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TITLE: Supporting Patient Decisions about Upper Extremity Surgery
in Cervical Spinal Cord Injury

PRINCIPAL INVESTIGATOR: Ida K. Fox, M.D.

CONTRACTING ORGANIZATION: Washington University School of Medicine,
St. Louis, MO 63110

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Ida K. Fox, M.D.

E-Mail: foxi@wustl.edu

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14. ABSTRACT

Year 2 Progress Report:
Purpose: To define and communicate information about upper extremity (UE) function in spinal cord injury (SCI).
Scope: Review information about spontaneous recovery and prospectively investigate recovery with and without surgical intervention.
Major Findings: People with cervical SCI have variability in their ability to perform activities of daily living (ADL's) and health related quality of life (QOL). Surgical intervention is associated with a decreased ability to perform ADL's in the short term. This effect is most prominent in those undergoing tendon compared to nerve transfer surgery.
Results:

1. To date, 23 people with mid-level cervical SCI have completed both the baseline and early follow up (or post-surgery) study procedures. Participants were majority male (75%) with mean age of 39 and over half (52%) were veterans.
2. All participants reported changes in the various domains of the SF-36 health related quality of life measures over time; these including physical functioning, role limitation, energy/fatigue, emotional well-being, social functioning, pain, and general health.
3. Surgery participants had a decrease in their self-reported ability to do activities of daily living as measured by the SCIM (Spinal Cord Independence Measure). Individuals undergoing tendon compared to nerve transfer surgery had a more pronounced decrease in SCIM scores.

15. SUBJECT TERMS
Spinal cord injury, SCI, tetraplegia, nerve transfer surgery, tendon transfer surgery, rehabilitation, caregiver, upper extremity function, hand function

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1. INTRODUCTION:

The overarching aim of this project is to define key information about improvement of upper extremity function after spinal cord injury (SCI) (time and extent of recovery, outcome of surgical and non-surgical interventions and the experience thereof) and communicate this information to patients and clinicians to support their treatment decisions. This will be achieved through the following three aims:

Aim 1: Using the EMSCI database initially and unbiased recursive partitioning statistical techniques, establish the time course and variability of spontaneous recovery of upper extremity function after cervical SCI in order to identify candidates who might benefit from nerve transfer surgery.

Aim 2: Using a mixed methods research approach, patient and caretaker outcomes data will be collected over time and across groups (non-intervention, nerve transfer versus tendon transfer) and domains (medical, financial, and psychosocial experiences). Standardized surveys and semi-structured interview data will be collected and analyzed. The interview guide will be developed and refined based on input from a multidisciplinary advisory panel.

Aim 3: Using information from Aims 1 and 2, as well as input from the advisory panel, a de novo decisional support intervention will be created and pilot tested. A pre-post study design will measure participant knowledge (terms, facts that differentiate outcomes), decision self-efficacy (self-confidence in their ability to make a decision), and confidence in choice before and after use of the decisional support intervention.

2. KEYWORDS:

Spinal cord injury, SCI, tetraplegia, nerve transfer surgery, tendon transfer surgery, rehabilitation, caregiver, upper extremity function, hand function

3. ACCOMPLISHMENTS:

- **What were the major goals of the project?**

Task/Milestone **Administrative:**	Target Completion Date/Quarter	Status
Complete IRB approval at WUSM primary site		COMPLETED 7/31/2017
Complete IRB approval at VA sites after approval obtained at WUSM primary site		COMPLETED 11/22/2017 and 12/14/2017
Complete paperwork for use of EMSCI database/Dr. Steeves work		COMPLETED March, 2018; payment confirmed 5/23/18.
Prepare protocol, consent forms, patient recruitment forms with appropriate DOD language and guidelines		COMPLETED
Complete second tier DOD human subjects regulatory review and approval process by HRPO.		COMPLETED 3/1/2018 for Primary site; 3/25/18 for sub-sites.
Identify and hire research assistants and coordinator; complete paperwork including human subjects' protection training as relevant. (Human research training has already been completed by all of the currently hired personnel at the primary and VA sites; the consultants (Dr. Steeves' group will complete deidentified database work).		COMPLETED at WU/VASTL; Coordinator hired at Stanford/VA Palo Alto on 4/18/18.

Specific Aim 1: Establish the time course of spontaneous recovery of upper extremity function after cervical SCI	Target Completion Date/Quarter	Status
Major Task 1 - Define clinically relevant data of interest within EMSCI database		
Subtask 1: Coordinate with Dr. Steeves (and team) to obtain latest data from EMSCI database.	Dec 2017 (Y1Q1)	COMPLETED Nov, 2017
Subtask 2: Define clinically relevant subgroups within EMSCI database.	Dec 2017 (Y1Q1)	COMPLETED Jan, 2018
Subtask 3: Use the EMSCI database to screen for individuals who have lost C7 function after cervical SCI and track recovery patterns for C7 function on each side of the body over the first year after injury.	Mar 2018 (Y1Q2)	COMPLETED Feb, 2018
Milestone 1: EMSCI data reviewed	Dec 2017 (Y1Q1)	COMPLETED Nov, 2017
Milestone 2: Clinically relevant subgroups identified	Mar 2018 (Y1Q2)	COMPLETED Jan, 2018

Major Task 2 - Perform statistical analysis of defined clinically relevant subgroups		
Subtask 1: Discuss and confirm statistical analysis plan with Dr. Steeves.	Mar 2018 (Y1Q2)	COMPLETED May, 2018
Subtask 2: Use descriptive statistical analysis and unbiased recursive partitioning (URP) statistics to predict what neurological and functional activity items most accurately identify surgical candidates.	July 2018 (Y1Q4)	COMPLETED Mar, 2019
Subtask 3: Completion of final statistical analysis by Dr. Steeves and team.	July 2018 (Y1Q4)	COMPLETED Mar, 2019
Subtask 4: Discuss summarized findings and present in layperson terms.	Sep 2018 (Y1Q4)	COMPLETED May, 2019
Milestone(s) Achieved: EMSCI database analysis completed with clinically appropriate data summarized in layperson terms.	Sep 2018 (Y1Q4)	COMPLETED May, 2019

Major Task 3 – Draft presentation/manuscript		
Subtask 1: Prepare abstract for submission for presentation with Dr. Steeves and team.	Mar 2019 (Y2Q2)	COMPLETED May, 2019
Subtask 2: Prepare manuscript sections with Dr. Steeves and team; revisions.	Aug 2019 (Y2Q4)	1 of 2 completed Sep/2019
Milestone(s) Achieved: Manuscript prepared, submitted and revised for publication.	Aug 2019 (Y2Q4)	1 of 2 ready for submission Sep/2019

Specific Aim 2: Describe outcomes after no surgery versus nerve/tendon transfer surgery	Target Completion Date/Quarter	Status
Major Task 1 Develop Interview Guides		
Subtask 1: Phone meeting between institutions/study sites—discuss interview guides.	Dec 2017 (Y1Q1)	COMPLETED 1/10/18 and 2/22/18
Subtask 2: Assemble advisory panel.	Dec 2017 (Y1Q1)	COMPLETED Feb, 2018
Subtask 3: Develop and revise interview guides.	Dec 2017 (Y1Q1)	COMPLETED Apr, 2018
Milestone 1: Advisory panel participants identified.	Dec 2017 (Y1Q1)	COMPLETED Feb, 2018

Milestone 2: Completion of interview guide.	Dec 2017 (Y1Q1)	COMPLETED Apr, 2018
Major Task 2 Enroll and collect data		
Subtask 1: Enroll study participants for Aim 2	Oct 2019 (Y2Q4)	IN PROGRESS
Subtask 2: Complete subject interviews/surveys	Oct 2019 (Y2Q4)	IN PROGRESS
Subtask 3: Complete interview and survey analysis	Aug 2020 (Y3Q4)	IN PROGRESS

Specific Aim 3: Develop and assess a decision support intervention tool	Target Completion Date/Quarter	Status
Major Task 1 Develop Decision Support Intervention (DSI)		
Subtask 1: Review findings of Aim 1 and 2; create decision support intervention and knowledge subtest	Mar 2020 (Y3Q2)	IN PROGRESS
Milestone(s) Achieved: Completion of decision support intervention creation.	Mar 2020 (Y3Q2)	IN PROGRESS

- **What was accomplished under these goals?**

Aim 1 – HRPO Log Number A-20223.1

We have prepared an abstract titled, *"Degree of Upper Extremity Function Recovery in Cervical Spinal Cord Injury: Implications for Peripheral Nerve Transfer Surgery to Restore Upper Limb Function"*. It has been accepted for oral presentation and Dr. Ida Fox will attend the International Spinal Cord Society (ISCoS)'s annual scientific meeting taking place in Nice, France on 5-7 November 2019 (see item #2 attached in the appendices).

Another abstract titled, "*Range of Independence with Feeding, Bladder Management and Transfers by Motor Level in Cervical-Level Spinal Cord Injury"* has been accepted for podium presentation at the American Society for Peripheral Nerve (ASPN) Annual Meeting, January 10-12, 2020 at the Marriott Harbor Beach in Ft. Lauderdale, FL (see item #3 attached in the appendices).

A third abstract titled, *"How soon is too soon? Motor recovery in tetraplegia and its implications for upper extremity restorative surgery"* has been submitted for presentation at the 2020 annual scientific meeting of the American Spinal Injury Association (ASIA). Its status is still pending at this time (see item #4 attached in the appendices).

In preparing a manuscript describing the EMSCI database analysis, we realized that there was too much information for just one paper. We have separated out the findings in terms of 1) spontaneous motor recovery and 2) functional recovery as captured in the Spinal Cord Independence measure (SCIM) questionnaire and have prepared separate manuscripts. The latter of these manuscripts will be submitted to the Journal of Hand Surgery (see item #5 attached in the appendices). We are just waiting for final author forms so have not yet completed the submission process. A second paper is being prepared and this is why we are somewhat delayed from our projected SOW.

Aim 2 – HRPO Log Numbers A-20223.2a, A-20223.2b, A-20223.2c, A-20223.2d

PROTOCOL 1 (of 2 total):
HRPO Assigned Numbers: A-20223.1 and A-20223.2a-d
Title: Supporting Patient Decisions about Upper Extremity Surgery in Cervical Spinal Cord Injury (AIM 1 and AIM 2)

STATUS:
i) Progress on subject recruitment: Number of SCI subjects reported as enrolled last quarter: 36.

	Wash U	STL VA	PA VA	Stanford	TOTAL	Y2Q4 Goal
Total Enrolled SCI Subjects[1]	18	6	14	2	40	40
# SCI Subject Interviews Obtained to date[2]	30	7	24	2	63	
# Caregiver Interviews Obtained to date[3]	25	7	10	2	44	
Total # Interviews Obtained to date	55	14	34	4	107	

Notes: [1] Includes 2 subject withdrawals prior to baseline visit, and 5 subjects who, for various clinical reasons, have not yet had a baseline visit.
[2] Subjects are in various stages of the study (i.e., Enrolled, Baseline, Early Follow-up and Late Follow-up); thus, there is not a perfect match between # enrolled and # of interviews obtained.
[3] Not all SCI subjects identified a caregiver to participate.

ii) Amendments: Enrollment of non-surgical participants from the VASTLHCS site has lagged and we are currently seeking a modification of recruitment procedures there to contact potential participants by phone, present the study, then mail a hard-copy of the informed consent document and await its return by mail.
iii) Any adverse event/unanticipated problems: One subject, #1202, died while on study on 4/24/2019. The incident was determined to be serious, unexpected and not related to the study. The event was reported to and acknowledged by the relevant IRB/HRPO boards per protocol.

Although the enrollment of human subjects has met goals to date, due to clinical care reasons, some participants have not yet completed their baseline visit and we are deciding whether to replace them or not. While in the original grant we specified that we would use the qualitative data as our main outcome measure, the preliminary findings of the SCIM data over time and the differences between non-surgical, nerve surgery participants compared to tendon transfer participants is so compelling that we hope to accrue more prospective tendon transfer group participants. This has made us slightly delayed in our Aim 2 work.

Qualitative coding and analysis of the interview transcripts (107 transcripts to date) is ongoing using NVivo software.
- 47 transcripts are double coded, reconciled and are complete
- 32 transcripts are double coded and awaiting reconciliation
- 28 transcripts are yet to be double coded and reconciled

Aim 3 –

We have completed quite a bit of work on the decision aid and have a working site map and detailed outline of content (see item #6 attached in the appendices). This has been discussed with the research team members as well as our advisory board. All of the input of those parties was incorporated and has valuably contributed to the current form and content of the planned decision aid. At present, we are working with the research team in thinking through future pilot testing of the decision aid including the inclusion of people with SCI alone versus inclusion of caregivers and other key stakeholders.

PROTOCOL 2 (of 2 total):
HRPO Assigned Number: Not yet assigned
Title: Supporting Patient Decisions about Upper Extremity Surgery in Cervical Spinal Cord Injury (AIM 3)
STATUS:
The protocol for pilot testing the Decision Aid has not been finalized. We will submit for IRB and DoD HRPO approvals for Aim 3 using information gained from Aims 1 & 2 and anticipate submission in the next quarter.

- **What opportunities for training and professional development has the project provided?**

Study team coordinators have been trained in the use of NVivo qualitative research software for transcript analysis purposes.

- **How were the results disseminated to communities of interest?**

On 8/7/2019, we presented a progress update to the project's Advisory Board via conference call. 10 out of the 12 members, along with study team members participated in the call. This was the 4th task for the Advisory Board, and they gave the study team feedback on the Decision Aid site map, as well as ideas for content:

- Need for graphics/videos
- Talking about gains in functions in terms of actions like, "to be able to pinch a little better", "to be able to open your hand".

- **What do you plan to do during the next reporting period to accomplish the goals?**

We will continue the work stated in this document and will focus on preparing and submitting the pilot testing protocol for regulatory approvals.

4. IMPACT:

- **What was the impact on the development of the principal discipline(s) of the project?** Nothing to Report.

- **What was the impact on other disciplines?** Nothing to Report.

- **What was the impact on technology transfer?** Nothing to Report.

- **What was the impact on society beyond science and technology?** Nothing to Report.

5. CHANGES/PROBLEMS:

- **Changes in approach and reasons for change**

Initially we had planned to exclude participants undergoing both nerve and tendon transfer surgery. However, one of the surgeon study team members felt that not offering nerve transfer to people getting tendon transfer surgery was unethical as the surgery (supinator to PIN nerve transfer) done with the traditional tendon transfers made such a profound functional difference for the individual undergoing surgery. This transfer (to restore hand opening) cannot be as successfully restored with tendon transfer and is not really an option for most people due to the lack of donor tendons available. After discussion within the research team, we decided that any participants undergoing dual transfers would be considered in the tendon transfer group. The immobilization/splinting and non-weight bearing status of the extremity would be the limiting factors for return to activity and would overshadow any diminished activity due to having nerve transfer alone.

- **Actual or anticipated problems or delays and actions or plans to resolve them**

For Aim 1 delay: we will plan to complete the second paper shortly and this issue should be resolved shortly pending journal review and feedback.

For Aim 2 delay: we will plan to aggressively identify and recruit a few more tendon transfer participants. If not present at our centers, then we will ask our advisory board member and colleague, Dr. Alan Peljovich if he would be willing to have us recruit and enroll his patients (we are currently discussing this option with our IRB). Another plan to resolve this issue is to consider a preliminary analysis of the qualitative data alone and decide if we should include more participants in a group that has already had surgery. So far we have enrolled 2 tendon transfer and 1 nerve transfer subjects as “Post-Surgical subjects”. These participants can provide valuable information, but since they do not provide ‘pre-operative’ data, we are not be able to include them in a pre / post comparison of the survey data (SCIM and SF-36). We are considering our options as we strive to reach stated goals.

- **Changes that had a significant impact on expenditures -** Nothing to report.

- **Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents -** Nothing to Report.

- **Significant changes in use or care of human subjects -** Nothing to Report.

- **Significant changes in use or care of vertebrate animals –** Not Applicable.

- **Significant changes in use of biohazards and/or select agents -** Not Applicable.

6. PRODUCTS:

- **Publications, conference papers, and presentations**

On page 6 of this report, we detailed three abstracts (two accepted, one pending) and two manuscripts (1 to be submitted soon) written to describe findings and insights from the Aim 1 data.

The project’s work and DOD funding has influenced the work of the Principal Investigator. Although not directly stating any results of the current project, her DOD funding was disclosed within articles of two other publications:

- *Current Best Peripheral Nerve Transfers for Spinal Cord Injury*. Plast Reconstr Surg.

2019 Jan;143(1):184e-198e. doi: 10.1097/PRS.0000000000005173 (see item #7 attached in the appendices).

- *Nerve transfers to restore upper limb function in tetraplegia.* Invited comment in: Lancet. 2019 Aug 17;394(10198):543-544. doi: 10.1016/S0140-6736(19)31332-7 (see item #8 attached in the appendices).

- **Website(s) or other Internet site(s) -** Nothing to Report.

- **Technologies or techniques -** Nothing to Report.

- **Inventions, patent applications, and/or licenses -** Nothing to Report.

- **Other Products –** Nothing to Report.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

- **What individuals have worked on the project?**
  Ida Fox – no change
  Catherine Curtin – no change
  Aimee James – no change
  John Steeves – no change
  Carie Kennedy – no change
  Deborah Kenney – no change

  New to list:
  Name: Mary Politi, PhD
  Project Role: Co-Investigator
  Nearest person month worked: 0.5
  Contribution to Project: Dr. Politi has assisted with the targeted analysis of Aim 2 data for inclusion in the Decision Aid (DA). She is also giving guidance for developing the structure and content of the DA using her expertise in health communication and medical decision making. She will assist in the implementation and testing of the DA and analysis of the results of the pilot study in Aim 3.

- **Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period? -** Nothing to Report.

- **What other organizations were involved as partners?**
  - **1) Organization Name: Veterans' Administration Healthcare System**
    - **Location of Organization:** St. Louis, Mo
    - **Partner's contribution to the project**
      - **In-kind support**
      - **Facilities**
      - **Collaboration**
      - **Other** – Study sub site
  - **2) Organization Name: Stanford University**
    - **Location of Organization:** Stanford, CA
    - **Partner's contribution to the project**
      - **In-kind support**
      - **Facilities**
      - **Collaboration**
      - **Other** – Study sub site

- **3) Organization Name: Palo Alto Veterans' Institute for Research**
  - **Location of Organization:** Palo Alto, CA
  - **Partner's contribution to the project**
    - **In-kind support**
    - **Facilities**
    - **Collaboration**
    - **Other** – Study sub site
- **4) Organization Name: European Multicenter Study about Spinal Cord Injury (EMSCI)**
  - **Location of Organization:** Zurich, Switzerland
  - **Partner's contribution to the project**
    - **Collaboration** – Provided access to data for Aim 1 study activities.
- **5) Organization Name: Health Literacy Media (HLM)**
  - **Location of Organization:** St. Louis, MO
  - **Partner's contribution to the project**
    - **Collaboration** – Providing guidance for Aim 3 study activities to make healthcare information easier to understand and act upon.

8. SPECIAL REPORTING REQUIREMENTS

- **QUAD CHARTS:** The updated Quad Chart is submitted in the appendices.

9. APPENDICES:

1. Quad Chart updated for Q4Y2 (pg.12)
2. Final ISCoS Abstract: "Degree of Upper Extremity Function Recovery in Cervical Spinal Cord Injury: Implications for Peripheral Nerve Transfer Surgery to Restore Upper Limb Function" (pg. 13)
3. Final ASPN abstract: "Range of Independence with Feeding, Bladder Management and Transfers by Motor Level in Cervical-Level Spinal Cord Injury" (pg. 14)
4. Final ASIA abstract: "How soon is too soon? Motor recovery in tetraplegia and its implications for upper extremity restorative surgery." (pg. 15)
5. Manuscript: "Range of Functional Independence in Cervical-Level Spinal Cord Injury: Implications for Peripheral Nerve Transfer Surgery to Restore Upper Limb Function" (pg. 16)
6. HLM draft of SCI decision tool text (pg. 43)
7. 2019 PRS article (pdf)
8. 2019 Lancet comment (pdf)

Appendix 1

Supporting Patient Decisions about Upper Extremity Surgery in Cervical Spinal Cord Injury

Log Number: **SC160046**
Award Number: **W81XWH-17-1-0285**

PI: Ida K. Fox, M.D. **Org:** Washington University in St. Louis School of Medicine **Award Amount:** $701,402

Study/Product Aim(s)

- Aim 1: Establish the time course of spontaneous recovery of upper extremity function after cervical spinal cord injury (SCI).
- Aim 2: Describe outcomes after no intervention compared to surgical intervention (nerve/tendon transfer) groups.
- Aim 3: Develop and assess a decision support intervention tool.

Approach

The overarching aim of this project is to define key information about improvement of upper extremity function after SCI (time and extent of recovery, outcome of surgical and non-surgical interventions and the experience thereof) and communicate this information to patients and clinicians to support their treatment decisions.

Accomplishments this Quarter

Aim 1: Three abstracts and two manuscripts describe findings/insights of EMSCI database analysis.

Aim 2: Enrollment goal met, but additional subjects sought to replace subjects who have withdrawn or haven't yet had baseline visit; 107 interviews done to date.

Aim 3: Content development for Decision Aid continues; preliminary planning begins for next phase to pilot test with SCI patients/stakeholders.

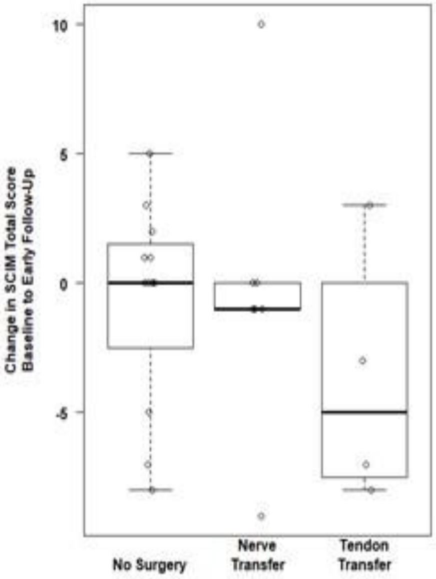
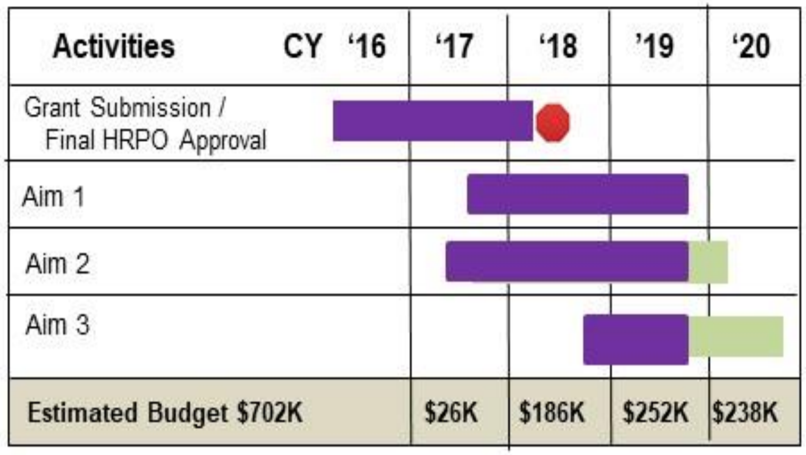


Figure Legend: Surgery participants had a decrease in their self-reported ability to do activities of daily living as measured by the SCIM (Spinal Cord Independence Measure). Individuals undergoing tendon compared to nerve transfer surgery had a more pronounced decrease in SCIM scores.

The SCIM is a standardized survey that asks participants about their ability to perform basic activities of daily living. This includes feeding, grooming, urinary function and transfers. These data were collected for participants with mid-level cervical spinal cord injury at baseline and at an early time point after baseline or after a surgical intervention to improve upper extremity function.

Timeline and Cost



Activities	CY '16	'17	'18	'19	'20
Grant Submission / Final HRPO Approval	🟪	🟪	🟥		
Aim 1		🟪	🟪	🟪	
Aim 2		🟪	🟪	🟪	🟩
Aim 3			🟪	🟪🟩	🟩
Estimated Budget $702K		$26K	$186K	$252K	$238K

Updated: 09/26/2019 Y2Q4

Goals/Milestones

CY16 Goal – Assemble research group and formulate grant proposal
☑ Complete grant submission
CY17 Goals – Aim 1 and 2
☑ Obtain IRB/HRPO approval
☑ Begin EMSCI database analysis
☑ Create interview guides
CY18 Goal – Aim 1, 2
☑ Summarize findings of EMSCI database analysis
☑ Enrolling Aim 2 subjects for outcomes collection (interviews/surveys)
CY19 Goal – Aim 2, 3
☐ Create and test decision support intervention tool

Comments/Challenges/Issues/Concerns

- Timeline issues: Aim 1 behind on SOW goals, Aim 2 remains on goal
- Spending comment: None.

Budget Expenditure to Date

Projected Expenditure: $474,566.00
Actual Expenditure: $424,139.62

Appendix 2

Degree of Upper Extremity Function Recovery in Cervical Spinal Cord Injury: Implications for Peripheral Nerve Transfer Surgery to Restore Upper Limb Function

Introduction: Time is an important consideration in the newest surgical technique to improve upper extremity function: nerve transfers. These techniques are poised to transform the management of the upper limbs for people with cervical SCI. However nerve transfers can be time sensitive due to axonal and muscle degeneration. There is a need for more information on natural recovery and function after SCI to help patient and clinician decision-making regarding this novel surgical treatment. The objective of this study was to establish the probability of spontaneous recovery of function and degree of gains in independence after cervical SCI, and to identify possible candidates who would benefit from early nerve transfer surgery.

Methods: Using the European Multi-center Study about Spinal Cord Injury (EMSCI) data set, analysis was undertaken of eligible individuals with traumatic SCI, motor level C5-C8. The EMSCI database includes rigorously and prospectively collected neurological and functional independence measurements. Recovery of motor function between 6 and 12 months after injury was ascertained. Data on feeding, bladder management and transfers (wheelchair to bed) were compared at 6 months and 12 months after injury for each neurologic level. Subgroup analyses of symmetric and asymmetric SCI, and between complete and incomplete SCI were performed. The impact of age, gender, and degree of asymmetry on functional independence was ascertained.

Results: From 6 to 12 months post-SCI, few patients recovered additional strong (MRC 4-5) function below the neurologic level. Specifically, analysis of 418 limbs showed that 4% of individuals with strong proximal cervical level function (C5 +/- C6 +/- C7 intact) and no C8 function at 6 months gained strong C8 level function (finger flexion) by 12 months. With respect to recovery of C7 (elbow extension) function, of those with intact proximal level function at 6 months (N=260 limbs), 6% gained antigravity (MRC 3/5) and 2% gained strong (MRC 4-5/5) C7 function at 12 months.

At 6 months post injury, data were available for 176 individuals with symmetric patterns of injury. At C5-level, assistance was required for feeding, bladder function and transfers. At C6-level, 35% of individuals could eat independently using assistive devices/partial assistance for cutting, 4% were independent with bladder management, and 2% could transfer independently. At C7-level, 58% could eat using assist devices/assistance for cutting, 28% had independent bladder function, and only 19% transferred independently. At C8-level, 84% could eat independently or with assistive devices/partial assistance for cutting, 52% had independent bladder management, and 36% transferred independently. There was no statistically significant change from 6 to 12 months though a trend towards gain in function was seen.

Conclusion: Overall, few patients spontaneously gained additional function from 6 to 12 months post-SCI. Individuals with C6 (active wrist extension and tenodesis-driven hand use) and C8 (some hand function) level injuries gained greater independence with feeding and bladder management tasks. Those with C8 gained greater independence with transfers than those with C7 (active elbow extension). This work supports early (within 6 months of injury) evaluation for possible peripheral nerve transfer surgery to augment upper limb function.

Fox I [1,2] , Dengler J [1] , Curt A [7] , Mehra M [6] , Miller A [1] , Curtin C [3] , Ota D [3] , Stenson K [2,1] , Kennedy C [1] , Novak C [4] ,Steeves J [5]

[1] Washington University, Saint Louis Missouri, USA
[2] VA St. Louis Healthcare System, Saint Louis Missouri, USA
[3] Palo Alto Veterans Healthcare System, Palo Alto California, USA
[4] University of Toronto, Toronto Ontario, Canada
[5] ICORD, University of British Columbia, Vancouver British Columbia, Canada
[6] Tigermed-BDM Inc., Gaithersburg Maryland, USA
[7] Spinal Cord Injury Center, University Hospital Balgrist, Zurich, Switzerland

Appendix 3

“Range of Independence with Feeding, Bladder Management and Transfers by Motor Level in Cervical-Level Spinal Cord Injury”

(346/400 words)

Background: The advent of upper limb nerve transfer surgery to improve function may transform management of cervical spinal cord injury (SCI). Surgery can restore elbow and wrist extension and finger flexion and extension. Information on the implications of having these movements on activities of daily living (ADL’s) is limited. The objective of this study was to assess the degree of gains in independence for a given level of upper extremity motor function.

Methods: Using the European Multi-center Study about Spinal Cord Injury (EMSCI) data set*, analysis was undertaken of eligible individuals with traumatic C5-C8 SCI to ascertain motor function recovery (6 and 12 months after injury, n = 388). Data on feeding, bladder management and transfers (bed to chair) were compared at 6 months and 12 months post-injury for each motor level. Subgroup analyses were performed: symmetric vs. asymmetric SCI; complete vs. incomplete SCI. The impact of age, gender, and degree of asymmetry on functional independence were analyzed.

Results: Independent feeding with or without assistive devices was noted in individuals with strong wrist extension (C6); feeding independently required strong finger flexion (C8). With bladder management, strong finger flexion (C8) was required for independence. Individuals that were younger, male or had trunk control (asymmetric SCI) had greater independence with bladder management. With transfers (bed to chair), elbow extension (C7) did not uniformly result in transfer independence, whereas finger flexion (C8) did. Subgroup analysis showed that people with younger age and/or trunk control also had improved ability to transfer. There was no significant increase in independence between 6 and 12 months with any activities, though a trend towards gain in function was seen.

Conclusion: Although independence with transfers might be expected in individuals with intact elbow extension movement, this was not seen. The presence of finger flexion had the most profound effect on independence with transfers, feeding and bladder function. This information that will be useful when counseling people with SCI who are considering surgical treatment for restoration of upper extremity motion.

*The EMSCI database includes rigorously and prospectively collected neurological and functional independence measurements.

Appendix 4

"How soon is too soon? Motor recovery in tetraplegia and its implications for upper extremity restorative surgery."

Objective: To describe the degree of spontaneous motor recovery in the 6-12 month period after cervical level spinal cord injury and discuss its relevance to restorative upper extremity surgery counseling and decision-making.

Design/ Method: The rigorously and prospectively collected European Multi-center Study about SCI (EMSCI) data set was used to compare motor function at 6 and 12 months post-injury. The 6 month motor level was defined as the level with Medical Research Council (MRC) grade 3, 4 or 5 function; all rostral levels had > (or equal to) 4 MRC function and all caudal levels had < (or equal to) 2 MRC function. Recovery of elbow extension (C7 function) and hand function (C8 and T1) were ascertained for each motor level.

Results: For people with <C5 motor level at 6 months (n=139), motor recovery of MRC 4 or 5 function at C7, C8 and T1 was seen in 1% of people. For a motor level of C5 at 6 months (n=85), motor recovery of MRC 4 or 5 function was seen in 1 % of people at C7, 2% at C8 and 0% at T1. For a motor level of C6 at 6 months (n=100), motor recovery of MRC of 4 or 5 was seen in 8% of people at C7, 2% at C8 and 0 % at T1. For a motor level of C7 at 6 months (n=80), recovery of MRC of 4 or 5 was seen in 9% of people at C8 and 4% at T1. For a motor level of C8 at 6 months (n=36), T1 recovery of MRC of 4 or 5 was seen in 22% of people.

Conclusion: Our data suggests that recovery in the C7, C8 and T1 levels is limited during the 6-12 month period after a cervical level C5-C7 injury. Individuals with C8 function at 6 months, however, may gain strong T1 level function. This is important information particularly when considering nerve transfer surgery. Nerve transfers can successfully restore function even years post-SCI, however, not all are candidates for this surgery at > 1year post-SCI. Moreover, recent literature suggests that early nerve transfer intervention (< 1 year post-SCI) may improve post-surgical gain in function. In conclusion, these data support early referral for work up and consideration of possible restorative surgery as spontaneous gain in function is limited from 6 to 12 months post injury.

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Appendix 5

Range of Functional Independence in Cervical-Level Spinal Cord Injury: Implications for Peripheral Nerve Transfer Surgery to Restore Upper Limb Function

Authors:
Jana **Dengler**, MD[1]
Munish **Mehra**, PhD[2]
John D **Steeves**, PhD[3]
DOD group
EMSCI group
Ida K **Fox**, MD[4,5]

DOD group:
Catherine **Curtin**, MD[6]
Carie **Kennedy**, BSN, RN[4]
Amanda **Miller**, MD[7]
Christine **Novak**, PhD[1]
Doug **Ota**, MD[6]
Katherine C **Stenson**, MD[4,5]

EMSCI group:
Armin **Curt**, MD[8]
Doris **Maier**, MD[9]
Rainer **Abel**, MD, PD[10]
Norbert **Weidner**, MD, PhD[11]
Rüdiger **Rupp**, MD, Ing.[11]
J **Vidal**, MD[12]
Jesus **Benito**, MD[12]
Yorck-Bernhard **Kalke**, MD[13]

Author Information:
[1] Division of Plastic and Reconstructive Surgery, Department of Surgery, University of Toronto, Toronto Ontario, Canada
[2] Tigermed-BDM Inc., Gaithersburg Maryland, USA
[3] ICORD, University of British Columbia, Vancouver British Columbia, Canada
[4] Division of Plastic and Reconstructive Surgery, Department of Surgery, Washington University School of Medicine, St. Louis, MO Missouri
[5] VA St. Louis Healthcare System, Saint Louis Missouri, USA
[6] Palo Alto Veterans Healthcare System, Palo Alto California, USA
[7] Division of Physical Medicine and Rehabilitation, Washington University School of Medicine, St. Louis, MO Missouri, USA
[8] Spinal Cord Injury Center, Balgrist University Hospital, Zurich, Switzerland
[9] BG-Trauma Center, Murnau, Germany
[10] Hohe Warte Bayreuth, Bayreuth, Germany
[11] Spinal Cord Injury Center, Heidelberg University Hospital, Heidelberg, Germany
[12] Institute Guttmann, Neurorehabilitation Hospital, Barcelona, Spain
[13] RKU Universitäts- und Rehabilitationskliniken Ulm, Ulm, Germany

Corresponding Author:

Ida K Fox, MD
Associate Professor
Division of Plastic and Reconstructive Surgery
Washington University in St. Louis
St. Louis, MO
Phone: (314) 454-6089
Email: foxi@wustl.edu

Running head: Functional Independence in Tetraplegia

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Range of Functional Independence in Cervical-Level Spinal Cord Injury: Implications for Peripheral Nerve Transfer Surgery to Restore Upper Limb Function

Abstract

Purpose

Functional gains can occur for years post spinal cord injury (SCI), but candidacy for nerve transfers can be time sensitive due to axon and muscle degeneration after injury. To identify eligibility criteria and allow for optimal timing of restorative surgical treatment for cervical SCI, more precise information is needed on the independence in activities of daily living within the first year after injury. This study evaluated the improvement in upper limb functional independence with no surgical intervention at differing levels of cervical SCI.

Methods

Using the comprehensive European Multi-center Study about Spinal Cord Injury data set, analysis was undertaken of individuals with traumatic SCI, motor level C5-C8. Data on feeding, bladder management and transfers (bed to wheelchair) were compared at 6 months and 12 months after injury. Subgroup analyses of symmetric and asymmetric SCI, and between complete and incomplete SCI were performed. The impact of age and gender on functional independence was ascertained.

Results

At 6 months post injury, data were available for participants with symmetric (n = 204) and asymmetric (n = 95) SCI. There was no significant increase in independence between 6 and 12 months for any activity of daily living. Feeding with assistive devices was reported for nearly all with strong wrist extension (C6). Independence in feeding and bladder management was noted with strong finger flexion (C8). Elbow extension (C7) did not uniformly result in the ability to transfer independently, whereas finger flexion (C8) did.

Conclusion

There are no significant gains in functional independence between 6 and 12 months post SCI. Thus, if individuals are interested in nerve transfers to gain function, evaluation for eligibility at 6 months post SCI is appropriate. The expected functional range from this study will guide expectations for independent self-care.

Level of Evidence: III (cohort study)

Keywords: cervical-level spinal cord injury, tetraplegia, spinal cord independence measure (SCIM), upper extremity function, nerve transfers

Introduction

Cervical-level spinal cord injury (SCI), tetraplegia, has a profound impact on upper limb function, affecting activities of daily living and self-care, and ultimately restricts community integration and quality of life. Approximately 50% of SCI occurs at the cervical level,[1] with an estimated annual incidence of over 10,000 cases in the United States.[2] Individuals with cervical-level SCI have identified improvement of upper limb function as a top priority.[3,4] Peripheral nerve transfers are an additional means of increasing independence in SCI,[5-16] have been shown to be safe,[6,7] and require less post-operative immobilization than other reconstructive options such as tendon transfers.[17] Candidacy for nerve transfers is time sensitive due to peripheral axon damage and concomitant muscle degeneration from direct lower motor neuron destruction that exists in some types of cervical SCI.[18,19] Nerve transfer success diminishes if performed beyond one year after SCI,[20,21] making timely and informed surgical planning critically important.

Gains in motor levels and functional independence occur during rehabilitation, and individuals with motor incomplete SCI may recover due to the reorganization of preserved (undamaged) central neural pathways.[29] The degree of motor recovery, however, remains highly variable,[30,31] and depends on a variety of factors, including the level of SCI, the severity (completeness) of the cord injury,[32-35] time to spinal cord decompression and stabilization surgery,[36,37] concomitant medical complications following injury,[34] the degree of spinal motor neuron damage,[32] body mass index (BMI),[34] and age.[38-42]

To add further complexity, a variety of patient factors negatively impact ADL performance, such as increased age,[36,43,44] autonomic dysreflexia,[45] brain injury,[46] and multiple comorbidities[45]. Therefore for a given motor level, there is a range of functional independence. Existing SCI classification systems (such as Asia Impairment Scale (AIS) A-D), are known to artificially limit the association of individual neurologic status with functional outcome.[47] Overall, there is a paucity of published data on the expected degree of ADL independence for a given cervical spinal motor level.[31,39,48]

The aim of this study was to define improvements in functional independence within the first year after SCI involving motor levels C5 to C8. The specific objectives were to establish 1) the range of functional independence for feeding, bladder management and wheelchair transfers, and 2) the relative degree of recovery in functional independence between 6 and 12 months after injury. We also wanted to assess how functional independence differs between symmetric and asymmetric cervical SCI (including degree of asymmetry), between complete and incomplete SCI, as well as the impact of age and gender on functional independence. The ultimate goal of this research was to guide decision making involving early nerve transfer surgery in cervical SCI.

Methods

EMSCI Database

This study analyzed prospectively collected data acquired by the SCI rehabilitation centers participating in the European Multicenter Study of Spinal Cord Injury (EMSCI) study group (www.emsci.org, ClinicalTrials.gov Identifier NCT01571531).[49] Institutional Review Board approval was obtained at the individual SCI centers participating in EMSCI. The database contains deidentified data and includes prospectively collected neurological and functional independence measurements. Within the EMSCI network, trained examiners using a uniform protocol assess participants with acute SCI within 2 weeks of initial SCI and subsequently at 1, 3, 6, and 12 months after SCI. Neurological assessments are performed according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI),[50] and include motor and sensory scoring of individual spinal cord segments. Upper extremity motor scores (UEMS) are based on muscle strength scores (Medical Research Council (MRC) 0-5) with primary innervation from a specific spinal cord segment (C5 elbow flexion, C6 wrist extension, C7 elbow extension, C8 finger flexion, T1 finger abduction).[51] Functional assessments of ADLs ("functional independence") are measured using the Spinal Cord Independence Measure (SCIM) a validated performance measure,[30,53] which evaluates several activities within the domains of self-care, respiration and sphincter management, and mobility.[52-53]

Data Collection

This study examined the relationship between upper extremity motor scores and the SCIM[52-53,63] at 6 and 12 months after SCI. A query of the central EMSCI database was performed to identify specific data subsets from participants at 6 months post injury with involved with motor levels C5, C6, C7, or C8 (as determined below: *"Determining Motor Level"*). Age at time of injury, sex, mechanism of injury, and grade (A-D) from the American Spinal Injury Association (ASIA) Impairment Scale (AIS) were collected. For each level of injury, SCIM items #1 (Feeding), #6 (Sphincter Management - Bladder) and #10 (Transfers - Bed-Wheelchair) were recorded at 6 months and 12 months after injury **(Figure 1)**. One item from each domain (self-care, respiration and sphincter management, mobility) was chosen to reflect functional independence across various cervical spinal cord motor levels. Participants with incomplete SCIM data were excluded.

Determining Motor Level

For this study, C5 motor level SCI was defined as having elbow flexion MRC grade 3, 4 or 5 with caudal levels C6-T1 as having an MRC grade 0, 1 or 2. Similarly, C6 motor level SCI was defined as having wrist extension of MRC grade 3, 4 or 5 with caudal levels C7-T1 of MRC grade 0, 1 or 2; C7 motor level was defined as having elbow extension of MRC grade 3, 4 or 5 with caudal levels C8-T1 of MRC grade 0, 1 or 2; and C8 motor level was defined as having finger flexion of MRC grade 3, 4 or 5 with T1 of MRC grade of 0, 1 or 2. All segments rostral to the motor level must have achieved a motor score of 4/5 or 5/5 or a normal sensory score at C4 where there is no testable motor score available; a normal segmental sensory score (2/2) infers a normal C4 segmental motor status. This purposely deviates from how motor level is typically defined by spinal cord clinicians using the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI), where the motor level is the first spinal segment (indexed by the key muscle group for that segment) having a muscle strength score of at least 3/5 (full range contraction against gravity alone), providing all the more rostral key muscle segmental motor scores are normal (5/5).[30] Injury patterns were categorized into symmetric and asymmetric SCI, with asymmetric SCI defined as one or more motor level difference between sides. Asymmetric patterns of injury were categorized according to the more caudal level (i.e. a C5 motor level on one side with a C7 motor level on the contralateral side was classified as a C7 level injury).

Range of SCIM Activities

The range of performance for each SCIM activity item for each individual was examined and correlated with the individual's motor level. SCIM item scores were classified by the authors into "independent", "partial assist" and "full assist" as shown in **Figure 1**. Range of functional independence between 6 and 12 months was compared. Sub-group analysis were performed between symmetric and asymmetric injuries, as well as motor complete (ASIA A, B) and motor incomplete (ASIA C, D) injury patterns. The impact of age (categorized as <40, 40-60, > 60 years), gender, and degree of asymmetry (for asymmetric SCI, number of intervening levels) on independence was ascertained.

Statistical Analysis

Descriptive statistics were used to summarize baseline characteristics. SCIM scores at each motor level were reported with 95% confidence intervals. The Fisher's Exact Test was used to compare SCIM scores for a given motor level among the following groups: 1) 6 versus 12 months post SCI, 2) symmetric versus asymmetric SCI, and 3) motor complete (ASIA A/B) versus motor incomplete (ASIA C/D) patterns of injury. The impact of age, gender and degree of asymmetry on SCIM scores was evaluated using Fisher's Exact Test.

Results

There were 299 participants with motor level C5 to C8 spinal cord injury at 6 months included in this study; 204 participants (68%) had symmetric SCI, and 95 (32%) had asymmetric patterns of SCI. Demographic data for symmetric and asymmetric groups are similar (mean age 42 ± 18 years; 81% males, **Table 1**). The most common cause of SCI was trauma (97%), followed by ischemia (3%). Participants were distributed by AIS category as follows: AIS A 47%, AIS B 25%, AIS C 19%, AIS D 9%. Motor level was distributed as follows: C5 n = 85 (28%), C6 n = 113 (38%), C7 n = 68 (23%) and C8 n = 33 (11%).

Feeding capacity

The range of functional independence in feeding (SCIM item 1) by motor level is shown in **Figure 2** for symmetric SCI and **Suppl Figure 1** for asymmetric SCI. Corresponding confidence intervals for all activities are shown in **Table 2** and **Suppl Table 1**. Feeding with personal assistance or adaptive devices was found for the majority of patients with MRC 3-5 wrist extension (C6 motor level), which enabled use of tenodesis-driven hand function. Feeding independently without need for assistance or adaptive devices was found only for individuals with MRC 3-5 finger flexion (C8 motor level). Independence with feeding did not significantly change between 6 and 12 months at any injury level. Subgroup analysis showed that participants were more independent in feeding at the C6 level if they were younger (<40 versus > 60 years, p = 0.02). No effect of gender, AIS category, or magnitude of asymmetry on independence with feeding was found.

Bladder Management

Range of functional independence on bladder management (SCIM item 6) by motor level is shown in **Figure 3** for symmetric SCI and **Suppl Figure 2** for asymmetric SCI. Independence with bladder management was found in those with MRC 3-5) finger flexion (C8 motor level). Independence with bladder management did not significantly change between 6 and 12 months at any injury level. Subgroup analysis showed that participants were more independent in bladder management at the C6 level if they had some trunk or lower extremity control (motor incomplete injuries, p = 0.003). No effect of age, gender, or magnitude of asymmetry on independence with bladder management was found.

Transfers (bed to wheelchair)

Range of functional independence in transfers, bed to wheelchair (SCIM item 10) by motor level is shown in **Figure 4** for symmetric SCI and **Suppl Figure 3** for asymmetric SCI. MRC 3-5 elbow extension (C7 motor level) did not uniformly result in the ability to transfer independently; 54-64% of participants with elbow extension were independent in transfers. Subgroup analysis showed that stronger elbow extension (MRC 5 > 4 > 3) did not result in increased independence with transfers. MRC 3-5 finger flexion (C8 motor level) however, was present in those who were independent with transfers. There was a small subset (5-13%) who were able to transfer independently without any elbow extension (C6 motor level). Independence with transfers did not significantly change between 6 and 12 months at any injury level. Subgroup analysis showed that participants were more independent with transfers at the C6 level if they were younger (p = 0.01), or at the C5, C6 or C7 level if they had trunk or lower extremity control (motor incomplete injuries, p = 0.04, 0.0001, 0.002 respectively). No effect of gender or magnitude of asymmetry on independence with transfers was found.

Discussion

The inherent heterogeneity of SCI[30-31] renders prediction of independence with self-care challenging,[48] and little has been published on this.[31,39,48] This information is necessary to select and counsel patients about time sensitive nerve transfer surgery to reconstruct the upper limb. Our study has established predicted functional independence levels associated with the ADLs (feeding, bladder management and wheelchair transfers) in individuals with cervical SCI at motor levels C5 to C8 at 6 and 12 months after injury. This knowledge can guide expectations on independence after SCI, and can be used to inform individuals with SCI and clinicians on decision-making around early post injury intervention and upper limb nerve transfer surgery.

Individuals with acute SCI process an overwhelming amount of information during rehabilitation to resume daily activities, including modification of mobility, bladder and bowel function, pressure-offloading, and spasticity management. The transition from inpatient rehabilitation to home requires careful planning and coordinated care. Knowledge of expected functional recovery and attainable levels of independence with activities is important to informed decisions about ongoing rehabilitation training and participation in potential therapeutic interventions. Previous studies have examined target values for SCIM scoring at various neurologic levels[64] or in tetraplegia as a whole.[61] Guidelines on expected independence one year after injury suggest that feeding with adaptive devices is possible with a C5 motor level and independence with feeding requires a C7 motor level.[65] By contrast, the results presented here suggest that feeding with assistive devices requires a C6 motor level, and full independence requires a C8 motor level. Greater independence with bladder management was seen in individuals with C8 finger flexion, which provides manipulation of a urinary catheter device, as well as intact motor levels for all other rostral cord segments. Guidelines suggest independence with transfers is possible for those with C7 motor level.[65] This study showed that strong C8 motor scores correlate better to independence with transfers. We postulate that finger flexion (C8) allows for successful independent transfers, as the individual is better able to stabilize their wrist if grip is intact. Subgroup analyses showed the impact of age, gender, and degree of motor completeness (AIS category) on independence. Previous studies have also shown that lower functional independence is associated with increased age[36,39-40,43-44] and motor complete injuries,[34,66-67] while other studies have shown no effect of age on SCIM scores.[66]

Increased independence with activities is not only highly desired by individuals with SCI, it can also reduce caregiver cost and burden.[68] Tendon transfers[69] and nerve transfers can restore a variety of upper limb functions. Unfortunately, as few as 14% of eligible individuals receive upper limb surgery to increase independence.[70] Depending on the level of injury and available intact donor nerves, nerve transfers have been used to restore wrist extension (brachialis (C5/6) to ECRL[12]), elbow extension (axillary (C5/6) to triceps[10,71]), finger flexion (brachialis (C5/6) / brachioradialis (C5/6) to median innervated finger flexors[8]) and finger extension (supinator (C5/6) to posterior interosseous nerve[11]). However, studies have shown that the results of nerve transfers diminish when surgery is done further from time of injury.[15,72]

Our results showed that there was no significant increase in independence with feeding, bladder management or transfers between 6 and 12 months post SCI. Previous work has also shown that SCIM scores do not change significantly if there is no motor level recovery or motor recovery of only one level.[30] Another study by our group shows that few individuals recover additional motor movement between 6 and 12 months: only 3% of individuals without C7 motor function at 6 months gain strong C7 motor function at 12 months, and only 3% without C8 motor function gain strong C8 motor function by 12 months (unpublished data). This suggests that surgical intervention as early as 6 months post SCI could be considered.

Database studies have inherent limitations. The rehabilitation care received by individuals in the EMSCI database may not parallel that of individuals in the United States or other countries. Motor recovery is in part due to strengthening of existing function,[74] and independence in activities is affected by learned behaviors; thus rehabilitation treatment and motivation can affect functional outcomes.[30,53,75-76] These results may over-predict gains in function that would be seen in more disadvantaged populations with less access to comprehensive and no-cost rehabilitation care.

The SCIM is focused on gains in functional independence and does not measure behavior. Accomplishing a task does not mean completing a task with the individual's desired behavior. Thus it may overestimate the "satisfactory" level of independence. The sample size in this study was limited by missing SCIM scores and inconsistent follow-up and may have been too small to determine significance (as was the case for impact of asymmetry on ADLs). Finally, this study was unable to assess other factors that are known to affect independence, such as BMI, traumatic brain injury, autonomic dysreflexia and multiple comorbidities,[34,45-46] as these data were not included in the database.

Our study shows that spontaneous gain in functional independence plateaus by 6 months after SCI. This time window enables well informed decision making for patients (some lived experience) and clinicians. Early surgical intervention could alter the improvements in upper extremity function. Prospective comparative studies are needed to assess the effect of surgical intervention versus natural recovery on motor function and SCIM scores.

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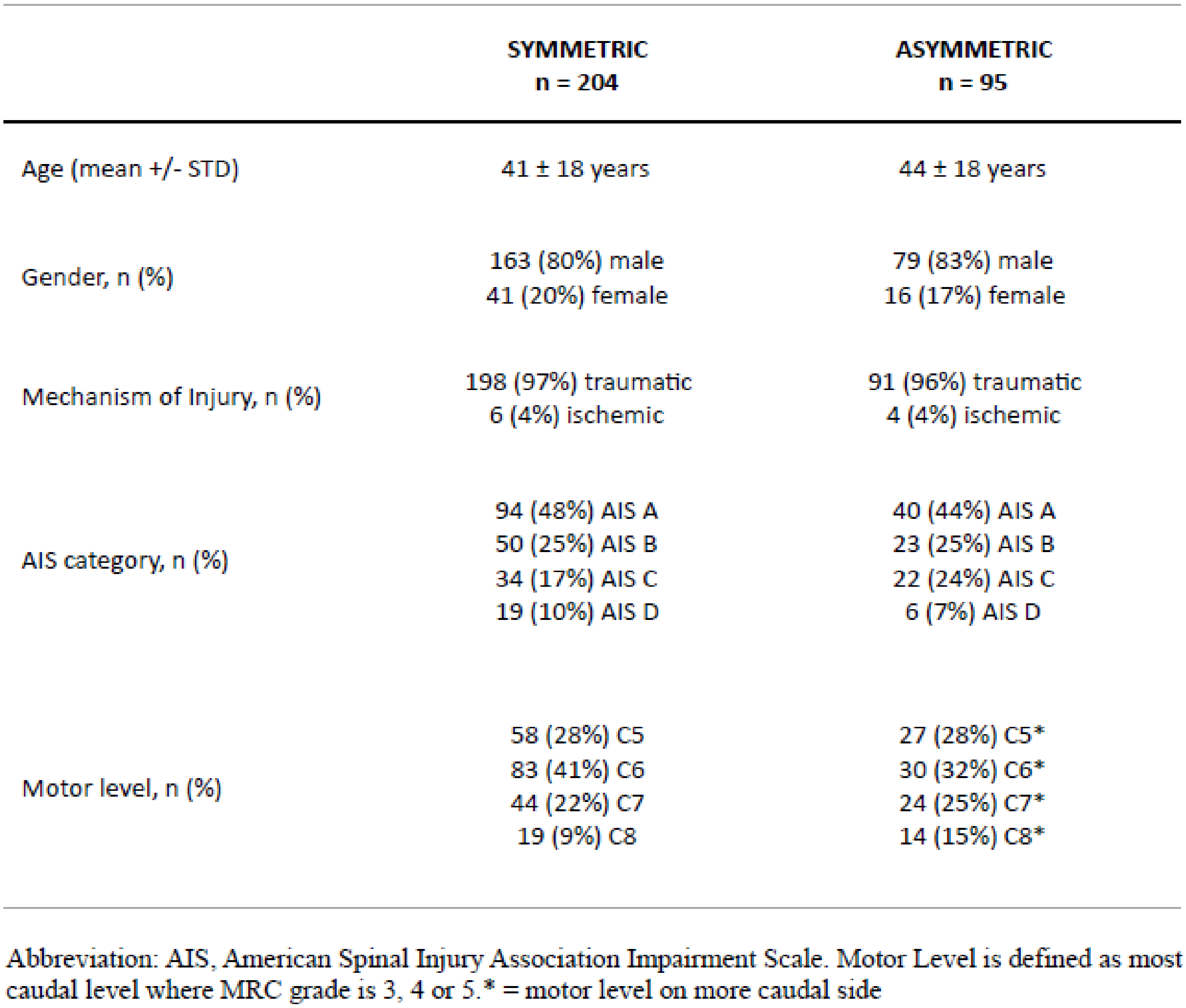
Tables

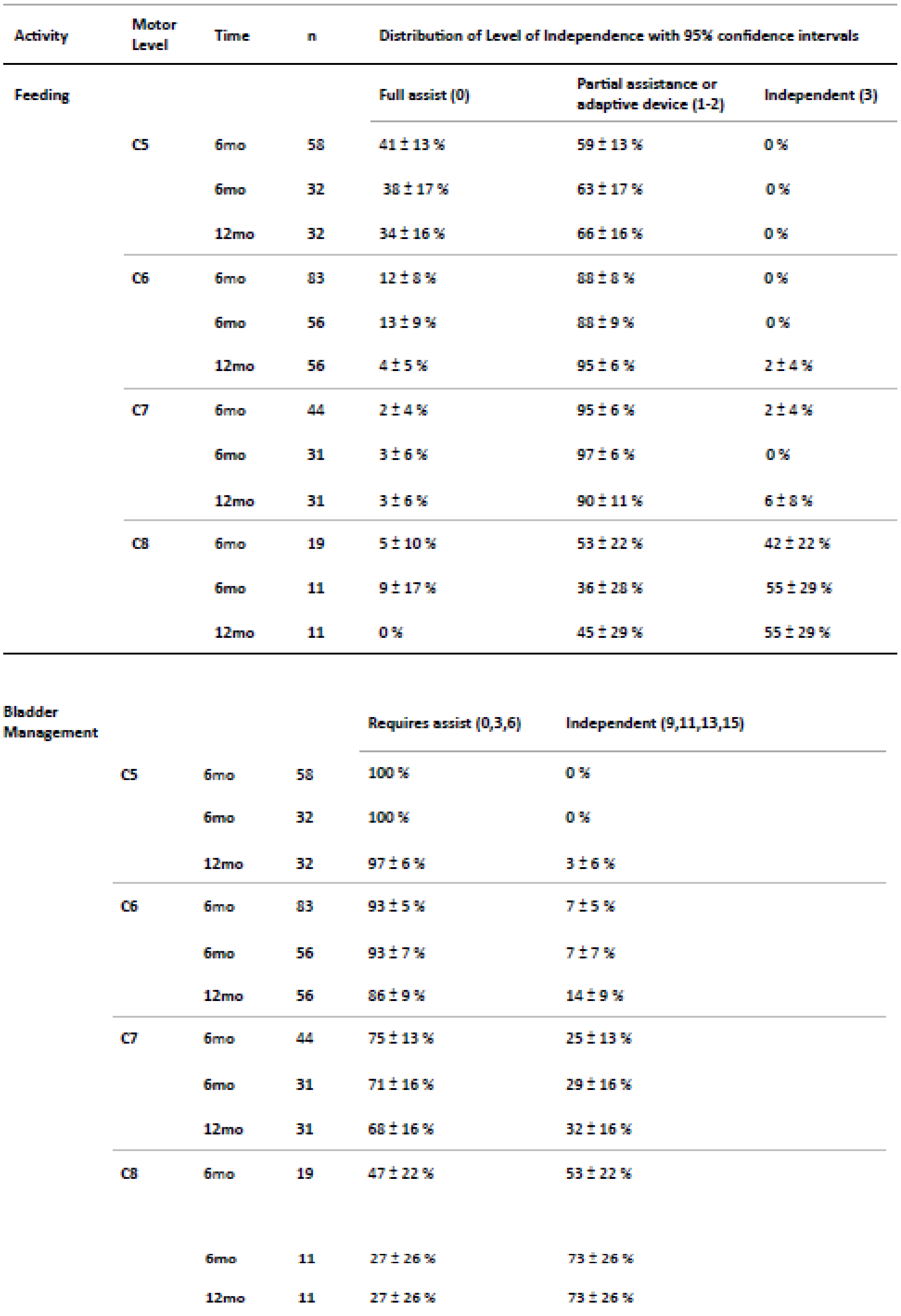
Table 1: Demographic data, SCI motor level C5-C8. Asymmetric pattern of injury was defined as one or more motor level difference between sides. AIS category is defined as: A complete, B sensory incomplete, C motor incomplete with > 50% of key muscles below the level graded as MRC < 3, and D motor incomplete with > 50% of key muscles below the level graded as MRC ≥ 3. Motor levels were assigned based on the most cephalad level at which MRC was graded 3, 4 or 5 with all rostral levels 4 or 5 and all caudal levels 0, 1 or 2.



	SYMMETRIC **n = 204**	**ASYMMETRIC** **n = 95**
Age (mean +/- STD)	41 ± 18 years	44 ± 18 years
Gender, n (%)	163 (80%) male 41 (20%) female	79 (83%) male 16 (17%) female
Mechanism of Injury, n (%)	198 (97%) traumatic 6 (4%) ischemic	91 (96%) traumatic 4 (4%) ischemic
AIS category, n (%)	94 (48%) AIS A 50 (25%) AIS B 34 (17%) AIS C 19 (10%) AIS D	40 (44%) AIS A 23 (25%) AIS B 22 (24%) AIS C 6 (7%) AIS D
Motor level, n (%)	58 (28%) C5 83 (41%) C6 44 (22%) C7 19 (9%) C8	27 (28%) C5* 30 (32%) C6* 24 (25%) C7* 14 (15%) C8*

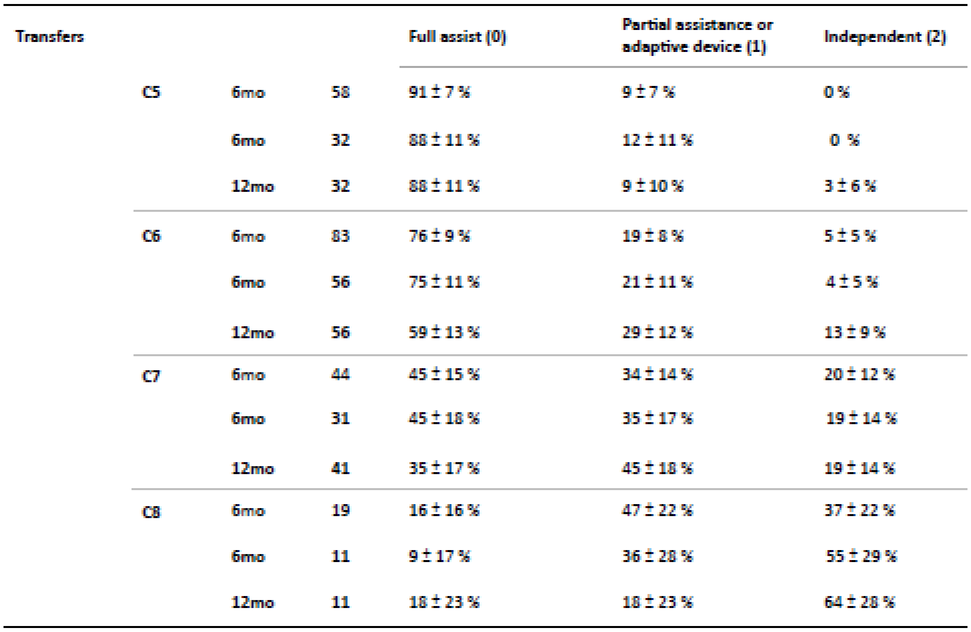
Abbreviation: AIS, American Spinal Injury Association Impairment Scale. Motor Level is defined as most caudal level where MRC grade is 3, 4 or 5.* = motor level on more caudal side

Table 2: Distribution of independence with feeding, bladder management and transfers (bed to wheelchair) for motor levels C5-C8 symmetric SCI, 6 months and 12 months after injury, as assessed by SCIM (items 1, 6, 10, respectively). Data presented as percent of total with 95% confidence intervals. Six-month data for all patients presented in addition to 6-month data for only those with corresponding 12-month data available (**bold**). Numbers in brackets (#) correspond to SCIM scores.



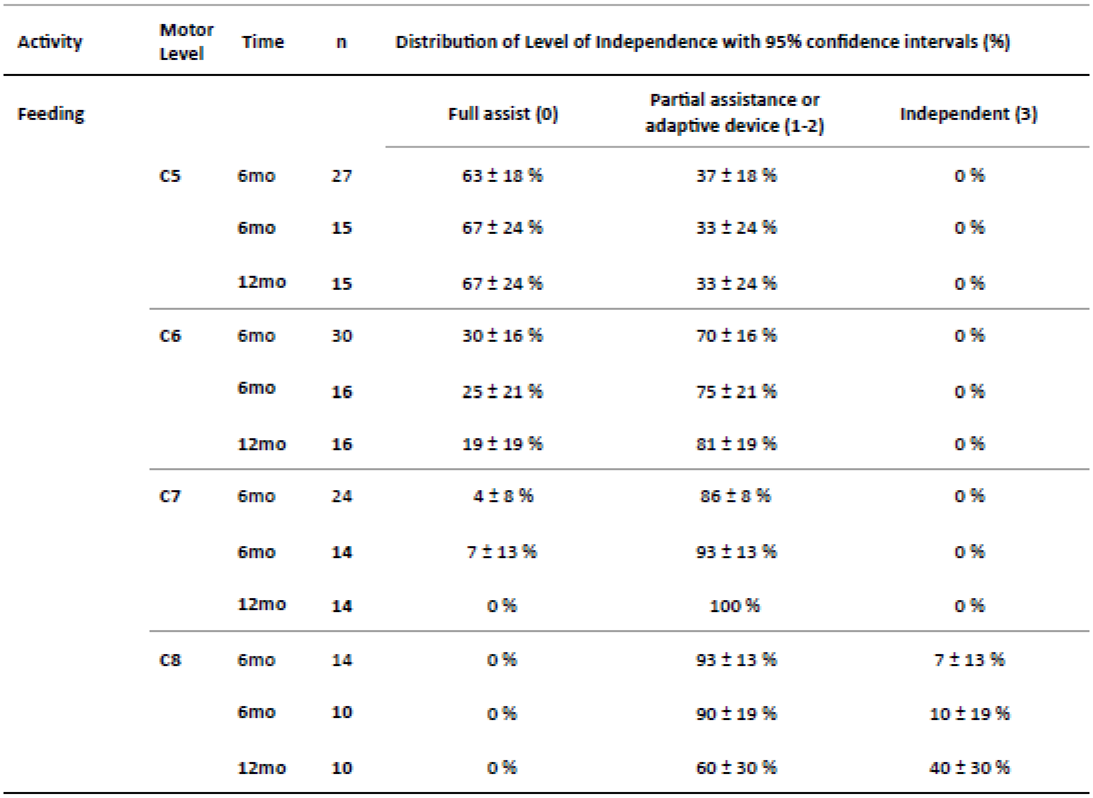
Activity	Motor Level	Time	n	Distribution of Level of Independence with 95% confidence intervals		
Feeding				Full assist (0)	Partial assistance or adaptive device (1-2)	Independent (3)
	C5	6mo	58	41 ± 13 %	59 ± 13 %	0 %
		6mo	32	38 ± 17 %	63 ± 17 %	0 %
		12mo	32	34 ± 16 %	66 ± 16 %	0 %
	C6	6mo	83	12 ± 8 %	88 ± 8 %	0 %
		6mo	56	13 ± 9 %	88 ± 9 %	0 %
		12mo	56	4 ± 5 %	95 ± 6 %	2 ± 4 %
	C7	6mo	44	2 ± 4 %	95 ± 6 %	2 ± 4 %
		6mo	31	3 ± 6 %	97 ± 6 %	0 %
		12mo	31	3 ± 6 %	90 ± 11 %	6 ± 8 %
	C8	6mo	19	5 ± 10 %	53 ± 22 %	42 ± 22 %
		6mo	11	9 ± 17 %	36 ± 28 %	55 ± 29 %
		12mo	11	0 %	45 ± 29 %	55 ± 29 %

Bladder Management				Requires assist (0,3,6)	Independent (9,11,13,15)
	C5	6mo	58	100 %	0 %
		6mo	32	100 %	0 %
		12mo	32	97 ± 6 %	3 ± 6 %
	C6	6mo	83	93 ± 5 %	7 ± 5 %
		6mo	56	93 ± 7 %	7 ± 7 %
		12mo	56	86 ± 9 %	14 ± 9 %
	C7	6mo	44	75 ± 13 %	25 ± 13 %
		6mo	31	71 ± 16 %	29 ± 16 %
		12mo	31	68 ± 16 %	32 ± 16 %
	C8	6mo	19	47 ± 22 %	53 ± 22 %
		6mo	11	27 ± 26 %	73 ± 26 %
		12mo	11	27 ± 26 %	73 ± 26 %



Transfers				Full assist (0)	Partial assistance or adaptive device (1)	Independent (2)
	C5	6mo	58	91 ± 7 %	9 ± 7 %	0 %
		6mo	**32**	**88 ± 11 %**	**12 ± 11 %**	**0 %**
		12mo	**32**	**88 ± 11 %**	**9 ± 10 %**	**3 ± 6 %**
	C6	6mo	83	76 ± 9 %	19 ± 8 %	5 ± 5 %
		6mo	**56**	**75 ± 11 %**	**21 ± 11 %**	**4 ± 5 %**
		12mo	**56**	**59 ± 13 %**	**29 ± 12 %**	**13 ± 9 %**
	C7	6mo	44	45 ± 15 %	34 ± 14 %	20 ± 12 %
		6mo	**31**	**45 ± 18 %**	**35 ± 17 %**	**19 ± 14 %**
		12mo	**41**	**35 ± 17 %**	**45 ± 18 %**	**19 ± 14 %**
	C8	6mo	19	16 ± 16 %	47 ± 22 %	37 ± 22 %
		6mo	**11**	**9 ± 17 %**	**36 ± 28 %**	**55 ± 29 %**
		12mo	**11**	**18 ± 23 %**	**18 ± 23 %**	**64 ± 28 %**

Supplemental Table 1: Distribution of independence with feeding, bladder management and transfers (bed to wheelchair) for motor levels C5-C8 symmetric SCI, 6 months and 12 months after injury, as assessed by SCIM (items 1, 6, 10, respectively). Data presented as percent of total with 95% confidence intervals. Six-month data for all patients presented in addition to 6-month data for only those with corresponding 12-month data available (**bolded**). Numbers in brackets (#) correspond to SCIM scores.



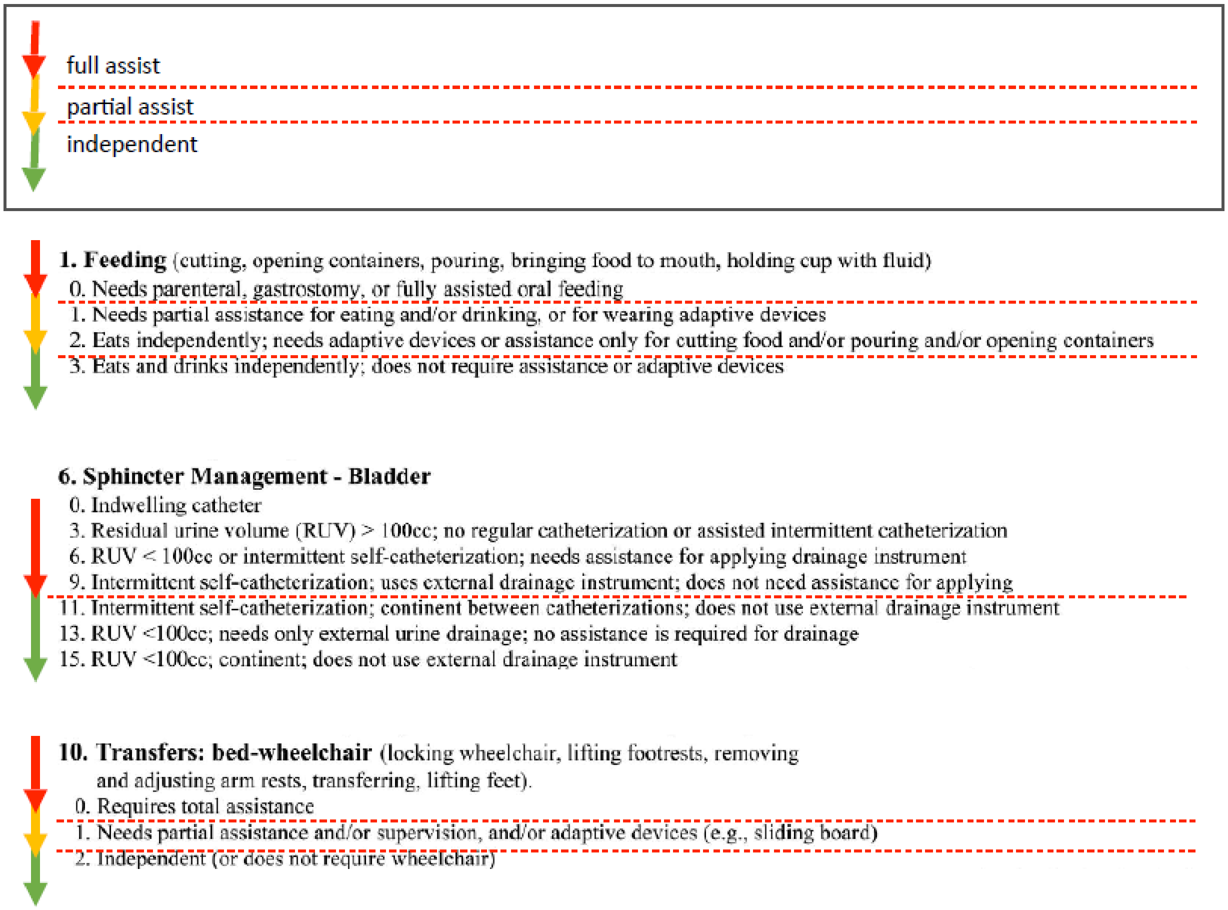
Activity	Motor Level	Time	n	Distribution of Level of Independence with 95% confidence intervals (%)		
Feeding				Full assist (0)	Partial assistance or adaptive device (1-2)	Independent (3)
	C5	6mo	27	63 ± 18 %	37 ± 18 %	0 %
		6mo	**15**	**67 ± 24 %**	**33 ± 24 %**	**0 %**
		12mo	**15**	**67 ± 24 %**	**33 ± 24 %**	**0 %**
	C6	6mo	30	30 ± 16 %	70 ± 16 %	0 %
		6mo	**16**	**25 ± 21 %**	**75 ± 21 %**	**0 %**
		12mo	**16**	**19 ± 19 %**	**81 ± 19 %**	**0 %**
	C7	6mo	24	4 ± 8 %	86 ± 8 %	0 %
		6mo	**14**	**7 ± 13 %**	**93 ± 13 %**	**0 %**
		12mo	**14**	**0 %**	**100 %**	**0 %**
	C8	6mo	14	0 %	93 ± 13 %	7 ± 13 %
		6mo	**10**	**0 %**	**90 ± 19 %**	**10 ± 19 %**
		12mo	**10**	**0 %**	**60 ± 30 %**	**40 ± 30 %**

Bladder Management				Requires assist (0,3,6)	Independent (9,11,13,15)
	C5	6mo	27	100 %	0 %
		6mo	15	100 %	0 %
		12mo	15	100 %	0 %
	C6	6mo	30	93 ± 9 %	7 ± 9 %
		6mo	16	94 ± 12 %	6 ± 12 %
		12mo	16	94 ± 12 %	6 ± 12 %
	C7	6mo	24	100 %	0 %
		6mo	14	100 %	0 %
		12mo	14	86 ± 18 %	14 ± 18 %
	C8	6mo	14	71 ± 24 %	29 ± 24 %
		6mo	10	80 ± 25 %	20 ± 25 %
		12mo	10	60 ± 30 %	40 ± 30 %

Transfers				Full assist (0)	Partial assistance or adaptive device (1)	Independent (2)
	C5	6mo	27	100 %	0 %	0 %
		6mo	15	100 %	0 %	0 %
		12mo	15	97 ± 9 %	3 ± 9 %	0 %
	C6	6mo	30	97 ± 6 %	0 %	3 ± 6 %
		6mo	16	94 ± 12 %	0 %	6 ± 12 %
		12mo	16	88 ± 16 %	6 ± 12 %	6 ± 12 %
	C7	6mo	24	67 ± 19 %	25 ± 17 %	8 ± 11 %
		6mo	14	57 ± 26 %	29 ± 24 %	14 ± 18 %
		12mo	14	57 ± 26 %	14 ± 18 %	29 ± 24 %
	C8	6mo	14	36 ± 25 %	36 ± 25 %	29 ± 24 %
		6mo	10	40 ± 30 %	20 ± 25 %	40 ± 30 %
		12mo	10	30 ± 28 %	30 ± 28 %	40 ± 30 %

Figure Legend

Figure 1: Spinal Cord Independence Measure (SCIM) items 1 (Feeding), 6 (Sphincter Management - Bladder) and 10 (Transfers: bed-wheelchair). One item from each domain (self-care, respiration and sphincter management, mobility) was chosen to widely reflect functional differences at various cervical spinal cord levels. SCIM answer choices were grouped into “independent” (green), “partial assist” (yellow) or “full assist” (red) as shown.



full assist
partial assist
independent

1. Feeding (cutting, opening containers, pouring, bringing food to mouth, holding cup with fluid)
0. Needs parenteral, gastrostomy, or fully assisted oral feeding
1. Needs partial assistance for eating and/or drinking, or for wearing adaptive devices
2. Eats independently; needs adaptive devices or assistance only for cutting food and/or pouring and/or opening containers
3. Eats and drinks independently; does not require assistance or adaptive devices

6. Sphincter Management - Bladder
0. Indwelling catheter
3. Residual urine volume (RUV) > 100cc; no regular catheterization or assisted intermittent catheterization
6. RUV < 100cc or intermittent self-catheterization; needs assistance for applying drainage instrument
9. Intermittent self-catheterization; uses external drainage instrument; does not need assistance for applying
11. Intermittent self-catheterization; continent between catheterizations; does not use external drainage instrument
13. RUV <100cc; needs only external urine drainage; no assistance is required for drainage
15. RUV <100cc; continent; does not use external drainage instrument

10. Transfers: bed-wheelchair (locking wheelchair, lifting footrests, removing and adjusting arm rests, transferring, lifting feet).
0. Requires total assistance
1. Needs partial assistance and/or supervision, and/or adaptive devices (e.g., sliding board)
2. Independent (or does not require wheelchair)

Figure 2: Feeding (SCIM item 1) by motor level for symmetric SCI, 6 months and 12 months after injury. Data presented as percentage of total. Feeding with assistance or adaptive devices was noted for the majority with strong (MRC 3-5) wrist extension (C6 function). Feeding independently without need for assistance or adaptive devices was noted only for individuals with strong (MRC 3-5) wrist flexion (C8 function). Independence with feeding did not significantly change between 6 and 12 months at any injury level, though a trend towards greater independence with greater time post-injury was seen.

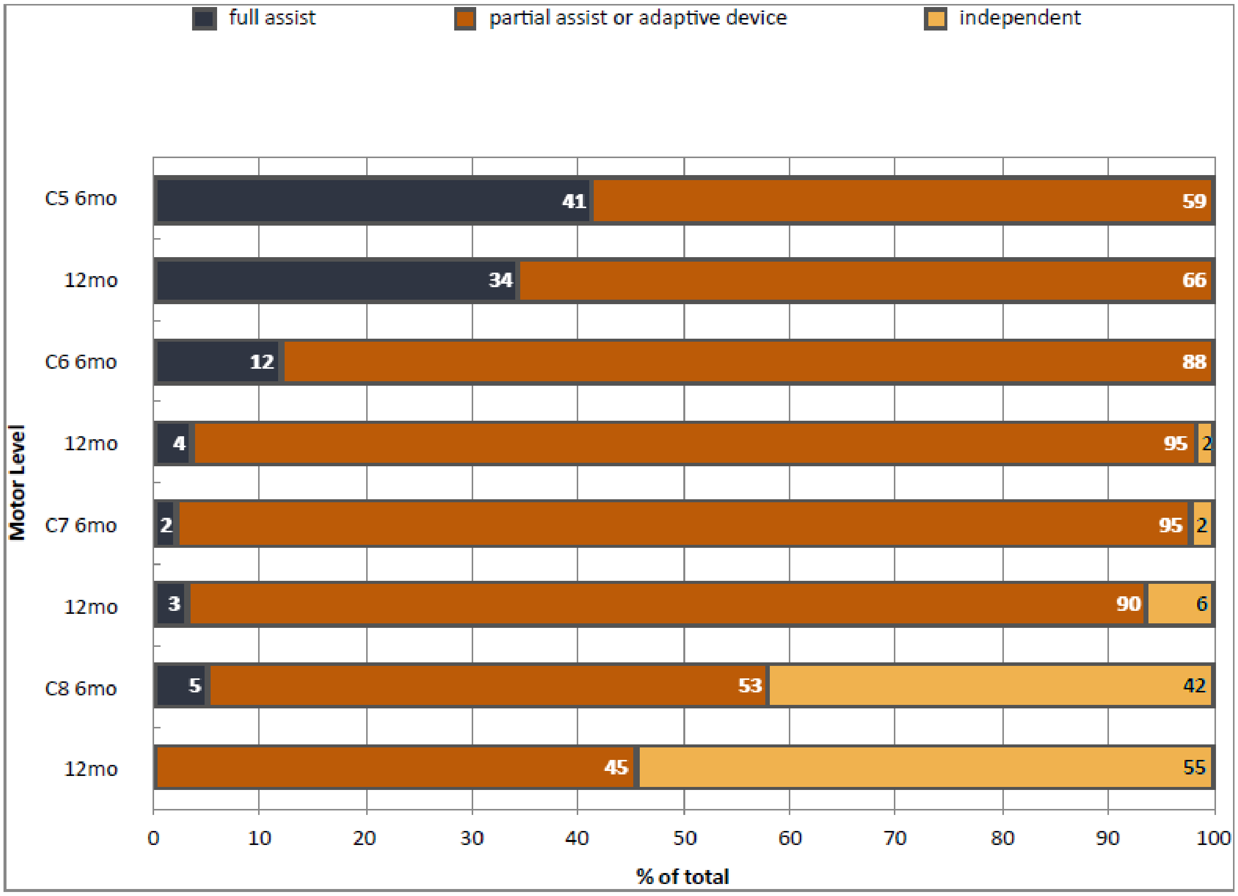


Figure 3: Bladder management (SCIM item 6) by motor level for symmetric SCI, 6 months and 12 months after injury. Data presented as percentage of total. Independence with bladder management was noted in those with strong (MRC 3-5) finger flexion (C8 function). Independence with bladder management did not significantly change between 6 and 12 months at any injury level, though again, trends towards greater independence with greater time post injury was seen.

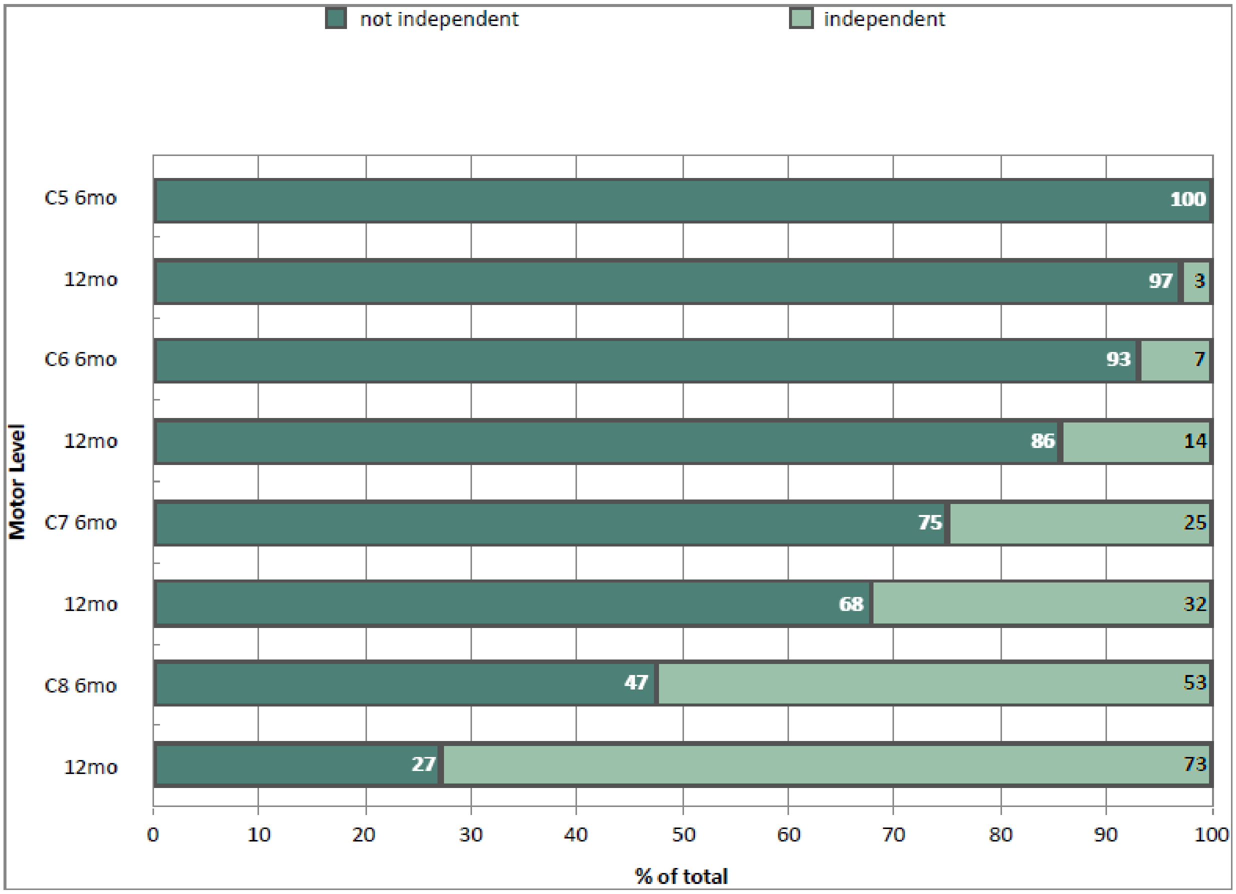
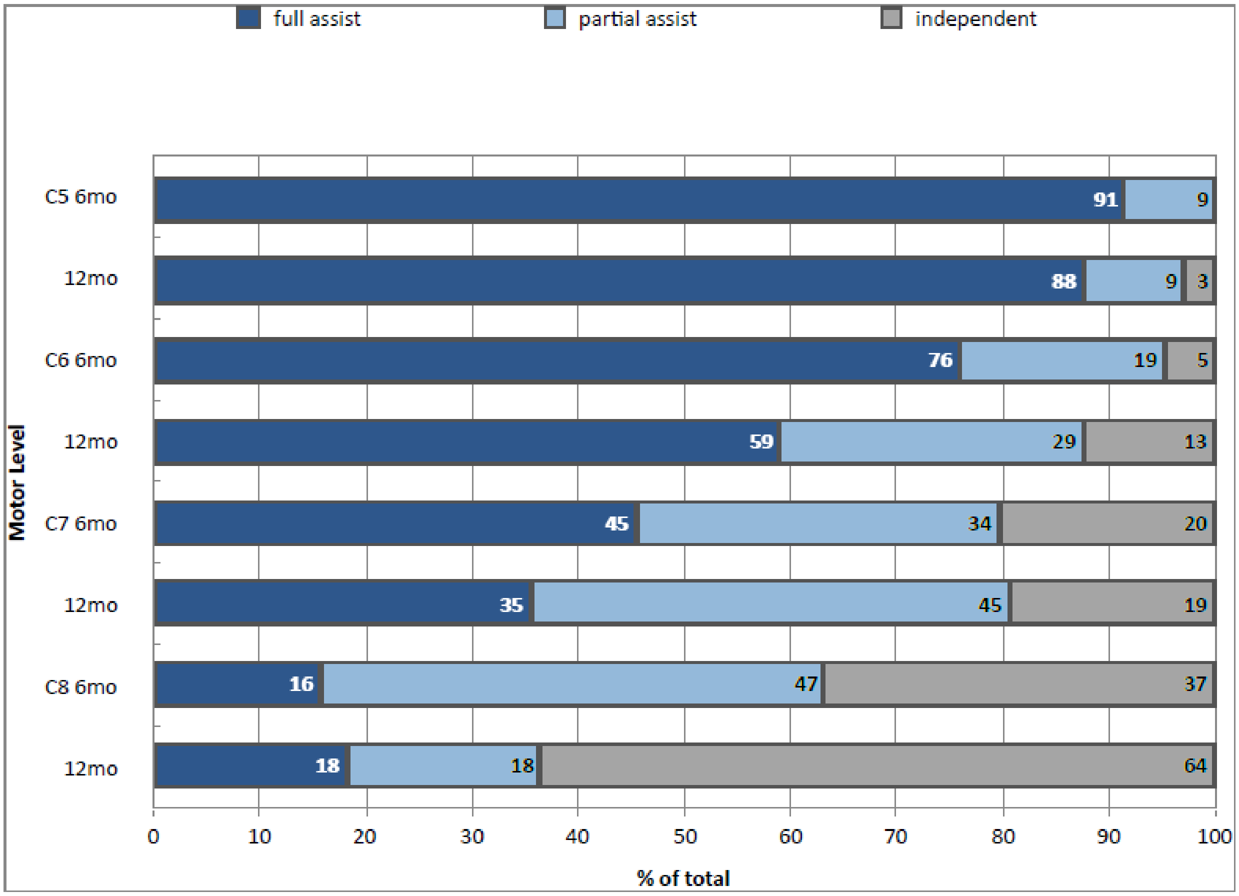
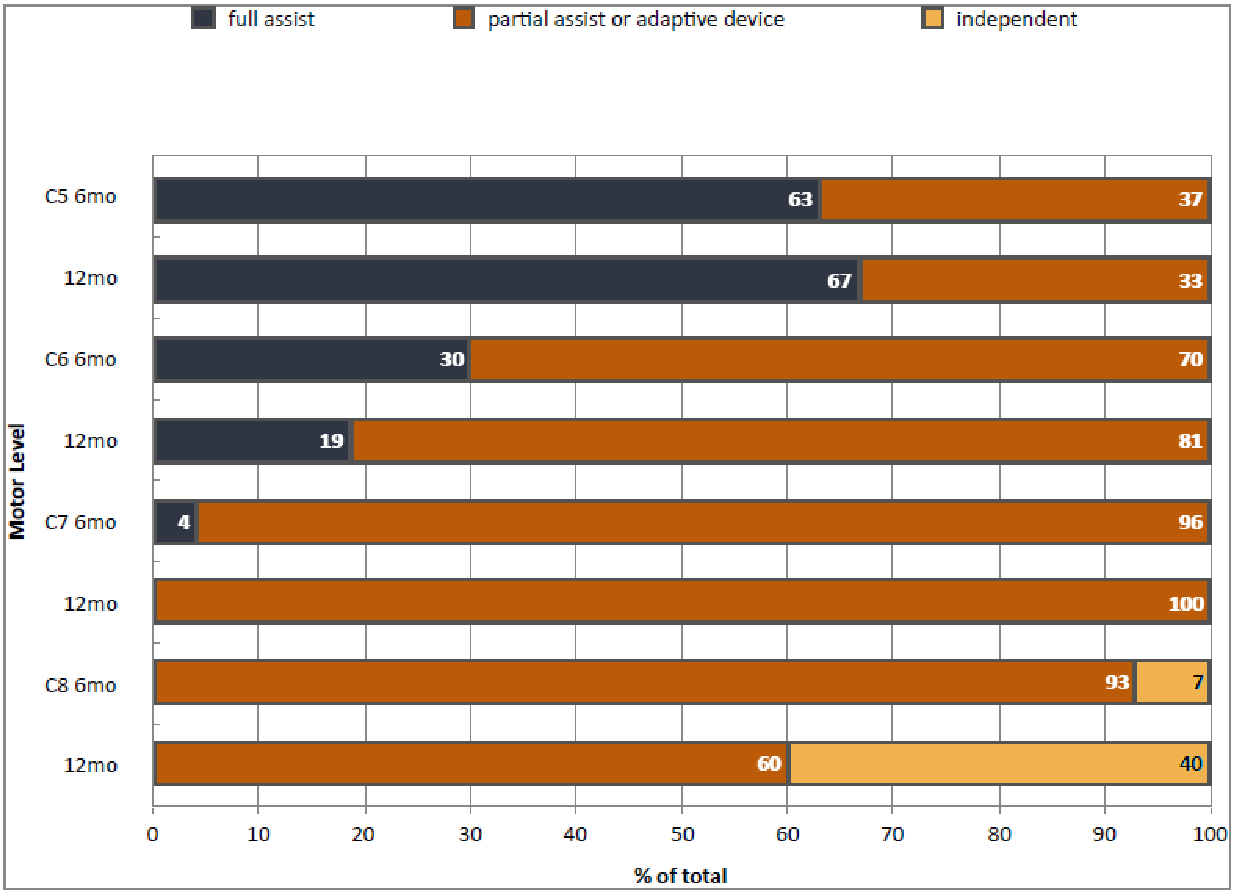


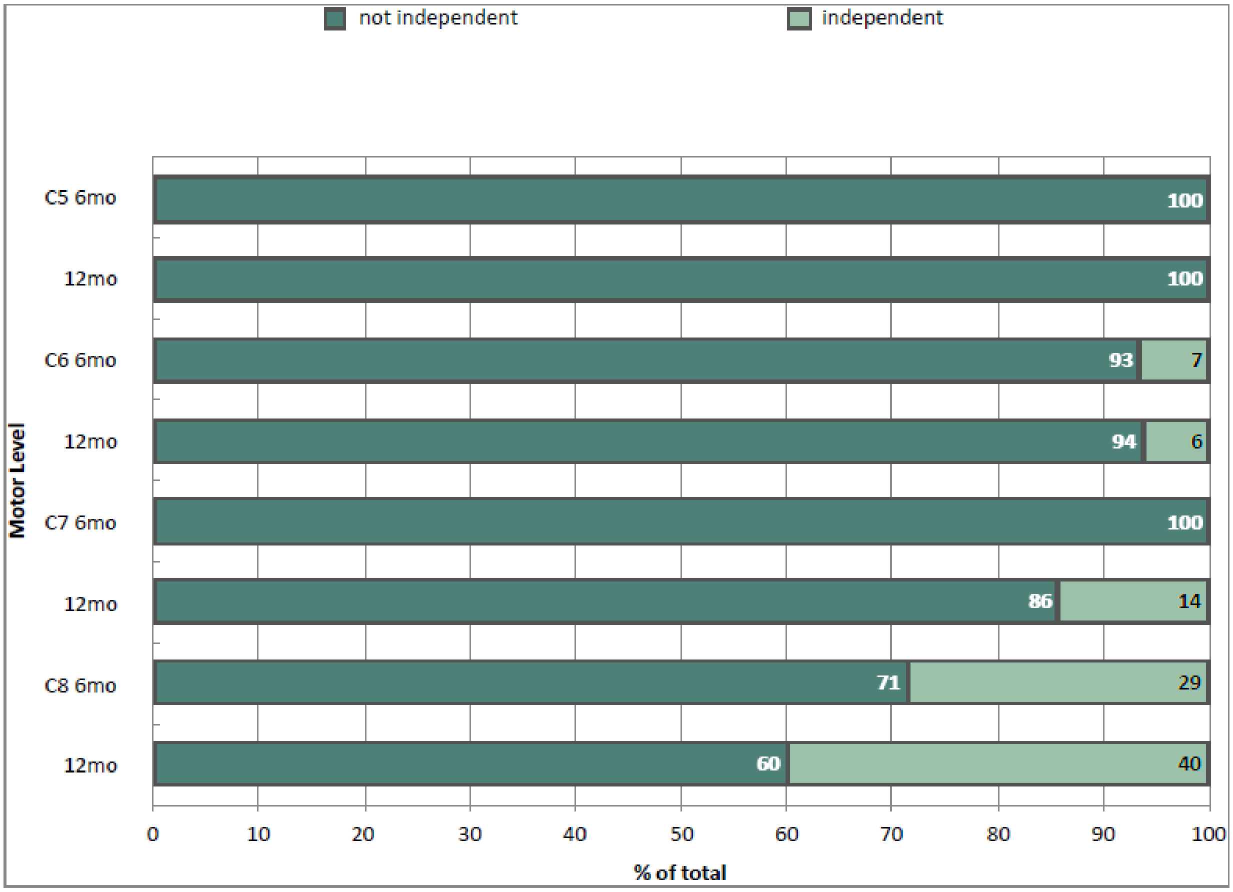
Figure 4: Transfers, bed to wheelchair (SCIM item 10) by motor level for symmetric SCI, 6 months and 12 months after injury. Data presented as percentage of total. Strong (MRC 3-5) elbow extension (C7 function) did not uniformly result in the ability to transfer independently; only 20% of participants with intact elbow extension were independent in transfers at 6 months. Strong (MRC 3-5) finger flexion (C8 function), however, was noted to be present in those who were independent with transfers. Notably, this data also shows that a small subset of 5-13% of individuals are able to transfer without any elbow extension present (C6 level). Independence with transfers did not significantly change between 6 and 12 months at any injury level, though again, trends towards greater independence with greater time post injury was seen.



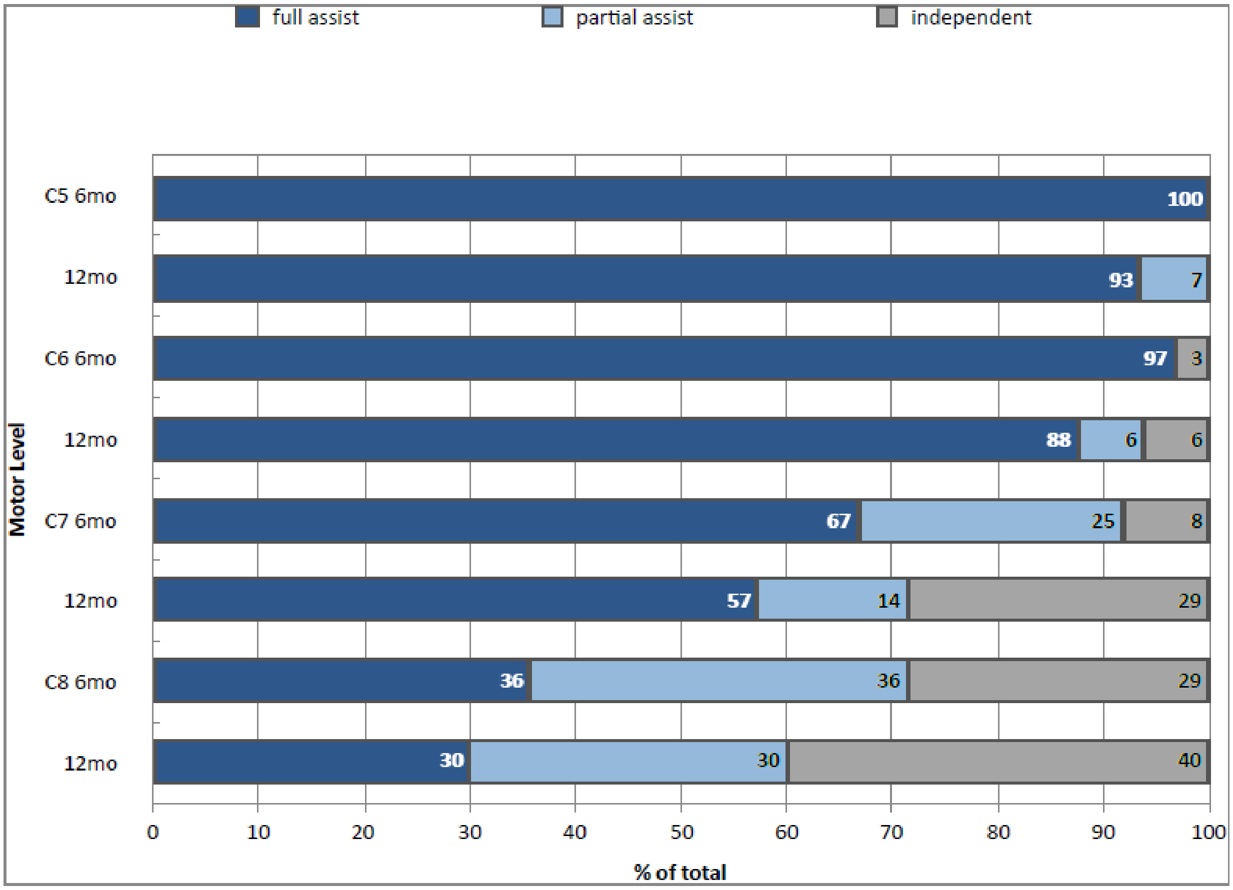
Supplemental Figure 1: Feeding (SCIM item 1) by motor level for asymmetric SCI, 6 months and 12 months after injury. Data presented as percentage of total. Feeding with assistance or adaptive devices was noted for the majority with strong (MRC 3-5) wrist extension (C6 function). Feeding independently without need for assistance or adaptive devices was noted only for individuals with strong (MRC 3-5) wrist flexion (C8 function). Independence with feeding did not significantly change between 6 and 12 months at any injury level, though a trend towards greater independence with greater time post-injury was seen.



Supplemental Figure 2: Bladder management (SCIM item 6) by motor level for asymmetric SCI, 6 months and 12 months after injury. Data presented as percentage of total. Independence with bladder management was noted in those with strong (MRC 3-5) finger flexion (C8 function). Independence with bladder management did not significantly change between 6 and 12 months at any injury level, though again, trends towards greater independence with greater time post injury was seen.



Supplemental Figure 3: Transfers, bed to wheelchair (SCIM item 10) by motor level for asymmetric SCI, 6 months and 12 months after injury. Data presented as percentage of total. Strong (MRC 3-5) elbow extension (C7 function) did not uniformly result in the ability to transfer independently; only 8% of participants with intact elbow extension were independent in transfers at 6 months. Strong (MRC 3-5) finger flexion (C8 function), however, was noted to be present in those who were independent with transfers. Notably, this data also shows that a small subset of 3-6% of individuals were able to transfer without any elbow extension present (C6 level). Independence with transfers did not significantly change between 6 and 12 months at any injury level, though again, trends towards greater independence with greater time post injury was seen.



Appendix 6

SCI decision aid website

Website content draft

1. WELCOME PAGE

Welcome to <<Name/brand?>>

- This website was designed for people who have had a cervical level spinal cord injury (SCI) that limits movement in their arms and hands

The information in this website will help you learn about 2 types of surgery that can help bring back (regain) movements you lost due to your injury. These surgeries are called **nerve transfer** and **tendon transfer.**
This website will also help you:

- Compare nerve transfer and tendon transfer surgeries
- Think about if surgery is an option for you, including costs
- Have a conversation with your doctor to decide if surgery is right for you

Surgery may work best within an ideal timeframe after SCI. If you want to make sure you keep all possible surgery options, it's best to talk to your doctor as soon as possible.
The information on this website is specific to surgery options that research shows can help people regain movement. If you want to learn more about options other than surgery, ask your doctor.

2. RECOVERY AFTER SPINAL CORD INJURY

What is spinal cord injury (SCI)?

Your spinal cord is the group of nerves that runs from your brain down your spine. It connects your brain to the rest of your body. It's like a pathway that your brain uses to communicate with the rest of your body by sending signals.
To move your body, your brain sends a signal **out** through your spinal cord to your body. For example, if you want to wave hello, your brain sends a signal to the muscles in your arm.
Other signals go **into** your brain through your spinal cord. For example, when your hand touches something that's hot or cold, you feel that sensation because the signal travels from your hand to your brain through your spinal cord.
<<Simplified anatomical illustration showing SCI>>

How does SCI affect movement?

SCI damages the pathway between your brain and body, which interrupts communication between your brain and body. As a result, SCI can limit movement and feeling in parts of your body. For example, if the signals that your brain sends to your wrists can't reach them, you won't be able to bend your wrists. Or, you may not be able to feel when something touches your skin.

How can I get movement back after SCI?

Natural recovery

Sometimes, part of the damage to your spinal cord can heal on its own, and you get some movement back. This is called natural recovery.
Dramatic gains in movement (natural recovery) usually happens early after your injury. Then it drops off. Between 6 and 12 months after injury, on average, only about 1 in 10 people have natural recovery after SCI.
Hyperlink or dropdown: Learn more about your chances of natural recovery based on your level of injury (2.1).

Surgery to regain movement

Surgery may also be an option to regain movement after SCI. Surgery may work best within an ideal timeframe after SCI. If you want to make sure you keep all possible surgery options, it's best to talk to your doctor as soon as possible (ideally within 6 months of injury).

2.1 NATURAL RECOVERY FOR SPINAL CORD INJURY ("OFFSHOOT" PAGE)

The chance of natural recovery depends on the level of SCI you have. Doctors name your level of injury based on the movement that is retained/you have.

<<Graphic: simplified anatomical illustration of spine, with cervical and upper thoracic vertebra labeled>>

Researchers have studied the number of people who do and do not have natural recovery after SCI. The table below shows the chance of natural recovery for people with different SCI levels. To see the chance of natural recovery for people with SCI like yours, find your SCI level in the table below. If you don't know the level of your SCI, ask your doctor.

Chance of natural recovery 12 months after SCI

SCI level	Movements you may have lost in your hands, wrist, and arm	People who recovered movement	People who didn't recover movement
C5	• Ability to bend your elbow and move it to rotate your palm up • Full range of shoulder movement		
C6	All the above functions, plus: • Ability to straighten and pull your wrist back • Ability to move your elbow to rotate your palm down • Ability to move your shoulders forward (hunch or round them) • Ability to move your shoulder to raise your arm	11% 6 out of 54 people	89% 48 out of 54 people
C7	All the above functions, plus: • Ability to straighten your elbow • Ability to straighten and bend your fingers and move thumb parallel to your fingers	9% 5 out of 54 people	91% 49 out of 54 people
C8	All the above functions, plus: • Ability to bend your fingers at their base and move your thumb to grab	4% 2 out of 47 people	96% 45 out of 47 people
T1	All of the above functions, plus: • Ability to spread your fingers apart	28% 5 out of 18 people	72% 13 out of 18 people

3. SURGERY TO REGAIN MOVEMENT

There are 2 types of surgery that can help regain (bring back) movement in the shoulders, arms, elbows, wrists, and hands after SCI: nerve transfer and tendon transfer. If you didn't fully lose a movement, these surgeries can also help strengthen movements that you still have.

Research has shown that these surgeries can help people with SCI regain movements, such as reaching out their arms and/or grasping and releasing things with their hands.
Surgery to regain movement does not guarantee that you will be able to do more activities (eating, transfers, writing, etc.). Movement that you regain from surgery cannot always be put to use to carry out an activity. It depends on other things such as your overall fitness, body weight, etc.

How do these surgeries work?

The basic idea of nerve transfer and tendon transfer surgery is that doctors connect a part of your body that works (that you can move) to a part of your body that does not work (that you can't move). Both types of surgery are done in the arm and/or hand not within the spinal cord.

Tendon transfer

Tendons are the rope-like tissues that attach your muscles to your bones. When your muscles flex, they pull on the bone, and this allows your joints, such as your elbows, wrists, and fingers, to move.
<<Simplified illustration of tendons working, e.g. elbow joint with flexed and relaxed bicep muscle, bending and straightening the elbow>>
In tendon transfer, doctors cut and attach a tendon from a muscle that you **can** move to one or more tendons that you can't move. After the tendon transfer heals,, the working muscle can help you regain a movement that you lost.
<<simplified illustration of tendon transfer, similar in style to illustration below>>
Source: https://www.assh.org/LinkClick.aspx?fileticket=wzH8DUQd3Fo%3D&portalid=1

Nerve transfer

Nerves are the that connect your brain to different parts of your body. Your brain sends signals through your nerves that tell your muscles to move.
<<simplified anatomical illustration of signal traveling from brain through a nerve>>
In nerve transfer, doctors connect a working nerve that **can** carry a signal from your brain to a nerve that has been damaged and can't carry a signal anymore. The transferred nerve can now carry the signal to your muscle and tells it to move. This helps you regain a movement that you lost.
<<simplified anatomical illustration of nerve transfer surgery>>

WHAT MOVEMENTS CAN SURGERY CAN HELP YOU REGAIN?

There are different types of tendon and nerve transfer surgeries. In general, both tendon transfer and nerve transfer can help you regain movements to:

- 4)Bend your thumb and fingers to actively close your hand
- 3)Straighten your thumb and fingers to actively open your hand
- 2)Straighten and pull your wrist back (which can allow passive or 'tenodesis' hand function)
- 1)Straighten your elbow
-

5) prevent clawing/restore more coordinated intrinsic muscle function These movements may be helpful for doing daily activities and things you want to do on your own, such as:

- Eating
- Writing
- Using a phone, computer or other electronics
- Accomplish urinary function (insert catheter, empty urinal, etc.)Help with transfers such as moving from your wheelchair to your bed

Keep in mind that with surgery there may be a trade-off in movement. When doctors transfer a working tendon or nerve, you may lose some or all of the movement that nerve or tendon allowed before surgery.
Every SCI is different and every person has different goals. You and your doctor can talk about:

- Your injury
- The kinds of movements you may regain with surgery
- How likely it is that these movements will be useful to you

Hyperlink or dropdown: Check out some things you may want to think about when deciding whether to have surgery (3.1)
Outcomes info

3.1. THINGS TO CONSIDER BEFORE SURGERY

Am I healthy enough for surgery at all?

Some health problems can prevent you from having surgery right now. You must take care of these problems before you can move ahead with surgery. These problems include:

- Pressure sores or other open wounds.
- Active infection (such as a urinary tract infection)
- High blood pressure or diabetes that is not under control
- Serious heart and lung problems; morbid obesity
- Progressive weakness or loss of movement might indicate a syrinx in the spinal cord—talk to your spine surgeon, primary care or Physical Medicine and Rehabilitation doctor for evaluation.

Other things such as pain, spasticity, joint contractures and stiffness may be relative contraindications for some surgery Spasticity may actually be treated by the nerve transfer surgery in other cases it must be treated before surgery. Realistic expectations and good mental health are also important. These surgeries cannot restore the function that you had before the SCI happened. They can give back some new movement and that can improve activity and quality of life amongst other things.

What should I think about?

Whether or not to have surgery is a serious decision that is affected by:

- Your personal thoughts, feelings, and goals
- The type of injury you have
- Your living situation, including things such as:
  - Your job and money
  - The amount of support you can get from other people

Your doctor can help you think about all these things.
To help you start thinking about your surgery options, answer the questions below. You can print out your answers and bring them to a doctor visit to guide your conversation about surgery.

1. **How long has it been since your injury?**
   - Less than 6 months
   - Between 6 and 12 months
   - 1 to 2 years
   - More than 2 years

2. **How much support do you have from other people in your life, such as family or close friends? For example, people who would be able to help you as you recover from surgery.**
   - I have 1 or more people that I can rely on for help every day
   - I have people who could help me, but not every day
   - I am mostly on my own

3. **How would you pay for surgery?**
   - I have health insurance that would pay for surgery
   - I have health coverage through the VA
   - I have other coverage, such as Medicare, that would pay for surgery
   - I'm not sure how I would pay for surgery

4. **How long can you wait to recover from surgery before you need to get back to work, school, or other things you do?**
   - I can take as long as I need to recover
   - I can take a couple of weeks or months to recover
   - I have to get back to something pretty soon after surgery

5. **Would you be able to go to rehabilitation (rehab), such as physical therapy, for <<frequency and duration of rehab>> after surgery?**
   - ○ Yes, I could go to rehab
   - ○ I might be able to go to rehab, but I'm not sure
   - ○ I would not be able to go to rehab

6. **How are you with pain?**
   - ○ I worry about and avoid pain as much as possible
   - ○ I can deal with some pain for a while
   - ○ I can deal with pain with no problem

7. **What are your goals for regaining movement? For example, is there a specific activity you want to be able to do on your own?**
   - ○ I'm not sure
   - ○ I have an idea, but I want to learn more.
   - ○ I have specific activities I want to do again: (please list:________________)

Also think about: copay, time, logistics, local availability of the surgeon/therapist (travel).

Do we want to state anything about long term and short terms goals (example Tendon transfer may give more downtime up front but might give more power in the long term versus tendon transfer may give less downtime up front, takes longer and might get less strength then a tendon transfer.

<<Link to download printable version of questions>>

Your answers to these questions (and other questions your doctor may ask) will help you and your doctor decide if surgery is right for you, and if so, which type of surgery.

Think about these questions as you read the rest of the information on this website.

Hyperlink or dropdown: Learn more about what you can do if surgery is not an option for you. (3.2)

3.2. WHAT IF SURGERY IS NOT AN OPTION FOR ME? ("OFFSHOOT" PAGE)

If you have a health problem other than your SCI that prevents you from having surgery, such as high blood pressure that's not under control, talk to your health care team about it.

You may be able to:

- Talk about your goals for surgery
- Make a plan for dealing with your health problem

If surgery is not an option for you due to the type of injury you have, your living situation, or other reasons, you may have options besides surgery for regaining some movement. The Resources page has information about things such as physical therapy or devices that can help some people.

4. COMPARE SURGERY TYPES

Nerve transfer and tendon transfer are both surgeries that can help you regain movement you lost due to SCI. For some people, it may be that one or the other is a better option. Other people can have both tendon transfer and nerve transfer, either at the same time or at separate times and/or on the same arm or different arms.

What should I know about surgery?

No surgery is risk-free. Problems can occur during and after any kind of surgery, including tendon transfer and nerve transfer. These problems include:

Problems caused by the anesthesia (the medicine doctors use to put you to sleep during surgery,) such as:

- Feeling sick to your stomach or throwing up
- Feeling cold or shivering
- A heart attack or stroke
- Pneumonia (an infection that fills your lungs with fluid and mucus)

Other possible problems include:

- Trouble breathing
- Bleeding

- Blood clots
- An infection at the surgery site

These problems are rare. However, people with SCI can have a higher chance of these problems happening.

nerve transfer and tendon transfer

The table below helps you look at nerve transfer and tendon transfer surgeries, and think about if they may be a good option for you (remember these can be combined):

Questions	**Nerve transfer**	**Tendon transfer**
What is the ideal timeframe after injury to have surgery?	Works best when done early after your injury.	No time limit after your injury. But some people felt worked better if it was done early after injury.
What kinds of movement can it help you regain?	Good for fine, delicate movements, such eating or using a phone. It can be slow to regain these movements; anywhere from 3 months to a year.	Good for a stronger, grabbing or pinching type of movement, such as grabbing onto bed rails. Regaining movement is faster; but you may not be allowed to use that movement freely until things have healed.
What tests do you need before surgery?	You need electrodiagnostic testing (a test that uses a small amount of electricity to see if a nerve can carry a signal and a needle needs to be put into the muscle to see if it is working)	Usually no special testing is needed before surgery.
How much pain does the surgery cause?	Testing may be painful. Less pain during recovery.	Recovery can be painful for some people.
How long does it take to recover (heal) from surgery?	Takes less time to heal after surgery; about 1 month of healing. No splint or cast needed.	Takes more time to heal after surgery. You need to wear a splint and a cast.
How much help and support will I need from others after surgery?	You'll need help for 2-4 weeks to do daily activities, though you may still be allowed to use the arms and hands for light activity.	You'll need help for 2-3 months to do daily activities. You will not be allowed to use the operative arm even for light activity for the first 1-2 months.
Rehab	Nerve transfer: usually can use arm for light activity immediately post-surgery. No use of arm for manual wheelchair propulsion, transfer, sports or other heavy duty activity. Use of the arm for weightbearing and manual wheelchair use is usually allowed between 2 and 4 weeks post surgery depending on healing. Sports and heavy duty activity is allowed at 4-8 weeks post surgery depending on healing. Therapy is usually once a month or once every three months until the nerve transfer	Tendon transfer: ideally (as in Europe or maybe the VA) you would be inpatient and get therapy 4x/day. More likely you will be in post op dressing/splint x 2 weeks, cast x 2 weeks with very limited or no use of the affected arm. Then start therapy with removable splint that you remove just for therapy exercises at 4 weeks post op. The splint is weaned at about 2 months post surgery. Sports and heavy duty activity is limited for about 3 (even up to 6 months) post surgery depending on function/healing.

	begins to work (typically at 6-12 months post-surgery). Until then, exercises in therapy and daily at home are important to learn how to make the transfer 'fire' or work. Once it does, therapy may increase to 1-4 times a month with a continued home exercise program.	Therapy can be a few times a week once started but the person should also be doing exercises at home several times a day.
Outcomes		

The type of surgery that is best for you also depends on things such as the amount of help and support you can get while you heal from surgery and how soon you need to get back to your job or school. You can answer some questions (link to 3.1) to help you think about these things.

NEXT STEPS

Talk to your doctor

You may decide you want to take the next step and look into having surgery. If so, you'll want to talk to your doctor or health care team about it. This website can help you with that discussion:

- Show your doctor the list of questions on this website. Talk about your answers, and how they affect your decision about surgery.
- Talk about your goals for regaining movement:
    - What do you want to be able to do more independently?
    - What is the chance that surgery will be able to help you do that?
- Ask about the kinds of help and support you may need while you are healing from surgery, and for how long

Get evaluated to see if surgery can help

Your doctor may tell you that you need to have some tests to see if surgery is an option for you. These tests may include:

- An exam to see if you have nerves or tendons that are working and can be used to regain movements using surgery
- An electrodiagnostic test with a device that uses a very small amount of electricity to see if your nerves can carry a signal (nerve conduction testing) and a needle that is inserted into muscle to see if they are working (electromyography)

With this information, your doctor will be able to tell you more about your surgery options. For example, they can tell you if you should get surgery as soon as possible or if you can wait a while.

Talk to your family and friends

Your family and friends can help you think about the choice to have surgery. Talk about the kinds of help and support you may need when you are healing from surgery.

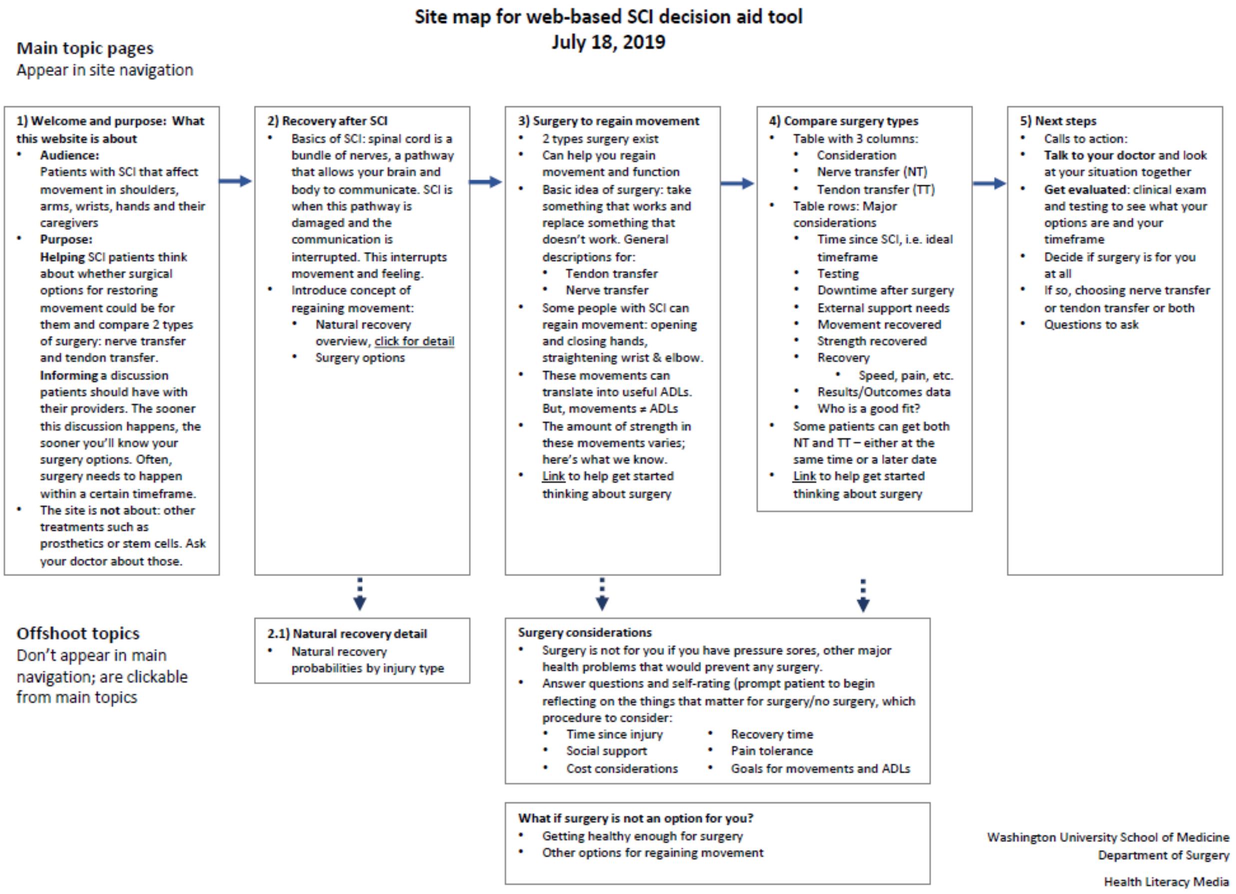
Think about surgery soon

When an SCI happens, it usually means a lot of changes for the way you live your life. These changes can be big, and you may be dealing with feelings and emotions that make it hard to think about things like surgery. However, some people with SCI say they wish they had thought about surgery sooner, since some options go away as time passes.

The choice to have surgery is personal, and your options depend on your situation. We wish you good luck as you continue to explore your options.

RESOURCES

- Look for a surgeon who does nerve or tendon transfers
- Learn more about other treatment options for SCI
- Learn more about ways people pay for surgery



Site map for web-based SCI decision aid tool
July 18, 2019

Main topic pages
Appear in site navigation

1) Welcome and purpose: What this website is about
- **Audience:**
  Patients with SCI that affect movement in shoulders, arms, wrists, hands and their caregivers
- **Purpose:**
  Helping SCI patients think about whether surgical options for restoring movement could be for them and compare 2 types of surgery: nerve transfer and tendon transfer.
  Informing a discussion patients should have with their providers. The sooner this discussion happens, the sooner you'll know your surgery options. Often, surgery needs to happen within a certain timeframe.
- The site is **not** about: other treatments such as prosthetics or stem cells. Ask your doctor about those.

2) Recovery after SCI
- Basics of SCI: spinal cord is a bundle of nerves, a pathway that allows your brain and body to communicate. SCI is when this pathway is damaged and the communication is interrupted. This interrupts movement and feeling.
- Introduce concept of regaining movement:
  - Natural recovery overview, click for detail
  - Surgery options

3) Surgery to regain movement
- 2 types surgery exist
- Can help you regain movement and function
- Basic idea of surgery: take something that works and replace something that doesn't work. General descriptions for:
  - Tendon transfer
  - Nerve transfer
- Some people with SCI can regain movement: opening and closing hands, straightening wrist & elbow.
- These movements can translate into useful ADLs. But, movements ≠ ADLs
- The amount of strength in these movements varies; here's what we know.
- Link to help get started thinking about surgery

4) Compare surgery types
- Table with 3 columns:
  - Consideration
  - Nerve transfer (NT)
  - Tendon transfer (TT)
- Table rows: Major considerations
  - Time since SCI, i.e. ideal timeframe
  - Testing
  - Downtime after surgery
  - External support needs
  - Movement recovered
  - Strength recovered
  - Recovery
    - Speed, pain, etc.
  - Results/Outcomes data
  - Who is a good fit?
- Some patients can get both NT and TT – either at the same time or a later date
- Link to help get started thinking about surgery

5) Next steps
- Calls to action:
- **Talk to your doctor** and look at your situation together
- **Get evaluated:** clinical exam and testing to see what your options are and your timeframe
- Decide if surgery is for you at all
- If so, choosing nerve transfer or tendon transfer or both
- Questions to ask

Offshoot topics
Don't appear in main navigation; are clickable from main topics

2.1) Natural recovery detail
- Natural recovery probabilities by injury type

Surgery considerations
- Surgery is not for you if you have pressure sores, other major health problems that would prevent any surgery.
- Answer questions and self-rating (prompt patient to begin reflecting on the things that matter for surgery/no surgery, which procedure to consider:
  - Time since injury
  - Social support
  - Cost considerations
  - Recovery time
  - Pain tolerance
  - Goals for movements and ADLs

What if surgery is not an option for you?
- Getting healthy enough for surgery
- Other options for regaining movement

Washington University School of Medicine
Department of Surgery

Health Literacy Media

Current Best Peripheral Nerve Transfers for Spinal Cord Injury

Elspeth J. R. Hill, M.D., Ph.D., M.Res.
Ida K. Fox, M.D.

St. Louis, Mo.

Learning Objectives: After reviewing this article, the participant should be able to: 1. Understand the anatomy and pathophysiology of spinal cord injury and the resulting upper and lower motor neuron syndromes. 2. Recognize who may benefit from nerve transfers. 3. Understand the role of history, examination, imaging, and electrodiagnostics in the determination of time-sensitive lower motor neuron injury versus non–time-sensitive upper motor neuron injury. 4. Outline the surgical options and perioperative care for those undergoing nerve transfer and the expected outcomes in restoring shoulder, elbow, wrist, and hand function.

Summary: This article outlines how to localize and differentiate upper motor neuron from combined upper and lower motor neuron injury patterns in spinal cord injury by means of detailed history, physical examination, imaging, and electrodiagnostic studies to formulate appropriate surgical plans to restore function in this complex population. (*Plast. Reconstr. Surg.* 143: 184e, 2019.)

Nerve transfers have transformed care available for restoration of motor function in people with peripheral nerve injury and brachial plexus injury.[1] However, nerve transfer to restore function after spinal cord injury is a rapidly evolving field that has demonstrated remarkable success. It is therefore timely to discuss under what circumstances nerve transfers should be considered for spinal cord injury. Previous CME review articles have focused on tendon and nerve transfers in the upper extremity[2] and have provided an overview of adult peripheral nerve and brachial plexus injury encompassing nerve entrapment, repair, and transfer.[1] Here, we focus on reviewing the fundamentals of nerve transfers in the setting of spinal cord injury, and delineate the significant challenges and specifics of treating this complex group.

After an injury to the spine, the resulting neuronal injury can occur within the spinal cord or less commonly in nearby nervous structures, including the nerve root and plexus, or more peripherally. Wherever the injury occurs, it may cause loss of function; the primary goal of nerve transfers is to improve quality of life by means of restoration of critical function. In spinal cord injury, the surgeon aims to restore movement, using an expendable donor nerve that remains under volitional control. Fundamentally, a nerve transfer involves the sacrifice of one muscle's innervation and

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Related Video content is available for this article. The videos can be found under the "Related Videos" section of the full-text article, or, for Ovid users, using the URL citations published in the article.

From the Division of Plastic and Reconstructive Surgery, Washington University.

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function to reroute it and restore volitional control to another, more essential muscle group. For example, supination can be performed by both the biceps and supinator muscles; the nerve to the supinator may therefore be expended as a donor to the posterior interosseous nerve to restore wrist, finger, and thumb function.[3–6]

Traditionally, tendon transfers, joint fusions, and tenodesis were the tools at the disposal of surgeons treating those with spinal cord injury. However, there are several key advantages of nerve transfers:

1. Nerve transfers may avoid the splinting and non–weight-bearing period of downtime associated with tendon transfers.
2. Nerve transfers may restore more precise volitional upper extremity function.
3. Nerve transfers may provide more options for people with limited tendon transfer options.

Use of nerve transfers in spinal cord injury, however, is a relatively new field.[3,5,7–11] Although initially described in the 1960s and 1980s,[12,13] until recent years, relatively little contemporary literature existed. Spinal cord injury is a devastating condition, which has a profound impact on an individual's health, independence, and quality of life. Therefore, advances in nerve transfer to restore critical upper extremity function have potential for significant impact. The surgical procedures themselves are relatively established and may be straightforward for an experienced upper extremity surgeon; however, the assessment, selection, and timing of appropriate nerve transfer are complex and integral to ensuring good outcomes. A strong understanding of the anatomy and pathophysiology of spinal cord injury, and the ability to synthesize data from a patient's clinical history, examination, imaging, and electrodiagnostic testing should equip plastic surgeons to recognize suitable candidates for nerve transfer and, if not to operate themselves, to refer appropriately.

Pathophysiology

It is important to distinguish between upper and lower motor neuron injury because they have different sequelae in terms of muscle degeneration (Fig. 1). After a lower motor neuron injury, the distal axon degenerates and the muscle therefore atrophies. Irreversible muscle atrophy occurs after approximately 18 months of denervation.[14] Thus, nerve transfers to restore lower motor neuron function are time sensitive. Nerves regenerate at the rate of 1 mm/day (approximately 1 inch/month). Because of this fixed rate of regeneration, the distance from the nerve transfer coaptation site to the target muscle, and time since injury, inform the operative decision-making process; they determine whether regeneration will occur before irreversible muscle atrophy has occurred.

By contrast, time since injury may not be as relevant to the spinal cord injury population with isolated loss of upper motor neuron control. In this case, the lower motor neuron remains intact, the motor unit remains innervated, and the muscle does not atrophy. Functional motor deficits are attributable to a lack of central nervous system control—the inability of the cortex to communicate with the lower motor neuron. Isolated upper motor neuron injury following spinal cord injury is therefore not time sensitive, and nerve transfers to restore function may be successful more than a decade after initial injury.[1,10,11,15–19]

Unfortunately, patterns of spinal cord injury are often more heterogeneous and loss of upper motor neuron function and differing degrees of lower motor neuron injury may be present at different levels, or even on different sides of a single individual.[16] People with upper and lower motor neuron dysfunction will have time-sensitive patterns of injury even in the setting of spinal cord injury. Differentiating between these types of injury patterns is at the crux of the complexity of managing this population.

PREOPERATIVE ASSESSMENT

History

A thorough history is paramount when evaluating people with spinal cord injury for potential nerve transfers. Their neurologic and medical conditions are complex. Often, their neuronal injury has occurred through high-velocity multiple trauma, wherein they may have sustained concomitant injuries such as traumatic brain injury. Ensuing respiratory failure, venous thromboembolism, and autonomic dysreflexia further complicate care. Even when considered relatively stabilized, people with spinal cord injury remain medically fragile and vulnerable to infections, pressure sores, and other issues that may preclude safe surgery.

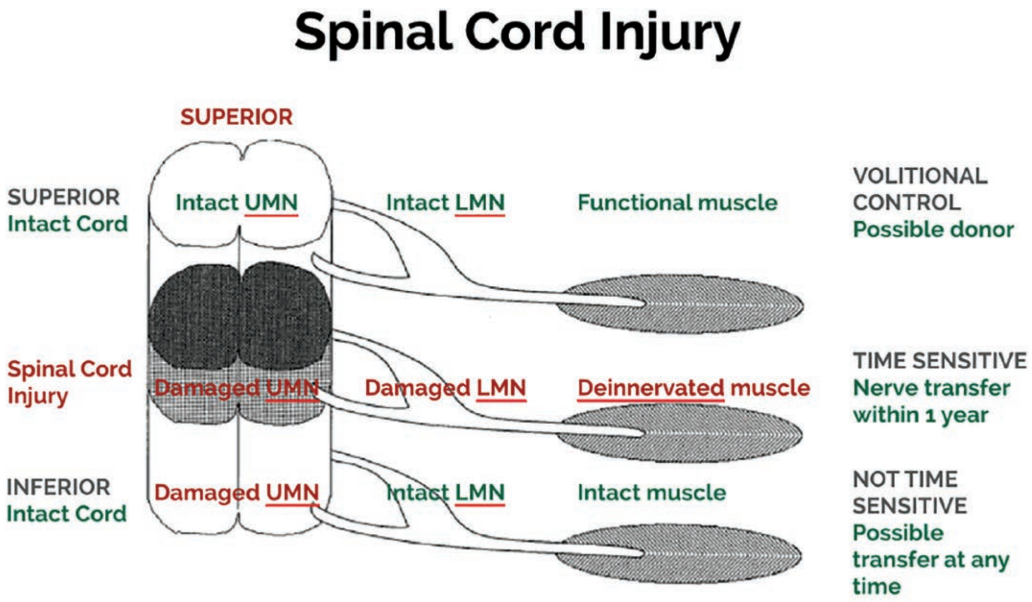

Fig. 1. Spinal cord injury may be divided into zones according to its effect on the upper motor neuron (*UMN*) and lower motor neuron (*LMN*). Superior to the spinal cord injury, there is intact upper motor neuron, lower motor neuron, and muscle and therefore volitional control; potential donors are found at this level. At the level of the spinal cord injury, there is direct damage to the lower motor neuron, causing denervation of these potential recipient muscles; therefore, there is a time-sensitive window to restore volitional control with nerve transfers. Below the level of spinal cord injury, there is loss of upper motor neuron input, but the lower motor neuron and muscle are intact; therefore, there is a non–time-sensitive window to restore volitional control to these potential recipients with nerve transfers. (Copyright 2017, nervesurgery.wustl.edu.)

The surgeon should obtain details of any upper extremity fractures or soft-tissue injuries that may affect the reconstructive options; it is important to identify concomitant plexus or peripheral nerve injury. A thorough discussion of the individual's current abilities (e.g., using electric chair, ability to self-catheterize, need for assistive devices in the home) and goals for reconstruction will assist operative planning.

Finally, spinal cord injury is a life-changing event in psychological and social terms. It requires significant adjustment in a person's psychological sense of self and their social environment. The surgeon should consider the timing of surgery, as inadequate psychosocial support may threaten postoperative rehabilitation and recovery. Furthermore, realistic expectations and informed consent are imperative in operative planning for reconstructive surgery.

Physical Examination

Examination should systematically assess bilateral motor and sensory function and range of motion (Tables 1 and 2). In addition to noting

Table 1. Basic Examination Principles*

- The examination should be performed with the person upright, seated in a locked and turned-off wheelchair
- The trunk must be supported for accurate strength testing
- Assess resting postures
- Individually palpate and resist motion in each muscle group
- Examination with gravity eliminated allows subtle motion to be appreciated
- Hand atrophy, spasticity, joint suppleness, contractures, scars, skin breakdown, and tenodesis positions (hand position with wrist maximally extended and flexed) are useful to note
- For testing of all digit motion, ensure that the wrist is blocked to avoid confounding tenodesis-driven motion
- Assess joint stability, particularly of the thumb; fusion may be an option but may require adjustments to transferring and weight-bearing techniques

It is helpful to understand how individuals use their hands for critical activities of daily living:

- Do they use a manual or electric wheelchair or both?
- Where is the wheelchair control?
- How do they maneuver in a manual chair? Do they use triceps to push, or use elbow flexors to pull up on wheel grips?
- Do they rely on passive tenodesis to grasp and maneuver objects?

*This table outlines pearls to aid in maximizing information from clinical examination of those with spinal cord injury.

Table 2. Examination of Upper Extremities for Nerve Transfers*

Function	Muscle	Examination and Functional Pearls
Shoulder and chest		
Scapular position and stability	Trapezius	Assessment of shoulder shrug against resistance; the trapezius is an important scapular stabilizer to prevent chronic shoulder instability and pain
	Latissimus dorsi	Palpate, asking the person to cough, or assess with resisted shoulder adduction
	Pectoralis	Clavicular head: raise arm to shoulder level and resist reaching across midline Sternocostal head: adduct arm at the shoulder against resistance
	Serratus	Long thoracic nerve responsible for flexion of the shoulder past 90 degrees, and stabilizing scapula. Assess for winging with resisted "push-up" motion
Rotator cuff motion	Supraspinatus Infraspinatus Teres major Teres minor Subscapularis	Assess shoulder: External rotation (infraspinatus and teres minor) Internal rotation (teres major, subscapularis) Extension (teres major) Abduction (supraspinatus)
Abduction	Deltoid†	Assess anterior, middle, and posterior deltoid function separately by palpating the muscle belly and resisting arm abduction with the arm positioned in front, to the side, and slightly behind the body
Elbow		
Flexion	Biceps	Test elbow flexion with forearm in supination
	Brachialis†	Test elbow flexion with forearm in pronation
	Brachioradialis†	Test elbow flexion with forearm in neutral; if muscle belly present and nondisplaceable, this may be a useful donor for either nerve or tendon transfers
Extension	Triceps	Test elbow extension against gravity; palpate three separate heads; functionally important for ability to transfer
Forearm		
Pronation	Pronator teres	Test with arm at patient's side, elbow flexed at 90 degrees, and thumb up; palpate at the proximal forearm ulnar border distal to the common flexor tendon with resisted forearm pronation
Supination	Supinator†	Resist forearm supination (with elbow in extension to eliminate biceps); palpate at dorsoradial forearm along border of radius during contraction
Wrist		
Flexion	Flexor carpi radialis	Palpate with wrist flexed and radially deviated against resistance
	Flexor carpi ulnaris	Palpate with wrist flexed and ulnarly deviated against resistance
	Palmaris longus	Test with small finger and thumb in opposition and wrist flexed
Extension	Extensor carpi radialis longus	Note any radial deviation with wrist extension if only remaining extensor under volitional control; palpate tendon at base of second metacarpal
	Extensor carpi radialis brevis	"Coffee bean sign" of extensor carpi radialis brevis and extensor carpi radialis longus muscle belly at proximal forearm show both are functional; palpate tendon at base of third metacarpal
	Extensor carpi ulnaris	Aids central wrist extension by balancing extensor carpi radialis longus/extensor carpi radialis brevis, palpate tendon at ulnar head
Hand		
Flexion	Flexor pollicis longus	Assess resisted thumb flexion
	Flexor digitorum profundus	Assess by means of resisted flexion at the distal interphalangeal joints of the fingers; note difference in strength between index and long, ring, and small fingers
	Flexor digitorum superficialis	Assess by means of resisted flexion at the proximal interphalangeal joints
Extension	Extensor pollicis longus; extensor indicis proprius; extensor digiti communis; extensor digiti minimi; abductor pollicis longus	These muscles should be examined individually as they may be variably present; do not be fooled by thumb and finger extension that results from the use of tenodesis or the presence of contractures, spasticity, or extrinsic tightness
Intrinsic hand muscles	Thenar muscles; hypothenar muscles; adductor; lumbricals; dorsal interossei; palmar interossei	Assess abductor pollicis brevis function by means of resisted palmar abduction of the thumb; palpate for the first dorsal interossei at the dorsal first webspace during pinch; note clawing

*Overview of clinical examination information required to guide operative planning for nerve transfers in people with spinal cord injury.
†Possible donors for nerve transfer.

neurologic deficits present, it is also important to assess preserved function that indicates potential donor nerves. Transfer should not be attempted if the donor function is abnormal (Medical Research Council grade <5/5).

Detailed manual muscle testing begins at the shoulder. Shoulder stability, adequate range of motion, and adequate strength provide the foundation for meaningful use of the entire upper extremity. Pain, instability, and loss of motion at the shoulder make downstream procedures to restore function less useful. Examination of elbow, forearm, wrist, and hand function is focused toward documenting the presence or absence of relevant function to formulate a tentative operative plan and guide subsequent diagnostic testing. The examination should be recorded separately for the right and left sides using the Medical Research Council grading system as much as possible. Certain muscles are difficult to grade, such as brachioradialis, and information about muscle bulk and displaceability of that muscle can be used to provide additional information regarding the utility of the muscle for use in a subsequent nerve or tendon transfer. The presence of spasticity and contractures should also be evaluated. People with spinal cord injury adapt to make best use of the function they have; they may develop substitution patterns, relying on gravity, tenodesis, and sometimes spasticity to maximize their hand function. [**See Video, Supplemental Digital Content 1**, which displays use of tenodesis without volitional control of grasp or finger extension to maneuver objects. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D218***.]

Video 1. Supplemental Digital Content 1 displays use of tenodesis without volitional control of grasp or finger extension to maneuver objects. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D218***.

Imaging

No specific imaging is the gold standard before initiating nerve transfers. Some have advocated strongly the need for preoperative cervical spine magnetic resonance imaging to assess for a syrinx, but this decision should must be made carefully on an individual basis. Magnetic resonance imaging is not a benign procedure, as prolonged periods on the x-ray table can lead to pressure sores or other complications.

Electrodiagnostics

Electrodiagnostic investigations are integral for preoperative planning, determination of upper motor neuron or combined upper and lower motor neuron injury patterns, and assessment of suitable donor nerves for transfer (Table 3). The exact role of this testing is evolving; building a collaborative relationship with a technically astute and meticulous electrodiagnostician is vital. Discussion regarding goals of treatment and testing facilitates communication and allows more nuanced interpretation of results.

A motor nerve conduction study provides information on continuity, speed of conduction, and degree of injury of the lower motor neuron. Electromyography helps to identify muscles supplied by injured lower motor neurons and the chronicity of such injuries; examining the distribution of muscles affected can help to better localize the injury.[17] Changes on nerve conduction study that indicate lower motor neuron injury include absent or reduced compound muscle action potential; these findings may indicate a time-sensitive injury. Electromyography of corresponding muscles may show fibrillation potentials and positive sharp waves, which indicate lower motor neuron denervation. If too much time has passed since the injury, irreversible muscle atrophy and fibrosis will occur and these changes will no longer be seen on electromyography. The electromyographic change associated with isolated upper motor neuron injury is reduced or absent activation, as the muscle lacks volitional control.

Electrodiagnostics are performed at 4 to 6 months after spinal cord injury and are not routinely repeated unless there is a change in clinical examination. Electromyography testing may also be used for testing potential donors. Ensuring

Table 3. Electrodiagnostic Assessment for Those Considering Nerve Transfer Surgery in the Setting of Cervical Level Spinal Cord Injury*

- Nerve conduction studies
  - Bilateral motor nerve conduction study of the following:
    - Median nerve (from the abductor pollicis brevis)
    - Ulnar nerve (from the abductor digiti minimi)
    - Radial nerve (from the extensor indicis)
  - Bilateral median and ulnar nerve antidromic sensory nerve conduction study (SNAPs) from digits 3 and 5
    - Bilateral radial nerve SNAPs from digit 1
- Electromyography
  - Electromyography of muscle innervated by donor nerve if clinically indicated (if weak or atrophic)
  - In addition, consider the following:
    - For axillary to radial nerve transfer:
      - Posterior head of the deltoid
      - Three heads of the triceps brachii
    - For brachialis-to–anterior interosseous nerve and flexor digitorum superficialis transfer:
      - Flexor pollicis longus
      - Abductor pollicis brevis; an easily testable surrogate providing information about C8/T1 innervation
    - For supinator-to–posterior interosseous nerve transfer:
      - Extensor indicis proprius
      - Extensor digitorum communis

SNAP, sensory nerve action potential.
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that no injury exists, for example, in the elbow flexor musculature (biceps, brachialis with or without brachioradialis) before sacrificing the nerve to one as a donor is critical to maintaining elbow flexion postoperatively.

RECONSTRUCTIVE OPTIONS

Surgical options may be divided according to the spinal level of the cord injury, which correlates with the motor deficits that are the targets for restoration. Further division is possible according to what function is being reconstructed, and whether they address the flexor or extensor phase of motion across said joint (Table 4).

In this section, we highlight what surgical procedures are possible to restore different motor abilities, although we emphasize the application of sound judgment for individual cases. Secondary to an availability of suitable donors, mid–cervical level spinal cord injury patterns have the most options for transfers.

Because this surgery involves the sacrifice of an expendable muscle's innervation to restore another's, one must be particularly wary in the spinal cord injury population that has relatively limited expendable function. For example, forearm supination can be performed by both biceps brachii and supinator; thus, the nerve to the supinator may be rerouted to the posterior interosseous nerve to restore digit extension. Forearm supination is maintained by intact biceps function; this does preclude later use of the biceps in a biceps-to-triceps tendon transfer, however, as then supination would be lost.

CURRENT BEST TRANSFERS FOR RECONSTRUCTION OF UPPER EXTREMITY FUNCTION IN SPINAL CORD INJURY

Here we describe in detail the current three best transfers we believe have the greatest utility and least morbidity to restore function in spinal cord injury (Fig. 2).

INTRAOPERATIVE PEARLS

Regardless of type of nerve injury, detailed knowledge of the upper extremity and internal topographic anatomy of the nerves is needed. However, in some cases of spinal cord injury, the recipient lower motor neuron cell body and axon remain intact. In this subset of cases, intraoperative stimulation can confirm the nerve fascicles to target for transfer. This allows final confirmation of recipient fascicles and ensures that extraneous sensory fascicles are excluded. It is critical that functioning fascicles under upper motor neuron control are deliberately excluded from the transfer so as not to downgrade function. This is particularly true of the transfers involving the median nerve, where functioning pronator teres and flexor carpi radialis fascicles should not be damaged in the course of transfer into nonfunctioning flexor digitorum superficialis, flexor pollicis longus, or flexor digitorum profundus fascicles.

If intraoperative stimulation is to be used, care must be taken to perform stimulation as soon as possible and certainly within the first hour under tourniquet. This avoids tourniquet palsy as a cause for a nonreactive nerve. Tension-free nerve coaptation is essential to maximize results and allow avoidance of postoperative splinting to protect repairs. Rather, tension-free repairs allow early hand therapy and nerve gliding to avoid scarring and maximize recovery.

RESTORATION OF ELBOW EXTENSION USING AXILLARY-TO-TRICEPS NERVE TRANSFER

Approach

The incision is marked preoperatively. A posterior arm incision is designed overlying the raphe between triceps heads and extending in a

Table 4. Nerve Transfers for Spinal Cord Injury*

Function	Nerve Transfer	Surgical Pearls
Proximal		
Shoulder and elbow	Spinal accessory to axillary or hypoglossal to axillary/musculocutaneous nerve	Typically, if without shoulder function, there are no expendable donors. Anecdotal reports of cranial nerve–to-limb transfers have had dismal results (personal communication). This area warrants further investigation before clinical adaptation; harvest of the spinal accessory nerve can lead to shoulder instability and pain and should not be undertaken lightly.
Elbow		
Extension	Axillary (teres minor branch) to triceps branch	Through an axillary incision, the teres minor branch of the axillary nerve is transferred to the triceps branch of the radial nerve to restore elbow extension. Bertelli and van Zyl groups report some M4 triceps function without downgrading of shoulder function.[6,18]
	Axillary (selective deltoid branches) to triceps branch	Through a posterior shoulder incision, one of the deltoid branches of axillary nerve is transferred to a triceps branch of radial nerve. Bertelli shows 5/7 subjects regain M4 function, and 2/7 regain M3 function.[3] Our group's results are mixed; further investigation is needed.[10]
Wrist		
Extension	Brachialis nerve to ECRL branch	The expendable brachialis branch of musculocutaneous nerve is transferred to the ECRL. A case report showed antigravity wrist extension at 5 mo after surgery, with resulting tenodesis hand function.[20] Our group has performed two; no long-term follow-up is available at this time.
	Supinator nerve to ECU branch	Supinator branch of radial nerve is used to transfer to ECU branch. A case report showed improved wrist stability without antigravity wrist extension. We do not recommend this selective transfer; transfer to the PIN as a whole is more useful and the finger extensors, which cross the wrist, can serve to augment weak wrist extension.[10]
Hand		
Flexion	Brachialis nerve to AIN/FDS	Brachialis branch of musculocutaneous nerve is transferred though medial arm incision to the median nerve, including anterior interosseous nerve, or a combination of AIN and the FDS fascicles with promising results from within our group and internationally.[6,10,21]
	Brachioradialis nerve to AIN	Similarly, brachioradialis branch of musculocutaneous nerve may be transferred to AIN. However, the authors prefer to preserve brachioradialis as a donor for salvage tendon transfer options to restore pinch function.[23]
	ECRB nerve to AIN	This is an attractive option, as it provides a shorter distance to target for nerve regeneration and good results have been reported. However, the authors have concerns about harvesting ECRB, which may not downgrade wrist extension power, but will result in more radial deviation on wrist extension, which can negatively affect tenodesis function. This also precludes future salvage tendon transfers using ECRL as a donor to restore finger flexion.[22]
	Musculocutaneus-to-median nerve transfer	A historical transfer, with potential for significant downgrading of pronation or wrist flexion.[12,13]
Extension	Supinator nerve to PIN	Supinator branch of radial nerve is transferred to the posterior interosseous nerve, restoring APB, EPL, EIP, and EDC function. This transfer is well established and reliable.[3,6,10] It may, however, overpower the hand closing phase. Also, some may not be candidates for this transfer, as the recipient may be in the zone of direct LMN depending on injury pattern. Harvest of the supinator precludes later biceps-to-triceps tendon transfer, as the biceps is the only remaining forearm supinator after supinator nerve harvest.
Intrinsic function	Staged brachioradialis-to–deep motor ulnar nerve transfer	Our group attempted a staged transfer to restore intrinsic muscle function; this did not work and deserves further investigation before adaptation. Tendon transfers, tenodesis, and fusion procedures remain the mainstay for replacement of absent intrinsic muscle function.

ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; PIN, posterior interosseous nerve; AIN, anterior interosseous nerve; FDS, flexor digitorum superficialis; ECRB, extensor carpi radialis brevis; APB, abductor pollicis brevis; EPL, extensor pollicis longus; EIP, extensor indicis proprius; EDC, extensor digitorum communis; LMN, lower motor neuron.

*Summary of available nerve transfers possible in spinal cord injury with associated reported literature.

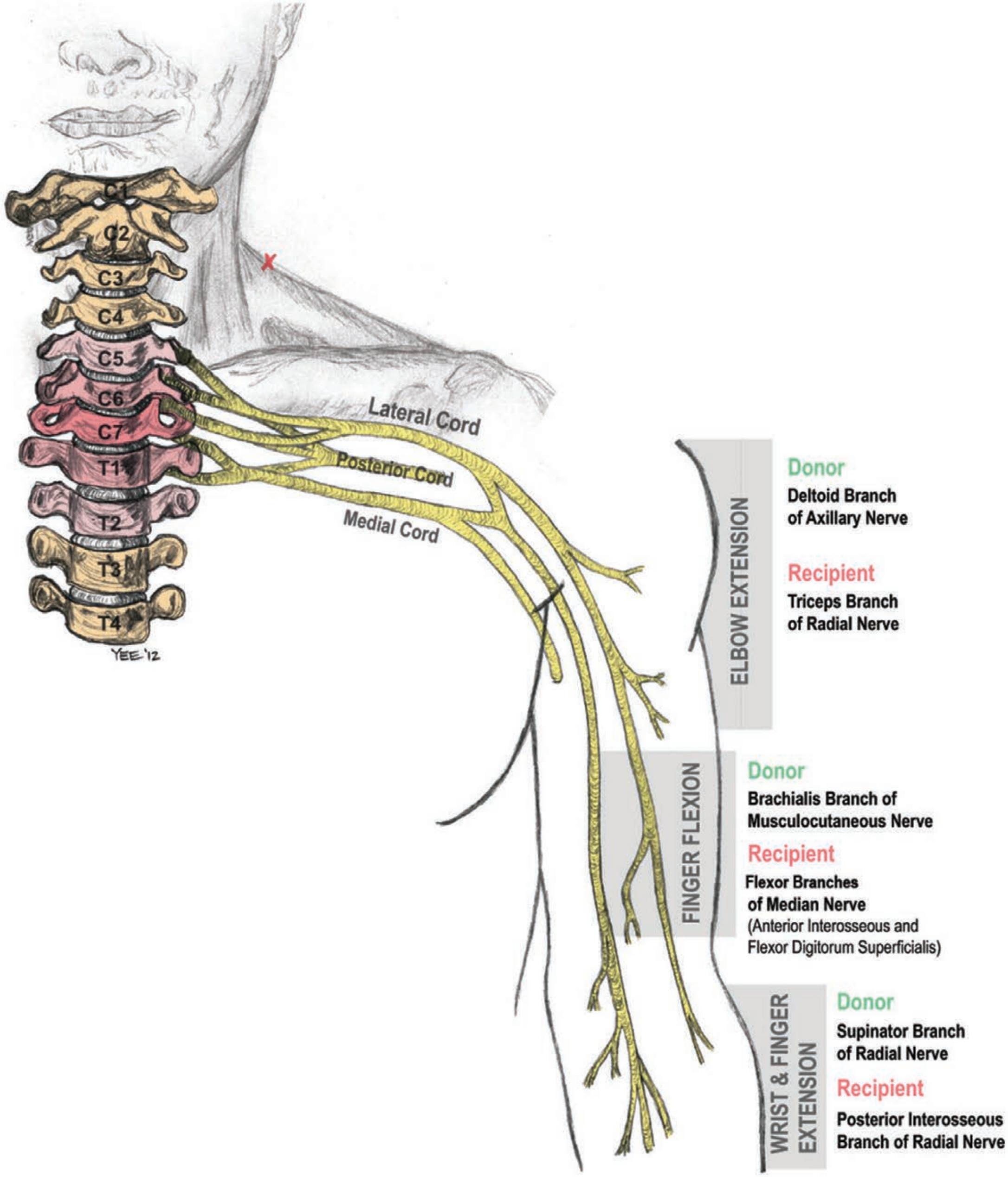


Fig. 2. Current best transfers for upper extremity reconstruction in spinal cord injury. (Copyright 2018, nerve-surgery.wustl.edu.)

hockey-stick fashion over the posterior deltoid (Fig. 3, *above, left*). Positioning is prone or lateral decubitus with the arm on an arm board. The entire extremity is prepared to allow for intraoperative stimulation of fascicles to be appreciated distally.

Donor: Posterior Deltoid Branch of the Axillary Nerve

After skin incision, reflection of the posterior deltoid allows identification of axillary nerve branches. The sensory branch may be followed down to the axillary nerve proper (Fig. 3, *above, right*). Intraoperative stimulation allows identification of the posterior deltoid branch. If more than one exists, a single branch can be used, sparing some posterior deltoid function.

Recipient: Triceps Branch of the Radial Nerve

The radial nerve may be identified emerging from underneath the teres major between the two posterior heads of the triceps muscle (Fig. 3, *below,*

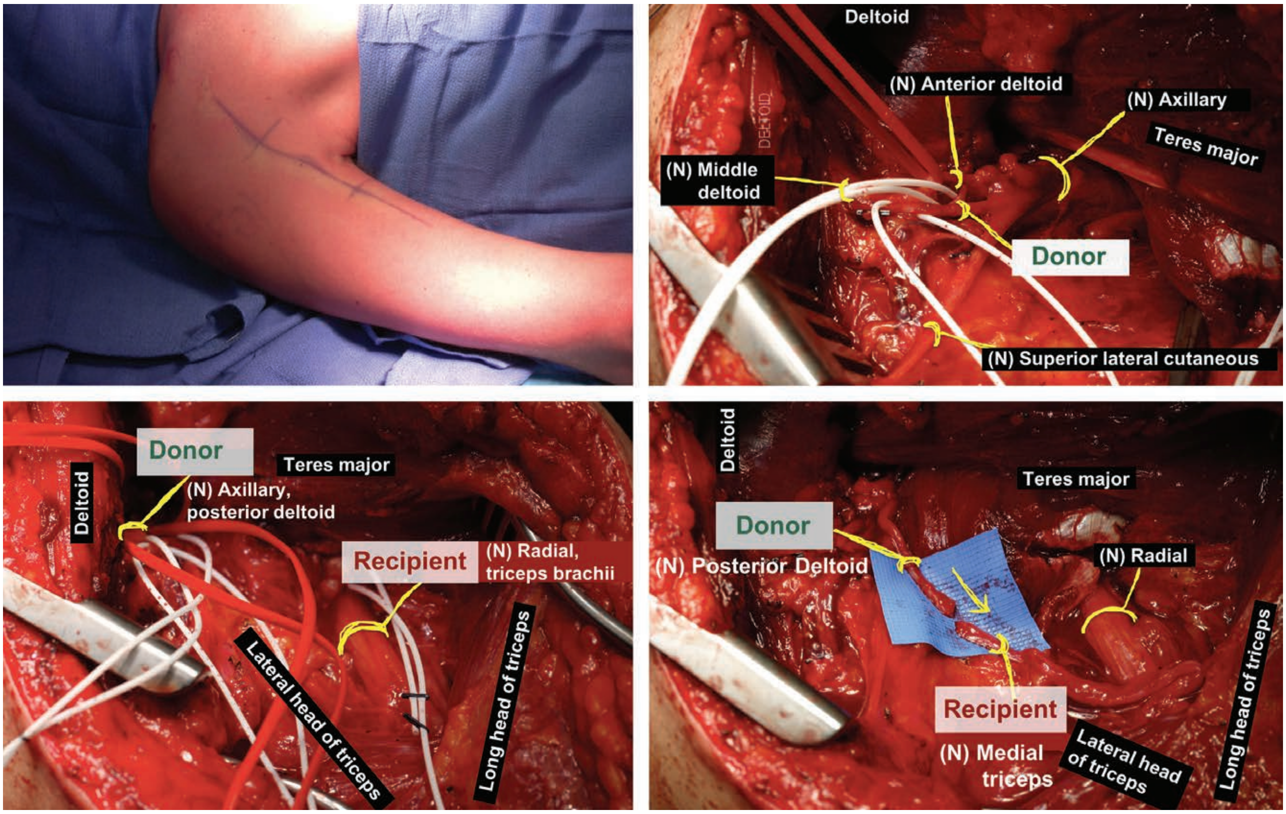


Fig. 3. Restoration of elbow extension using axillary-to-triceps nerve transfer. (*Above*, *left*) Prone positioning allows access to the posterior shoulder. (*Above*, *right*) The axillary nerve may be exposed by reflecting the posterior deltoid muscle. (*Below*, *left*) Exposure of the radial nerve between the lateral and long head of the triceps muscle by means of a posterior approach. (*Below*, *right*) Coaptation of the posterior deltoid to triceps nerve in a tension-free manner. (Copyright 2018, nervesurgery.wustl.edu.)

left). Next, identify the nerve branches to long, lateral, and medial heads of the triceps. To gain enough length for tension-free nerve coaptation, a muscle-splitting approach may be needed to follow the donor nerve distally. Preoperative examination and electrodiagnostics determine which triceps branch to transfer into; choose a recipient branch that lacks volitional control.

Coaptation

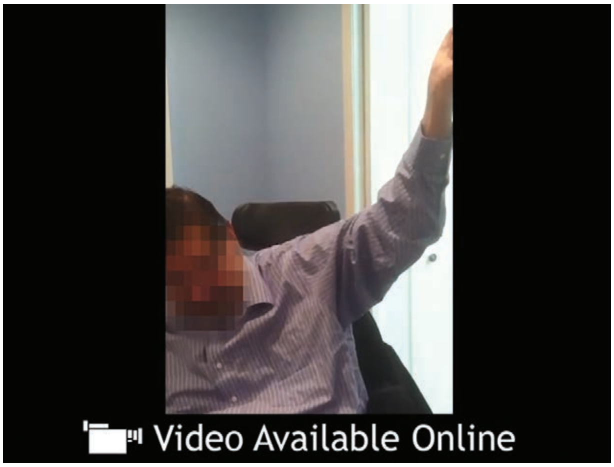
The nerves are divided (donor as distal as possible, recipient as proximal as possible) and an end-to-end nerve coaptation is performed in a tension-free manner with 9-0 microsuture using the operating room microscope (Fig. 3, *below*, *right*). Fibrin glue is applied to reinforce the repair. This is standard for all our nerve transfers. Preoperative, early postoperative, and 2-year postoperative results are shown. (**See Video, Supplemental Digital Content 2**, which displays posterior deltoid–to–triceps nerve transfer: preoperative examination. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the “related videos” section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D219***. **See Video, Supplemental Digital Content 3**, which displays posterior deltoid–to–triceps nerve transfer: early 8-month postoperative results. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the “related videos” section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D220***. **See Video, Supplemental Digital Content 4**, which displays posterior deltoid–to–triceps nerve transfer: 2-year results showing antigravity motion. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the “related videos” section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D221***.]

RESTORATION OF FINGER AND THUMB FLEXION USING BRACHIALIS-TO–ANTERIOR INTEROSSEOUS AND FLEXOR DIGITORUM SUPERFICIALIS NERVE TRANSFER

Approach

A longitudinal incision is made at the medial arm in the interval between the biceps and triceps

Video 2. Supplemental Digital Content 2 displays posterior deltoid–to–triceps nerve transfer: preoperative examination. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D219***.



Video 4. Supplemental Digital Content 4 displays posterior deltoid–to–triceps nerve transfer: 2-year results showing antigravity motion. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D221***.

Video 3. Supplemental Digital Content 3 displays posterior deltoid–to–triceps nerve transfer: early 8-month postoperative results. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D220***.

musculature. Positioning is supine with the entire arm prepared and positioned on a hand table.

Donor: Brachialis Branch of the Musculocutaneous Nerve

Incision is made, protecting medial antebrachial cutaneous nerve branches, and the biceps muscle is retracted laterally to identify the lateral antebrachial cutaneous nerve, and more proximally the brachialis branches of the musculocutaneous nerve (Fig. 4). The brachialis branches are dissected as distally as possible before division.

Recipient: Anterior Interosseous and Flexor Digitorum Superficialis Fascicles of the Median Nerve

The median nerve proper should then be identified lying more superficially and medially within the incision. The predissection of brachialis branches allows estimation of where on the median nerve they will comfortably transfer across to without tension; the intraneural median nerve dissection should be focused at this level. The anterior interosseous and flexor digitorum superficialis branches are then identified, and confirmed with intraoperative stimulation if the lower motor neuron is intact. Otherwise, topographic anatomy must be used (Fig. 5). Be sure to exclude any fascicles already under volitional control (such as pronator or flexor carpi radialis fascicles) and sensory fascicles to maximize motor-to-motor reinnervation.

Coaptation

The brachialis nerve branch donor is transected as distally as possible and transposed over to the median nerve. The recipient median nerve branches are separated from the median nerve proper by internal neurolysis and transected proximally; a tension-free coaptation is performed. Postoperative results from two patients are shown [**See Video, Supplemental Digital Content 5**, which displays brachialis-to–flexor digitorum superficialis and anterior interosseous nerve transfer. Postoperative results are displayed as well. This video is available in the "related videos" section of the full-text

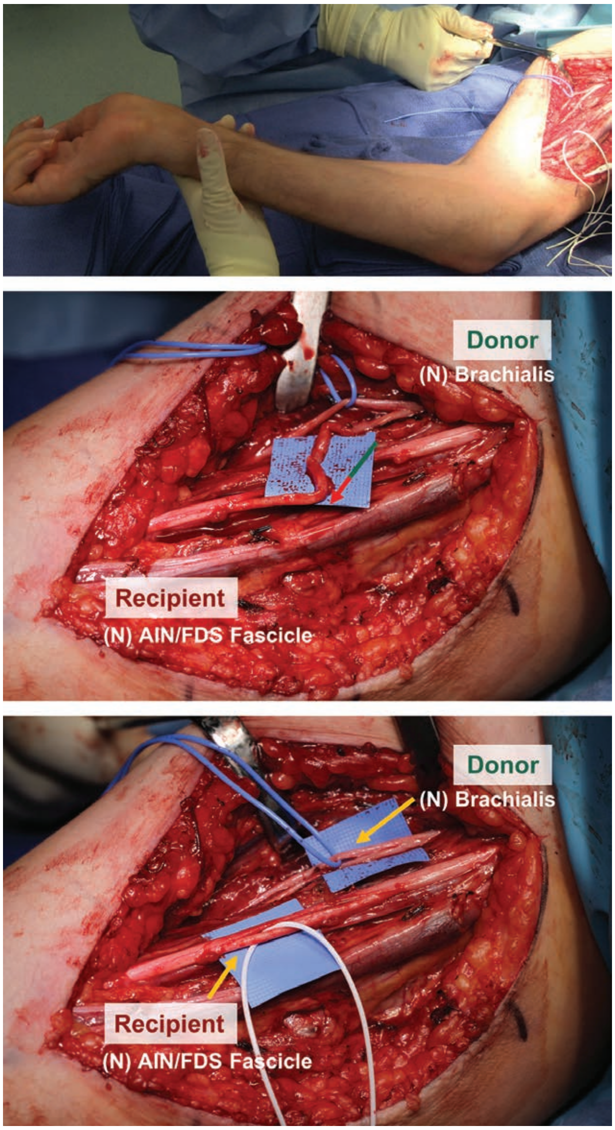


Fig. 4. Restoration of finger and thumb flexion using brachialis-to–anterior interosseous and flexor digitorum superficialis nerve transfer. (*Above*) Supine positioning allows approach at medial upper arm at the junction of biceps and triceps. (*Center*) Exposure of the brachialis branch of the musculocutaneous nerve and median fascicles supplying the flexor digitorum superficialis (*FDS*) and anterior interosseous nerve (*AIN*). (*Below*) Nerve coaptation in tension-free manner. (Copyright 2018, nervesurgery.wustl.edu.)

article on prsjournal.com or at ***http://links.lww.com/PRS/D222***. **See Video, Supplemental Digital Content 6**, which displays brachialis-to–flexor digitorum superficialis and anterior interosseous nerve transfer: additional postoperative result. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D223***.]

RESTORATION OF FINGER AND THUMB EXTENSION USING SUPINATOR-TO–POSTERIOR INTEROSSEOUS NERVE TRANSFER

Approach

The incision is marked preoperatively by identifying the brachioradialis muscle belly, and positioning the incision along its dorsal edge at the proximal forearm. Surgery may be performed in a supine or prone position. Incision is carried down through fascia between the brachioradialis and extensor carpi radialis longus interval. Here, the radial nerve branches to the extensor carpi radialis brevis, radial sensory, and posterior interosseous nerves are identified.

Donor: Supinator Branch of the Radial Nerve

Supinator branches may be identified more proximally through the same incision, entering the supinator muscle, and stimulated for confirmation.

Recipient: Posterior Interosseous Branch of the Radial Nerve

Once identified, the posterior interosseous nerve dives beneath the leading edge of supinator fascia, or arcade of Frohse, which should be divided for more length and to prevent compression on the regenerating nerve. Likewise, the accompanying crossing vessels (leash of Henry) should be carefully clipped to avoid compression or bleeding.

Coaptation

Again, the donor should be divided distally and the recipient proximally to ensure tension-free coaptation. Postoperative results from patients after this transfer are shown. [**See Video, Supplemental Digital Content 7**, which displays early and later postoperative results for two patients after supinator-to–posterior interosseous nerve transfer. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D224***. **See Video, Supplemental Digital Content 8**, which displays early and later postoperative results for two patients after supinator-to–posterior interosseous nerve transfer. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D225***.]

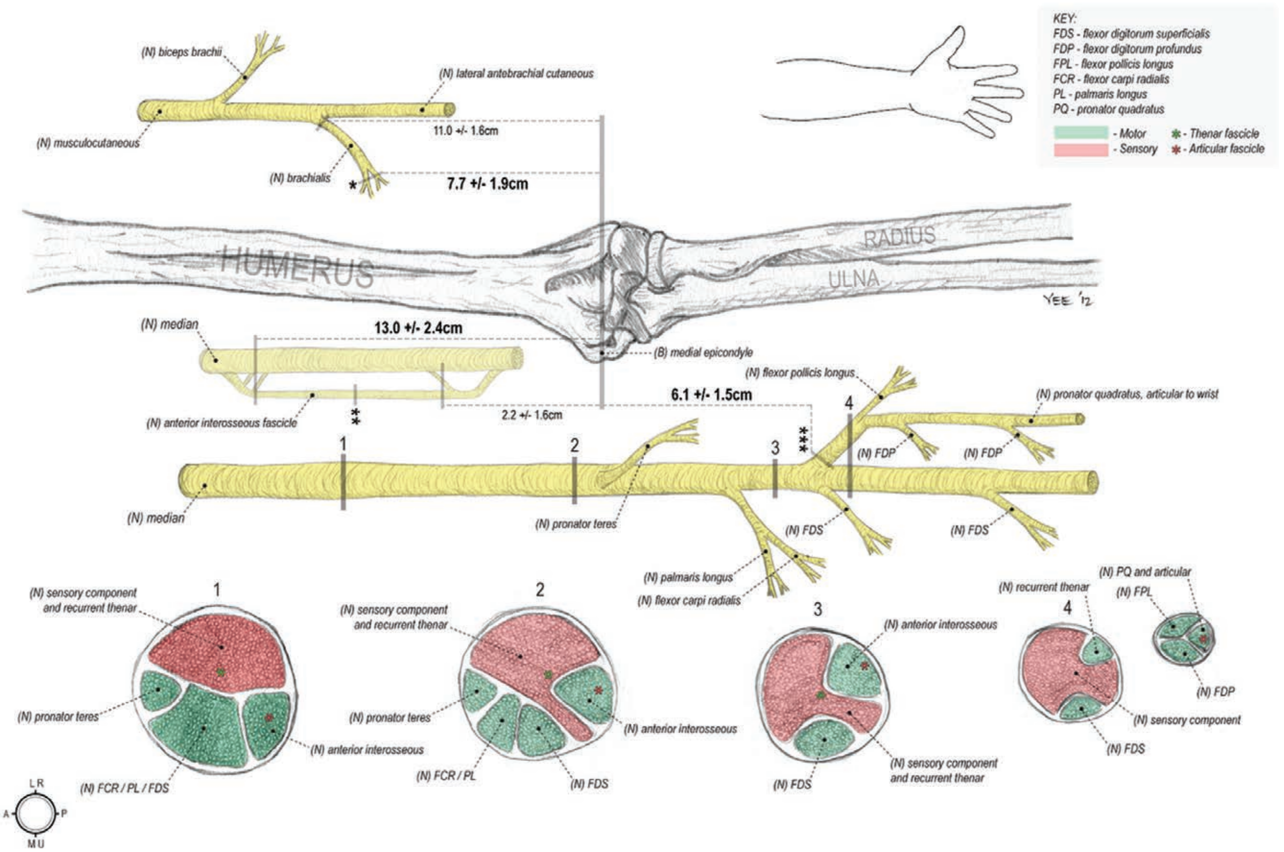


Fig. 5. Topographic anatomy of musculocutaneous and median nerve branches. (Copyright 2018, nervesurgery.wustl.edu.)

Video 5. Supplemental Digital Content 5, which displays brachialis-to–flexor digitorum superficialis and anterior interosseous nerve transfer: Postoperative results are displayed as well. This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D222***.

Video 6. Supplemental Digital Content 6, which displays brachialis-to–flexor digitorum superficialis and anterior interosseous nerve transfer: additional postoperative result. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D223***.

PERIOPERATIVE MANAGEMENT

Although often young and otherwise healthy, those with spinal cord injury do not have normal physiology and have lower functional reserves. They should therefore be evaluated carefully in the clinic and also in the immediate preoperative period on the day of surgery. Surgery should be postponed if there is evidence of urinary tract,

Video 7. Supplemental Digital Content 7 displays early and later postoperative results for two patients after supinator-to–posterior interosseous nerve transfer. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D224***.

Video 8. Supplemental Digital Content 8, which displays early and later postoperative results for two patients after supinator-to–posterior interosseous nerve transfer. (Copyright 2018, nervesurgery.wustl.edu.) This video is available in the "related videos" section of the full-text article on prsjournal.com or at ***http://links.lww.com/PRS/D225***.

upper respiratory, or other infections (Figs. 6 and 7 and Table 5).

POSTOPERATIVE REHABILITATION

Nerve transfers avoid the prolonged immobilization associated with tendon transfers. Our regimen is to apply a simple dressing for 48 hours; once removed, normal bathing may resume. Use of the operative extremity is restricted to light activities of daily living until the skin is healed. Normal activity including use of a manual wheelchair and sports are resumed at 2 to 4 weeks after surgery, depending on skin healing.

Reinnervation is slow and dependent on the distance from the transfer site to the target muscle; 1 year or more may pass before reinnervation results in improved motor function. An experienced hand therapist is essential to optimize success of nerve transfers. Education about the rewiring procedure, activation of donor muscles, and co-contraction exercises of the reinnervated muscle alongside the contralateral arm (where possible) is an important component of motor reeducation. Learned adaptive strategies should be unlearned through therapy to maximize function of the new transfer and incorporate this successfully into functional activities. In our center, monthly hand therapy visits and a rigorous home exercise program are recommended. Splinting is often used to help isolate and strengthen new movements (e.g., splinting of the wrist for exercises to block tenodesis and encourage finger flexion/extension using the reinnervated musculature).

CONTROVERSIES

Undertaking nerve transfers for those with unrealistic expectations or those who may be unwilling or unable to commit to motor reeducation may not have good outcomes. Similarly, for individuals who desire increased power rather than improved dexterity, tendon transfers may be a better option. Furthermore, any time nerve transfers are performed, the surgeon must be mindful that each transfer sacrifices the innervation to a muscle group as a donor that could have been used in the future for a tendon transfer. For example, if brachialis nerve is used as a nerve transfer for flexor digitorum superficialis/anterior interosseous nerve function, the biceps is the only elbow flexor remaining, and cannot be used as a tendon transfer for elbow extension. Similarly, if the supinator nerve is transferred into the posterior interosseous nerve for hand extension, the biceps is the only remaining forearm supinator remaining, and cannot be used as a tendon transfer for elbow extension. Finally, balancing early spontaneous recovery after spinal cord injury versus moving forward with irreversible surgical intervention (including nerve and tendon transfers) is challenging for cases with more time-sensitive patterns of injury.

CONCLUSIONS

Nerve transfers have transformed the management of peripheral nerve injury in recent times,

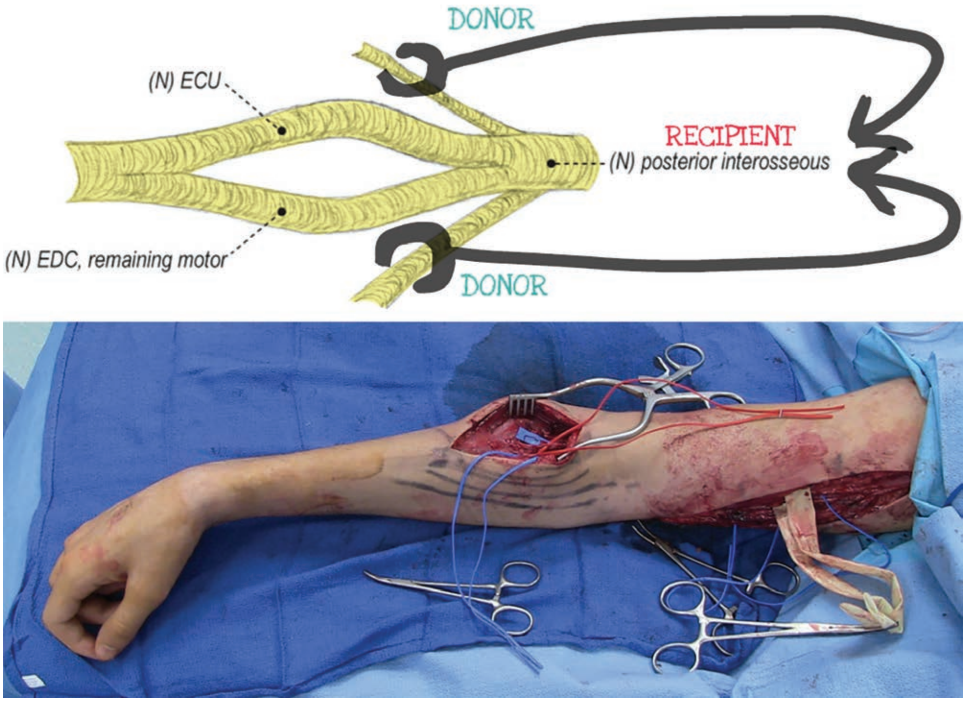


Fig. 6. Restoration of finger and thumb extension using supinator-to–posterior interosseous nerve transfer. (*Above*) Illustration of radial nerve anatomy showing supinator donor branches for transfer into the posterior interosseous nerve recipient branches of the radial nerve in the forearm. (*Below*) Exposure of the radial nerve at the proximal forearm dorsal to the brachioradialis muscle belly. *ECU*, extensor carpi ulnaris; *EDC*, extensor digitorum communis.

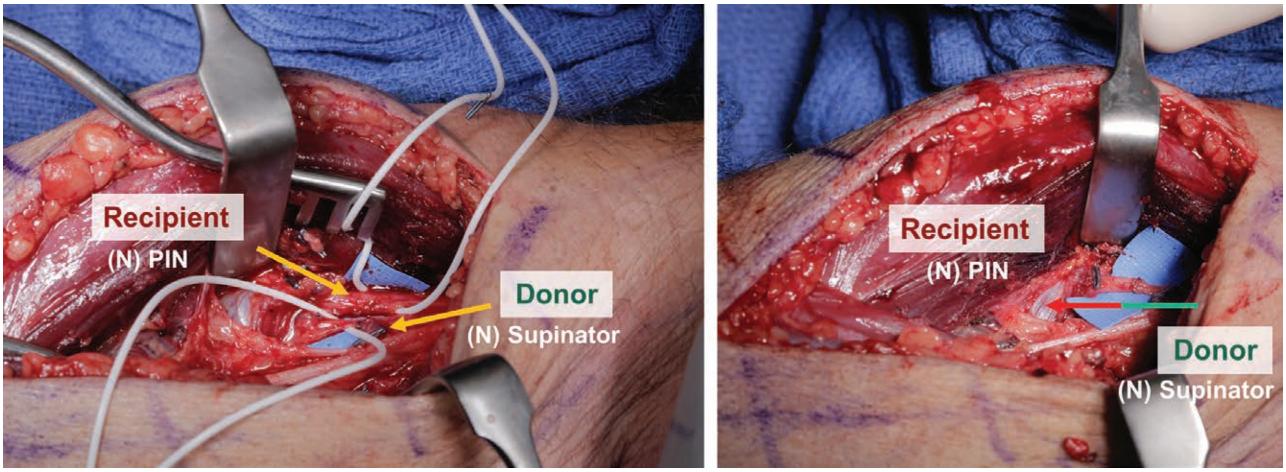


Fig. 7. (*Left*) Supinator and posterior interosseous nerve (*PIN*) branches identified. (*Right*) Coaptation of supinator to posterior interosseous nerve. (Copyright 2018, nervesurgery.wustl.edu.)

and now offer an exciting and novel option for restoring upper extremity function in people with spinal cord injury. In such individuals, nerve transfers have the potential to remarkably improve motor function and levels of independence. Nerve transfers avoid the prolonged immobilization associated with tendon transfer surgery, and also have the advantage of finer control of the upper limb. For those with midlevel cervical spinal cord injury, early referral to an upper extremity nerve surgeon for evaluation of pattern of injury is warranted. Although some will have injury patterns that will make the option of nerve transfer surgery time-sensitive, they should not be rushed into nerve transfer surgery, which requires significant participation to be successful. Tendon transfers

Table 5. Perioperative Checklists for Nerve Transfers in Spinal Cord Injury

Day-of-surgery checklist:
- Ensure free of urinary tract infection
- Ensure free of upper respiratory tract infection
- Perform skin check; do not miss ulcers or sores
- No stretcher; transfer directly from wheelchair to bed in preoperative holding area
- Keep warm in preoperative period with warmer
- Do not catheterize until under deep general anesthesia

Intraoperative checklist:
- Nonparalytic anesthesia to enable intraoperative nerve stimulation
- Warmed fluids
- Careful positioning

Postoperative checklist:
- Low-air-loss mattress, turning, and assists with meals
- Autonomic dysreflexia precautions with close monitoring postoperatively
- Resume home medications, bladder and bowel regimen
- Discharge to home on postoperative day 1

Postoperative rehabilitation:
- No need for prolonged immobilization; restrict use of hand to light activities of daily living only until skin healed
- Experienced hand therapist essential for motor reeducation, and incorporation of transfer functionality into normal activities

are well characterized, may be offered at any time after injury, and should remain a viable option for these individuals even as our understanding of the role of nerve transfers develops.

Ida K. Fox, M.D.
1150 Northwest Tower
660 South Euclid
St. Louis, Mo. 63110
foxi@wustl.edu

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Nerve transfers to restore upper limb function in tetraplegia

Washington University School of Medicine

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"For those who have nothing, a little is a lot."[1] As Sterling Bunnell, a pioneer of tetraplegic extremity reconstruction observed, small gains in function for people with spinal cord injury can equate to enormous gains in independence. People with mid-cervical spinal cord injury usually retain volitional movement at the shoulder and some control of their elbows and wrists. Hand opening and closing, a capacity that patients rate as more important to regain than walking or sexual function, is often lost.[2] Reconstruction with tendon transfers can restore motion within the upper limbs,[3] yet few undergo such procedures.[4,5] Nerve transfers, in which expendable donor nerves are rerouted to non-functional recipient nerves, were developed to treat peripheral nerve and brachial plexus injuries. Donor nerve fibres grow from the transfer site along the path of the recipient nerve to reach the muscle and restore volitional motor control.[6]

Injuries to the spinal cord are neurologically complex; both upper and lower motor neurons can be damaged.[7] In lower motor neuron paralysis, because the nerve degeneration that occurs leads to irreversible muscular atrophy, muscle reinnervation must be done within 12–18 months of injury if any function is to be restored.[6] Conversely, in upper motor neuron paralysis, the intact lower motor neuron preserves the muscle; thus, transfers to restore volitional control in this context have no discernible time limit.[8] Many nerve transfer options exist for spinal cord injury.[8–11]

In Natasha van Zyl and colleagues' prospective case series[12] in *The Lancet*, participants with upper limb paralysis due to motor level C5–C7 spinal cord injury underwent single or multiple nerve transfers in one or both upper limbs for restoration of elbow extension, grasp, pinch, and hand opening. 59 nerve transfers were completed in 16 participants (13 men and three women; 27 limbs). In ten participants (12 limbs), nerve transfers were combined with tendon transfers. In the 13 participants (22 limbs) who completed follow-up, improvements at 24 months versus baseline were recorded for all primary outcomes: action research arm test total score (median 34·0 [IQR 24·0–38·3] *vs* 16·5 [12·0–22·0], p<0·0001), grasp release test total score (125·2 [65·1–154·4] *vs* 35·0 [21·0–52·3], p<0·0001), and spinal cord independence measure total score (mean 39·3 [SD 13·8] *vs* 31·2 [7·9], greater than minimal clinically important difference). Three participants had four failed nerve transfers (Medical Research Council grade 0–1), two had a permanent decrease in sensation, and two had a temporary decrease in wrist strength that resolved by 1 year post surgery. These findings show that tendon and nerve transfers improve upper limb movement in cervical spinal cord injury, as is portrayed in the patient testimonial video for this study.[12]

As van Zyl and colleagues suggest, nerve transfers seem to restore more natural movement and finer motor control than are achieved by tendon transfers.[6,12] Nerve transfers also harness existing anatomy and physiology,[7] which circumvents risky spine-level surgery, foreign cells, complex special equipment, and implantation of devices.[8] A single donor nerve can reinnervate multiple muscles,[6,12] which is especially important in spinal cord injuries with few available donor nerves. Additionally, patients can resume light activity immediately after the procedure, avoiding the prolonged immobilisation and non-weightbearing necessary following tendon transfer.[6] Furthermore, whereas tendon transfers can stretch out over time, results from nerve transfers improve over time through cortical plasticity.[6]

The disadvantages of nerve transfers include the months before new motion is seen and the years until full strength is achieved.[6,8,10] van Zyl and colleagues maximised results in their patients by using the most distal donor nerves available. However, nerve transfers sometimes fail,[8,10,12,13] and patient satisfaction does not always correlate directly with measurable gains in strength or function.

An individualised approach to surgical assessment and management is vital in this heterogeneous population. In our experience, each person with spinal cord injury responds uniquely, and injury patterns, clinical examinations, electrodiagnostic testing, social situations, and functional goals are diverse. Shared physician–patient decision making is imperative to develop a plan that meets an individual's expectations and biopsychosocial situation. In van Zyl and colleagues' practice setting, both nerve and tendon transfers are possible.[12] We envisage a role for nerve transfers in settings where the intensive therapy and immobilisation required to optimise complementary tendon transfers are unavailable.

Stem cells and neuroprostheses could change the landscape of regenerative medicine in the future. For now, nerve transfers are a cost-effective way to harness the body's innate capability to restore movement in a paralysed limb. As nerve transfers are adopted and their uses adapted, careful ongoing outcomes research is paramount to advancing the field. This research should include efforts to compare nerve transfer with tendon transfer; find the optimal timing of such surgeries; and determine which approach produces the greatest functional improvement. Detailed study of the reasons for nerve transfer failure is also required, as is improving our understanding of the effects of biopsychosocial factors, including access to information and care, psychological readiness, and social support, on patient decision making and outcomes.

Nerve transfers represent a huge advance in reconstruction to restore hand function following spinal cord injury.[12] Expanding surgical options enables more choice for those with such injuries. Given the time sensitivity of nerve transfers in combined upper motor neuron and lower motor neuron injury,[7,8] referral to an extremity surgeon well versed in both nerve and tendon transfer surgery at 6 months post injury is important, as almost half of those who present later are no longer candidates for nerve surgery.[13] Surgeons who integrate nerve transfers into their spinal cord injury practice should take a careful and measured approach, and rigorously study and disseminate their outcomes to advance this growing field. We hope that increased awareness of nerve transfer surgery will stimulate early referral, wide discussion, and appropriate use of this treatment option throughout the world.

*Elspeth J R Hill, *Ida K Fox*
Division of Plastic and Reconstructive Surgery, Washington University, St Louis, MO 63110, USA (EJRH, IKF); and Plastic and Reconstructive Surgery Core, VA St Louis Health Care System, St Louis, MO, USA (IKF)
foxi@wustl.edu

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Interleukin-23 blockade: another breakthrough in the treatment of psoriasis

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Before risankizumab's introduction, there were ten biologic therapies approved for psoriasis, with two more in development. Do we really need all of these expensive therapies for this disease? A close look at the data shows that we do not have any treatments that reliably achieve complete clearing as evidenced by psoriasis area and severity index (PASI) 100, and only the newest treatments achieve PASI 90 in high proportions of patients. Moreover, many treatments require frequent injections or are less effective in patients who have not had success with other therapies. In *The Lancet*, Kristian Reich and colleagues[1] report their trial of risankizumab compared with adalimumab for the treatment of psoriasis. 218 (72%) of 301 patients treated with risankizumab achieved PASI 90 at week 16 compared with 144 (47%) of 304 patients treated with adalimumab (95% CI 17·5–32·4;