⁷ and might not represent the entire patient population.

Depending on which part of CC7 was served, the incidence of donor-site morbidity following partial CC7 transfers varied dramatically. For example, transecting part of CC7 that most contains sensory fibers would cause high sensory and low motor morbidity incidence. In Sammer's study, the anterosuperior half of the C7 that contains more sensory fibers was divided and transferred to preserve the portions providing wrist and hand motion.³⁰ All 55 patients reported subjective abnormality in sensation and but only 18 patients (33%) had motor weakness at the donor site immediately after surgery. On the other

hand, Bertelli reported there was not any sensory disturbance after C7 motor rootlet transfer, but 75% of patients experienced motor deficit.¹⁹

Sensory abnormality mainly happened in the median innervated area of the hand, whereas motor deficit most often involved radial nerve innervated muscles. These findings are in accordance with the main dominance of C7 root.³⁵ Nevertheless, because C7 roots are widely contributed to the posterior, medial and lateral cord of the brachial plexus,³⁷ sensory abnormality in other areas and motor weakness in flexor muscles were also detected occasionally.

Although rare, 2% of patients remained without complete donor-site morbidity recovery in the long term.^{9, 12, 13, 15, 16, 30, 34} Notably, in 2 cases hand muscle weakness was severe enough (M3) to affect daily activities, and therefore needed tendon transfer.^{9, 30} Intrinsic hand muscles are mostly innervated by C8 and T1, not C7.³⁸ Hence, anatomic variation may be the reason for these serious morbidities. For example, donor-site deficits will happen following C7 transfer³⁹ if there is a prefixed plexus with a substantial C4 or postfixed plexus with T2 contribution and a diminished C5 component.³⁹

Several studies offered recommendations to safely perform CC7 transfer.^{23, 39, 11, 40, 41} First, the C7 transection site should not be too distal to injury the fibers branching off from upper and lower trunks.⁴¹ Second, exploration of all five roots is recommended to identify normal anatomic relationships of a prefixed or postfixed plexus.³⁹ Third, intraoperative use of electromyography is helpful to exclude significant anomalous innervation before C7 transection.^{11, 23, 40} However, currently there is no widely accepted method to anticipate the functional loss of C7 either before or during harvest.

There are several limitations in this systematic review. First, elimination of some non-English studies may reduce the power of this review. Furthermore, most included studies were retrospective uncontrolled studies with small number of patients. In addition, the heterogeneity of the case series, especially regarding different partial CC7 parts and multiple donor-site morbidity varieties, did not allow for the comparison of different subgroups and might confound the study summaries. Lastly, we did not explore the potential for neuropathic pain owing to divisions of the normal C7 nerve. This complication had been only mentioned in a few studies with insufficient case numbers and limited extractable information so was not able to draw a useful conclusion. We suggest cooperation among multiple centers to conduct a prospective outcomes study with independent examination of participants to more precisely define donor-site morbidity after CC7 transfer.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Figure 1. Flow diagram of database search and number of studies retrieved and excluded from review; see Appendix I for all included articles.

Figure 2.
Sensory abnormality areas in 403 patients after CC7 transfer

Figure 3.
Involved muscles of motor deficit resulting from CC7 transfer. *Percentage added up to 99.8 because of rounding.

Table 1**Inclusion and exclusion criteria**

Inclusion criteria	
Literature style	
Original article	
Human subjects	
Published from Jan 1, 1986 to April 1, 2014	
Treatment option	
Whole or partial contralateral C 7 transfer to the injured nerve or free muscle for treatment of traumatic brachial plexus injury	
Report of donor-site morbidity after CC7 transfer (at least 1 of following)	
Sensory abnormality with/without recovery time	
Motor deficit with/without recovery time	
Exclusion criteria (at least 1 of following)	
Review article	
Without CC7 transfer report	
CC7 transfer without morbidity of donor-site report	
CC7 transfer for neonatal brachial plexus injuries	
Data duplication from the same author	
Lacking extractable data in the study	

Table 2
Study and patient demographics, number of patients with donor-site morbidity of CC7 transfer[§]

Study	Location	N	Male	Age, y	CC7 Type (part)	Follow-up, mo	Sensory Abnormality N	Motor Defect N
Gu 1992 ¹⁰	Shanghai, China	49	46	29	NA	NA	42	NA
Holland 1997 ¹¹	Baltimore, USA	1	1	33	Whole	NA	1	1
Liu 1997 ¹²	Singapore	1	1	26	Partial (anterior division)	24	1	1
		1	1	19	Whole	18	1	1
Chuang 1998 ¹³	Taipei, Taiwan	21	18	22	NA	52	11	4
Bertelli 1999 ¹⁴	Santa Catarina, Brazil	1	1	26	Partial (motor rootlets)	24	0	1
Sungpet 1999 ¹⁵	Bangkok, Thailand	24	23	27	Whole	NA	24	NA
Waikakul 1999 ⁷	Bangkok, Thailand	96	96	27	Partial (anterior part of C7 root)	36	11	15
Songcharoen 2001 ¹⁶	Bangkok, Thailand	111	NA	NA	Partial (posterosuperior half)	NA	108	3
El-Gammal 2002 ¹⁸	Assiut, Egypt	7	7	26	Whole	35	NA	1
Ali 2002 ¹⁷	Baltimore, USA	5	3	25	Whole	NA	2	1
Bertelli 2004 ¹⁹	Santa Catarina, Brazil	24	23	22	Partial (motor rootlets)	36	0	18
Hattori 2005 ²⁰	Oguri, Japan	3	2	7	Whole	47	3	0
Hierner 2007 ²¹	Leuven, Belgium	10	NA	NA	Partial (NA)	60	10	0
Xu 2008 ²²	Shanghai, China	8	8	30	Whole	12	8	NA
Terzis 2009 ²³	Norfolk, USA	56	NA	23	Partial (NA)	73	40	0
Zou 2010 ²⁵	Qingdao, China	34	NA	NA	Whole	18	34	NA
		30	NA	NA	Partial (anterior part)	18	30	NA
Feng 2010 ²⁴	Shanghai, China	4	3	26	Whole	32	4	4
Bertelli 2011 ²⁶	Santa Catarina, Brazil	1	1	20	Partial (motor rootlets)	20	0	0

Study	Location	N	Male	Age, y	CC7 Type (part)	Follow-up, mo	Sensory Abnormality N	Motor Defect N
Lin 2011 ²⁷	Shanghai, China	10	6	26	Whole	39	8	5
Muhetdier 2011 ²⁸	Urumqi, China	22	22	33	Whole	18	13	4
Chuang 2012 ²⁹	Taoyuan, Taiwan	101	NA	23	Whole	48	37	11
Sammer 2012 ³⁰	Rochester, USA	55	NA	NA	Partial (anterosuperior half)	16	55	18
Wang 2012 ³¹	Beijing, China	41	37	29	Whole	47	41	NA
Gao 2013 ³²	Shanghai, China	22	20	26	Whole	76 [£]	22	22
Gao 2013 ³³	Shanghai, China	51	46	29	NA	83 [£]	51	NA
Wang 2013 ³⁴	Beijing, China	75	70	28	Whole	57	75	NA [‡]
Tu 2014 ⁹	Tainan, Taiwan	20	18	27	Whole	72	20	6
		20	18	27	Partial (anterosuperior half)	72	16	2

[§]N, number of patients; y, year; mo, month; NA, not available;

[£]These data were not counted in mean recovery time because of the extreme long period in the studies.

[‡]The number of patient who had motor deficit were not available, but one patient had long-term motor deficit in this study.

Table 3

Summaries of donor-site morbidity of CC7 transfer (The data were extracted from different available studies.)[§]

Study N	Patient N	Male, % (N)	Mean Age ± SD, y	Mean Follow- up period ± SD, mo	Sensory Abnormality			Motor Deficit					
					Incidence % (N)	Recovery Rate % (N)	Recovery Time % (N)	Incidence % (N)	Recovery Rate % (N)	Recovery Time % (N)			
					Mean Recovery Time± SD, mo			Mean Recovery Time± SD, mo					
					3 mo			6 mo					
					> 3 mo			>6 mo					
Overall	27 [†]	904	25±5	41±22	74% (668/897)	98% (618/633)	85% (220/260)	15% (40/260)	20% (118/592)	91% (107/117)	6±6	95% (61/64)	5% (3/64)
Whole CC7	16	378	26±6	40 ±21	79% (293/371)	96% (248/258)	83% (137/166)	17% (29/166)	29% (56/196)	89% (49/55)	6±8	91% (10/11)	9% (1/11)
Partial CC7	11	405	24±3	38±22	67% (271/405)	98% (266/271)	79% (41/52)	21% (11/52)	15% (58/375)	95% (55/58)	5±5	96% (51/53)	4% (2/53)

[§]N, number; y, year; mo, month;

[†]Three studies^{9, 12, 25} reported two CC7 types, and the CC7 types were not available in 3 studies^{10, 13, 33}, so there were 27 studies.

Table 4

Long-term functional defects of CC7 transfer in the included studies[§]

Study	Patient N	CC7 Type (Part)	Follow-up Period, mo	Sensory Abnormality	Motor Deficit
Liu 1997 ¹²	1	Partial (anterior division)	24		Power in elbow extension, forearm pronation, wrist flexion and all hand movements of grade 4 or less. Thumb and digit functions in particular were severely affected. Hand grasp, key pinch, and three-jaw pinch were graded as 0 up to 2 weeks after surgery. The motor functional deficits began to recovery at 10 days. Small muscles of the hand were still weaker at 1 year after surgery. However, recovery continued even at 2 years after surgery.
Chuang 1998 ¹³	1	NA	24		The patient had the triceps weakness lasting for 2 years.
Sungpet 1999 ¹⁵	1	Whole	20	Had sensory abnormalities on the tip of index finger for more than 20 months after operation. There was slight atrophy at the tip of index finger with wrinkled volar skin, but no ulcer was found.	
Songcharoen 2001 ¹⁶	1	Partial (posterolateral half)	36		The patient had M2 isolated weakness of the extensor digitorum communis that gradually improved to M4 over 3 years.
Sammer 2012 ³⁰	1	Partial (anterosuperior half)	24	The patient had 9-mm two-point discrimination at the time of the latest follow-up two years postoperatively. This was not bothersome to the patient.	
	1	Partial (anterosuperior half)	10	The patient had 15-mm two-point discrimination at the time of the latest follow-up ten months postoperatively, and sensory loss was associated with neuropathic pain. The pain was managed successfully with non-narcotic analgesics.	The patient had M2-M3 weakness in the median and ulnar nerve distributions in the hand, including loss of intrinsic and thenar function, and loss of FDP and FDS function. The patient required tendon transfer on the donor side.
Wang 2013 ³⁴	1		12		The muscle strength of the EDC decreased to M0 and that of triceps decreased to M2 postoperatively, and they recovered to M3 and M4, respectively, 12 months postoperatively.
Tu 2014 ⁹	9	Whole	72	Nine patients developed donor site complications including paresthesia of the donor limb for more than 6 months.	Six of these 9 patients developed motor weakness of the donor limb. One of them suffered from weakness (M3) of FDP and intrinsic muscle function. The patient needed a subsequent tendon transfer.

Study	Patient N	CC7 Type (Part)	Follow-up Period, mo	Sensory Abnormality	Motor Deficit
	3	Partial (anterosuperior half)	72	Three patients developed numbness on the index pulp and paresthesia of the NM area of the palm that lasted for more than 6 months.	

§N, number; mo, month; NA, not available; FDS, flexor digitorum superficialis; FDP, flexor digitorum profundus; EDC, extensor digitorum communis