Xth International Meeting on Surgical Rehabilitation
Of the Tetraplegic Upper Limb

TETRA HAND 2010

20-22 September
Paris, France

FINAL PROGRAM

MUSÉE DES INVALIDES
129, rue de Grenelle
75007 Paris, France

www.tetraplegia-paris2010.com
WELCOME LETTER

Dear Colleagues
Dear Friends

In June 1978, a small group of surgeons, physiatrists and therapists met in Edinburgh for what was to become the First International Conference on Surgical Rehabilitation of the Upper Limb in tetraplegic patients.

The conference set the bases of functional restoration of the paralysed upper limbs in cervical spinal cord injury patients. At that meeting, a surgical classification was developed, which was subsequently established in its current form as the «International Classification», during a second conference held six years later in Giens, France (1984).

Due to growing awareness of the potential of upper limb surgery in tetraplegia, many conferences followed, with increasing number of participants, and the last conference held in Philadelphia in September 2007 was very successful.

We invite you to attend the 10th Tetraplegia Hand Conference, which will take place in Paris, next September 20-22, 2010. The meeting will be hosted by the prestigious Institution Nationale des Invalides, and will take place in the historic Musée National des Invalides, right next to Napoleon’s tomb.

We will try our best to make your visit memorable, and we are looking forward to welcoming you in Paris.

Scientific committee
Rod Hentz, MD
Scott Kozin, MD
Jan Friden, MD
Brigitte Perrouin-Verbe, MD

Organizing committee
Caroline Leclercq, MD
Thierry Albert, MD
Charles Fattal, MD
Jacques Teissier, MD

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CONFERECE VENUE

Musée des Invalides
129 rue de Grenelle
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METRO

- Invalides (lines 8/13/RER C)
- Latour-Maubourg (line 8)
- Varenne (line 13)

MAP OF THE INVALIDES

Conference room : Austerlitz Amphitheatre
Exhibition, coffee and lunch : Salon du Quesnoy
PROGRAM AT A GLANCE

Monday 20 September 2010: pre-meeting workshops

W1: SURGICAL TECHNIQUES (Full day)
Location: Faculté de Médecine René Descartes
45 rue des Saints Pères, 75007 – Paris

W2: EXAMINATION AND REHABILITATION OF THE TETRAPLEGIC SHOULDER (Half day)
Location: Neurologic Rehabilitation Centre - Coubert 77 (bus transportation from Paris)

W3: SPASTICITY AND BOTULIN TOXIN (Half day)
Location: Neurologic Rehabilitation Centre - Coubert 77 (bus transportation from Paris)

Tuesday 21 September 2010: Conference

7h30 Registration opens
8h15 THEME 1: PREPARING THE PATIENT FOR SURGERY
10h20 Coffee Break
10h50 THEME 2: INCOMPLETE INJURIES
12h15 Lunch
13h30 THEME 3: BASIC SCIENCE APPLICABLE TO THE TETRAPLEGIC UPPER LIMB
17h40 – 18h30 Guided visit to the Musée des Invalides and Napoleon’s tomb
20h00 Gala dinner

Wednesday 22 September 2010: Conference

8h00 THEME 4: THE SHOULDER OF THE TETRAPLEGIC PATIENT
10h30 Coffee break
11h00 Miscellaneous
12h00 THEME 5: SURGERY, REHABILITATION, AND OUTCOMES
   Surgery
12h30 Lunch
13h30 Business meeting
   13h50 Surgery (Contin.)
   14h45 Rehabilitation
   15h15 Outcomes
15h40 Coffee Break
   16h10 Outcomes (Contin.)
17h30 Meeting adjourns
WORKSHOPS
Monday 20 September 2010

W1. SURGICAL TECHNIQUES

8h00  Registration opens

1. 8h30 Tendon sutures techniques – M.Bednar + J.Friden
2. 8h50 Deltoid to triceps – J.Teissier
3. 10h00 Biceps – M.Revol and S.Kozin
   Biceps to triceps: M.Revol
   Biceps rerouting: S.Kozin:
4. 11h25 The brachioradialis muscle: harvesting and uses – J.Friden

12h30- 14h00 – Lunch

5. 14h00 Passive pinch - VR.Hentz (+lasso+split FPL)
6. 15h20 Intrinsics procedures – J.House
7. 15h30 Extensor tenodesis – C.Leclercq
8. 16h15 Thumb refinements – B.Coulet

17h00 – 17h30
    Mini-workshop : Ligamentotaxor – AREX

17h45  Adjourn
W2. EXAMINATION AND REHABILITATION OF THE TETRAPLEGIC SHOULDER
Chair: Th ALBERT (Paris) - Ch FATTAL (Montpellier)

1 - Physiopathology of shoulder pain in the tetraplegic patient. - Anne SINNOTT

2 - Clinical examination of the painful shoulder in tetraplegic patients - Thierry MARC.

3 - Examination protocol and assessment of the upper limb at PROPARA - Charles FATTAL.

*Hands on – 30mn*

4 - Treatment of the painful shoulder: manual techniques applied to the tetraplegic patient - Thierry MARC.
Rehabilitative techniques for the tetraplegic shoulder - Blandine GOMET

5 - Shoulder pain and daily living. Problems, prevention, adaptative devices, and robotics. - Sophie REGNIER

*Hands on – 30mn*

W3. SPASTICITY AND BOTULINUM TOXIN
Chair: S. KOCER (Paris)

1 - The spastic muscle - Richard LIEBER

- Physiology of the normal / spastic muscle
- Spontaneous evolution of the spastic muscle
- Mechanism of action of BT in the spastic muscle
- Long term evolution of the spastic muscle treated with BT

2 - Evaluation and treatment - Kasuko SHEM

- Evaluation of spasticity, of its consequences and of the results of treatment
- Upper limb spasticity in the tetraplegic patient and its treatment
- Role of BT in the treatment
- When to refer the patient to the surgeon?

3 - Botulinum Toxin and spasticity - Serdar KOCER

- The techniques of injection of BT
- Presentation of the ultra sound guided technique
- Demonstration of the ultra-sound guided technique with simultaneous video-projection

*Hands-on: Ultrasound identification of upper limb muscles*
CONFERENCE
Tuesday, 21 September, 2010

7h30 Registration opens

8h15 Welcome remarks: Caroline Leclercq

8h20 Welcome introduction: General Louis Cador, Head of the Medical Department, Institution Nationale des Invalides, Paris

THEME 1: PREPARING THE PATIENT FOR SURGERY
Moderators: A. Rotwell / T. Albert

8h30 Invited Presentation: *Are we surgeons becoming obsolete? A challenge*
Charles Hamlin, MD, Attending Hand Surgeon, Craig Rehabilitation Institute; Denver, USA

8h40 Invited Presentation: *Acute management of SCI: surgery or not surgery? Still a debate?*
Roger Robert, MD, Professor of Anatomy, Neurosurgeon, Head of the Neurosciences Department, University Hospital; Nantes, France

9h00 Discussion

9h07 Paper 1. *The natural history of neurological recovery of the hand and upper extremity in complete traumatic tetraplegia: Implications for surgical criteria*
A. Peljovich, J. Candia, P. Ackerman; Atlanta, USA

9h14 Paper 2. *Level of improvement in motor and sensory function and prehension experienced by individuals with tetraplegia*
IM. Velestra, H. Van Hedel, M. Baumberger, A. Curt; Nottwill, Switzerland

9h21 Paper 3. *What are the elements that help a quadriplegic to decide to have surgery of the upper limb*
E. Toledano, H. Tournebise, Y. Allieu; Montpellier, France

9h28 Paper 4. *Getting a good grip on it: people with quadriplegia making decisions about upper limb surgery*
J. Dunn, J. Hay-Smith, L. Whitehead, S. Keeling; Christchurch, New Zealand

9h35 Discussion

9h40 Invited Presentation: *Patient Education facing the challenges of the shared decision process in the context of Tetra Hand Surgery*
Marie Annie Le Mouel, MD and Catherine Tourette-Turgis, PhD; Neurologic Rehabilitation Centre, Coubert, and Pierre & Marie Curie University, Paris, France

10h00 Debate: *Why I chose/did not choose hand surgery: a dialog between two physicians who have experienced a cervical spine injury*
Moderator: V.R. Hentz
Doug Ota, MD, Attending Physician, Spinal Cord Injury Unit, VAMC; Palo Alto, USA / Claes Hultling, MD, PhD, Medical Director SCI Unit, Karolinska Univ.Hospital; Stockholm, Sweden

10h05 Discussion

10h20 Coffee Break
THEME 2 : INCOMPLETE INJURIES

Moderator : B. Perrouin-Verbe / K. Shem

10h50 Invited presentation : Incomplete Injuries: understanding the variable patterns and the terminology of injury
Brigitte Perrouin-Verbe, MD Professor, Head of the Neurological Physical Medicine and Rehabilitation Department, University Hospital; Nantes, France.

11h05 Invited presentation : Post-traumatic cervical myelopathies and their consequences on upper limb surgery
Olivier Hamel, MD, MC, Neurotraumatology Department, University Hospital; Nantes, France

11h25 Invited summary : Spasticity and Botulinum toxin: What’s new from the Monday workshop
Serdar Kocer, MD, Head of Handicap Evaluation unit, Consultant in Pediatric Rehabilitation; Coubert and St Maurice, France

11h35 Invited presentation : Classifying the spastic upper limb in tetraplegia
Yves Allieu, MD, Honorary Professor, Medical School, and Consulting Surgeon and Scientific Director; Institut Montpelliérain de la Main; Montpellier, France

11h42 Paper 5. Effect of neurotoxin dose and volume on muscle function
R Lieber, J. Hulst, V. Minamoto, S. Ward; San Diego, USA

11h49 Paper 6. Surgical treatment of spasticity in tetraplegia
C. Reinholdt, J. Friden; Göteborg, Sweden

11h56 Paper 7. Active mobilization immediately after spasticity – reducing surgery
A. Lamberg, J. Wangell, C. Reinholdt, J. Friden; Göteborg, Sweden

12h03 Discussion

12h15 Lunch

THEME 3 : BASIC SCIENCE APPLICABLE TO THE TETRAPLEGIC UPPER LIMB

Moderators: M. Keith / A. Privat

13h30 Invited Presentation : Update on spinal cord injury and regeneration
Alain Privat, MD, PhD, Inserm and Neurosciences Institute (INM), University Hospital; Montpellier, France

13h50 Invited Presentation : Update on muscles: What do we really know?
Richard Lieber, PhD, Professor and Vice Chair, Department of Orthopaedic Surgery, University of California and VACM; San Diego, USA

14h05 Paper 8. First muscle and then tendon adapts after chronic stretch in a rabbit model of tendon transfer
R. Lieber, M. Takahashi, S. Ward, J. Friden; San Diego USA

14h12 Invited Presentation : Muscle and aponeurosis of the upper limb: new anatomy and concept
François Bonnel, Professor, Department of Anatomy, Faculté de Médecine; Montpellier, France
14h27  Paper 9. **Muscle architecture determines functional properties proportional to surgical release**
S. Ward, T. Winters, M. Lim, M. Takahashi, J. Friden, R. Lieber; San Diego, USA and Göteborg, Sweden

14:34  Discussion

14h44  Invited Presentation: **Update on modeling–has it helped us? Can it help us?**
W. Murray, Rehabilitation Institute of Chicago, Assistant Professor, Northwestern University, Chicago, USA

15h00  Paper 10. **Using musculoskeletal modeling to identify factors that limit pinch force following Br-FPL transfer**
J. Mogk, M. Johanson, V. Hentz, K. Saul, W. Murray; Chicago, Palo Alto, Winston Salem, USA

15h07  Paper 11. **Brachioradialis muscle volume and pinch force following tendon transfer**
K. Saul, E. Johanson, V. Hentz, W. Murray; Winston-Salem, Palo Alto, and Chicago, USA

15h15  Coffee Break

Moderators: G. Snoek / B. Coulet

15h45  Invited Presentation: **Update on control of muscles**
Francisco Valero-Cuevas, PhD, Department of Biomedical Engineering University of Southern California; Los Angeles, USA, and Lisa Johanson, RPT, PhD, Bone and Joint Center, VAMC; Palo Alto, USA

16h05  Paper 12. **Direction control of finger forces: a new clinically useful measure of dexterity**
HP. Slijper, S. Dayanidhhi, N. Nelson, F.J. Valero-Cuevas; Rotterdam, The Netherlands; Los Angeles, USA

16h12  Paper 13. **Restoring function in tetraplegia using innovative methods from peripheral nerve injury**
A Gohritz, P.M. Vogt, J. Friden; Hannover, Germany and Göteborg, Sweden

16h22  Discussion

16h27  Paper 14. **Involuntary, electrically excitable nerve transfer for denervation: results from an animal model**
H. Hoyen, D. Masters, T. Cowan, S. Narayan, R. Kirsch; Cleveland, USA

16h34  Paper 15. **A networked neuro-prosthetic system**
K. Kilgore, M. Keith, H. Hoyen, A. Bryden, P. Peckham; Cleveland, USA

16h41  Paper 16. **Saggital plane strength characteristics of people with tetraplegia**
S. Gooch, AJ. Medland, AR. Rothwell, J. Dunn, MJ. Falconer; Christchurch, New Zealand.

16h48  Paper 17. **Mechanical feasibility of immediate mobilization of the brachioradialis muscle after tendon transfer**
J. Friden, M. Shillito, E. Chehab, J. Finneran, SR. Ward, R. Lieber; Göteborg, Sweden and San Diego, USA

17h05  Paper 18. **A multi-center assessment of surgical tensioning of the brachioradialis to flexor pollicis longus tendon transfer**
W. Murray, V. Hentz, J. Lee, M. Johanson, J. Boakes, M. Bednar, J. Friden, H. Hoyen, M. James, M. Keith, S. Kozin; Palo Alto, USA

17:12  Discussion
**Introduction : C. Leclercq**

17h20 Tetraplegia : A very personal point of view: An interview with Professor Yves Allieu by Brigitte Perrouin-Verbe

17h35 Brief business meeting

17h40-18h30 Guided visit to the Musée des Invalides and Napoleon’s tomb

20h00 Gala dinner at LAVINIA

**Wednesday, 22 September 2010**

8h00

**THEME 4 : THE SHOULDER OF THE TETRAPLEGIC PATIENT**

Round Table

**Moderators : J. Teissier / C. Fattal / FM. Mirza**

8h00 Introduction : C. Fattal

8h05 **A - Biomechanics and pathomechanics of the tetraplegic shoulder**
François Bonnel, Professor, Department of Anatomy, Faculté de Médecine ; Montpellier, France

8h20 **B - Identification of shoulder problems and classification**
Paper 19. Shoulder Range of Motion and Strength in Tetraplegia
A. Bryden, R. Hart, K. Kilgore, R. Kirsch, H. Hoyen, M. Keith; Cleveland, USA
Paper 19b. Shoulder muscles in traumatic tetraplegia
K. Mohammed, B. Campbell, A. Rothwell, K. Dalzell; Christchurch, New Zealand
**Proposal of a new classification**
Harry Hoyen, MD, Associate professor, Orthopedic Surgery, Case Western University, Metrohealth Medical Center; Cleveland, USA

8h35 **C - Shoulder pain**
Shoulder pain in the first months after the onset of tetraplegia: diagnosis and medical treatment
Paul Calmels, MD, PH and Laboratoire de Physiologie de l’Exercice, University Hospital; St. Etienne, France

8h45 **D - The overused shoulder of the tetraplegic patient**
Clinical examination and diagnosis
Govert J. Snoek, MD, PhD, Specialist in Rehabilitation & SCI Medicine, Roessingh Rehabilitation Center, and Researcher, Roessingh Research and Development; Enschede, Netherlands
**Surgical treatment of the aging tetraplegic shoulder**
Jacques Teissier, Orthopedic Surgeon, Specialist in Upper Extremity Surgery; Montpellier, France
**Post-surgical rehabilitation**
Thierry Marc, PT, Cadre de santé, President of the French Society for Shoulder Rehabilitation; Montpellier, France
**Proposal of a preventative strategy : « shoulder school » concept, recommendations**
Charles Fattal, MD, PhD, Médecin-chef CMN Propara ; Montpellier, France

Proposal of a surgical strategy : recommendations
Jacques Teissier, Orthopedic Surgeon, Specialist in Upper Extremity Surgery; Montpellier, France

10h00  **E - Future perspectives**
New methods for restoring shoulder function in high tetraplegia
Michael Keith, MD, Professor of Orthopedic Surgery, Case Western University, Cleveland, USA

10h10  Discussion

10h30  Coffee break

**Moderators: C. Curtin / C. Hamlin**

11h00  Invited Presentation. Epidemiology of SCI : are the demographics changing?
Finn Biering-Sorensen, MD, Professor and chair, Clinic for Spinal Cord Injuries, The Neuro-Science Centre, Rigshospitalet, University of Copenhagen, Denmark

11h15  Panel Discussion : Who should and how to educate our colleagues
Moderators : Catherine Curtin, Palo Alto and Charles Hamlin, Denver, USA

11h45  Paper 21. A CASAM study on the feasibility of developing a pre-operative test for evaluating the strength of the individual wrist extensors in tetraplegia
A. Kerver, L. Carati, G. Kleinrensink, E. Walbeehm; Rotterdam, The Netherlands.

11h52  Paper 22. Motor branch of ECRL: anatomic localization for selective motor branch block, a useful technique before muscle transfer in tetraplegia
F. Genet, K. Autret, L. Schnitzler, C. Lautridou, B. Bernuz, L. Malhian, P. Denormaldie, Y. Allieu, B. Parrate; Garches, France

12:00  Discussion

THEME 5 : SURGERY, REHABILITATION, AND OUTCOMES

Moderators : S. Kozin/ J. Ip

12h05  Paper 23. Grip reconstruction in a one stage procedure
C. Reinholdt, J. Friden; Goteborg, Sweden

12h12  Paper 24. Opponensplasty and extensor carpi radialis longus to flexor digitorum profundus transfer in the treatment of the tetraplegic hand: objective functional outcome
F. Dachs, A. DelArco, M. Ochoa, L. Ledesma, JE. Prim, J. Vidal; Institut Guttman, Spain

12h19  Paper 25. Arthrodesis or conservation of the carpo-metacarpal joint when constructing a key-grip in tetraplegic patients: a comparative study on 40 key grips
B. Coulet, J. Teissier, C. Fattal, D. Lumens, Y. Allieu, M. Chammas; Montpellier, France

12h26  Discussion

12h30  Lunch

13h30  Business meeting
Moderators: M. Bednar / M. Revol

13h50 Paper 26. Mechanical strength of the side-to-side versus weave tendon repair
R. Lieber, S. Brown, E. Hentzen, S. Ward; San Diego, USA

13h57 Paper 27. A comparison of dacron and hamstring grafts in deltoid to triceps transfers in traumatic tetraplegia
K. Mohammed, A. Rothwell, J. Dunn; Christchurch, New Zealand

14h04 Paper 28. Revision surgery for failed biceps to triceps transfer
D. Zlotolow, C. Sylvan, D. Hutchinson, S. Kozin; Philadelphia, USA

14h11 Discussion

14h16 Debate: Biceps to triceps or deltoid to triceps?
Khalid Mohammed, MD, Burwood Spinal Unit; Christchurch, New-Zealand /Scott Kozin, MD, Professor of Orthopedics, Shriners Hospital for Children; Philadelphia, USA

14h30 Brief presentations: technique or case report
Paper 29. CMC fusion by shape memory staples in tetraplegia
G. Kantunakis, G. Caserta, A. Pellacani, A. Landi; Modena, Italy
Paper 30. A case of triceps tendon dislocation as sequelae of deltoid to triceps transfer
L.G. Conforti, MP. Tarello, PL. Tos, B. Battison; Torino, Italy
Paper 31. Rupture of the extensor carpi radialis brevis following tendon transfer in a tetraplegic patient
G. Jacquemin, I. Robidoux, A. Delure, PG. Harris, T. Moser, AM. Danino; Montreal, Canada
Paper 32. I want to drive my car and win races. Don’t give up
I. Turcsanyi; Nyíregyháza, Hungary
Paper 33. Fifty-two year follow-up of Bunnell’s procedure-Tribute to Jenő Manninger in Hungary
I. Turcsanyi; Nyíregyháza, Hungary

REHABILITATION

Moderators: A. Sinnott / T. Marc

14h45 Paper 34. Multi-center survey of rehabilitation protocols after tendon transfer to restore pinch in tetraplegia
E. Johanson, J. Jaramillo, W. Murray, V. Hentz, S. Ashworth, A. Bryden, S. Lamberg, P. O’Brien, M. O’Dell, E. Mayland, J. Weis; Palo Alto, USA

14h52 Paper 35. Early active training of deltoid to triceps transfers: a controlled study
A. Lamberg, J. Friden; Göteborg, Sweden

14h59 Paper 36. Enhanced post operative training after grip reconstruction facilitates return to critical functions
A. Lamberg, J. Wangdell, C. Reinholdt, J. Friden; Göteborg, Sweden

15:06 Discussion

OUTCOMES

15h15 Paper 37. Evaluation of the long term results of functional surgery of the upper limbs in tetraplegic individuals
T. Albert, A. Carles, P. Vincenti, L. Floris, B. Gomet, MA. Le Mouel, C. Leclercq; Coubert, France
15:22  Paper 38. **Posterior deltoid to triceps reconstruction after C4-C6 spinal cord injuries – A retrospective review of outcomes**
A. Lamberg, J. Friden; Göteborg, Sweden

15:29  Paper 39. **Long term patient satisfaction after reconstructive upper extremity surgery to improve arm-hand function in tetraplegia**
R. Jaspers Focks-Feenstra, G. Snoek, H. Bongers-Janssen, A. Nene; Enschede, Netherlands

15:36  Discussion

15:40  Coffee Break

**Moderators: J. House / M.A. Le Mouel**

16:10  Papers 40 and 41. **Functional outcomes after implantation of a myoelectrically-controlled neuroprosthesis in people with tetraplegia**
A. Bryden, K. Kilgore, MB. Lipka, R. Hart, H. Hoyen, PH. Peckham, M. Keith; Cleveland, USA
**Implanted neuroprostheses for high tetraplegia; A two patient review**
A. Bryden, W. Memberg, R. Hart, R. Kirsch, H. Hoyen, M. Keith; Cleveland, USA

16:20  Discussion

16:25  Paper 42. **Perceived activity performance is not correlated with functional factors**
J. Wangdell, J. Friden; Göteborg, Sweden

16:32  Paper 43. **Assessment model of tendon transfer in cervical spinal cord injury**
M. Ochoa, A. Del Arco, F. Dachs, JE. Prim, J. Vidal, J. Medina; Barcelona, Spain

16:39  Paper 44. **Self-catherization acquisition after hand reanimation protocols in C5-C7 tetraplegic patients**
B. Bernuz, A. Guinet, C. Rech, A. Even-Schneider, P. Denys, M. Revol, I. Laffont; Garches, France

16:46  Discussant: Brigitte Perrouin-Verbe

16:50  Discussion

16:55  Paper 45. **Reaching international consensus on outcome measures used to determine the effectiveness over time of reconstructive hand surgery for tetraplegia**
A. Sinnott, J. Dunn, J. Prakasim, J. Wangdell, A. Lamberg, ME. Johanson, A. Bryden; Christchurch, New Zealand

17:02  Paper 46. **Measuring functional outcomes after upper extremity reconstructive surgery: developing a prospective case control study**
A. Bryden, K. Kilgore, H. Hoyen, M. Keith; Cleveland, USA

17:10  Discussion

17:20  Closing remarks

17:30  Adjourn
1. **Surgical improvement of upper extremity function in high-level spinal cord injuries due to diving accidents**  
J. Fridén, C. Reinholdt, A. Gohritz; Göteborg, Sweden and Hannover, Germany

2. **Steps in the development of reconstructive tetraplegia surgery in Hungary from 1958 to 2010**  
I. Turcsanyi, J. Fridén; Nyíregyháza, Hungary and Göteborg, Sweden

3. **Intermuscularmyofascial connections of flexor carpi ulnaris contribute to wrist flexion torque in the spastic arm of cerebral palsy patients**  
M. de Bruin, M. Smeulders, M. Kreulen; Amsterdam, Netherlands

4. **Effect of gravity compensation on kinematics, muscle activation and training of the shoulder and arm in cervical spinal cord injury**  
M. Kloosterman, M. Kouwenhoven, G. Snoek, A. Nene, M. Jannink; Enschede, Netherlands

5. **Dependence of elbow flexion strength on shoulder joint rigidity**  
D. Crouch, K. Holzbaur; Wake Forest, USA

6. **Building a program for tendon transfer in tetraplegia: the Montreal experience.**  
G. Jacquemin, A. Delure, I. Robidoux, M-T. Laramée, D. Raymond, P.G. Harris, A.M. Danino; Montreal, Canada

7. **Evaluating the needs of upper limb surgery in a tetraplegic population: presentation of the criteria for rejection of surgery.**  
G. Jacquemin, I. Robidoux, A. Delure, M-T. Laramée, P.G. Harris, A. M. Danino; Montreal, Canada

8. **A rehabilitative protocol after posterior deltoid to triceps for elbow extension restoration in quadriplegic patients.**  
M. Loffredo, S. Paolucci, M. Alessi, G. Caserta, A. Landi; Santarcangelo and Modena, Italy

9. **Preoperative evaluation and rehabilitation treatment in patients of group 4 and 5 (Giens International Classification) operated with tenodesis of the extensor muscles, arthrodesis of TM and BR to FPL, ECRL to FDP and PR to FDS**  
M. Loffredo, M. Alessi, S. Paolucci, C. Balsemin, L. Buscaroli, S. Sartini, G. Caserta, A. Landi; Modena, Santarcangelo and Imola, Italy

10. **Tetraplegia Group 4 and 5: long term surgical treatment follow up and new treatment proposal**  
A. Pellacani, G. Caserta, G.C. Kantunakis, A. Landi; Modena, Italy

11. **Satisfaction with upper limb surgery in individuals with tetraplegia**  
H. Gregersen, M. Lybæk, I. LaugeJohannesen, P. Leicht, F. Biering-Sørensen, U. VigNissen; Copenhagen, Denmark

12. **Prevention of Shoulder Subluxation following an Incomplete Cervical Spinal Cord Injury**  
L. Wallace, T. Hems, D. Allan; Glasgow, Scotland
ABSTRACTS

Paper 1
The natural history of neurological recovery of the hand and upper extremity in complete traumatic tetraplegia: Implications for surgical criteria

Presenter: A. Peljovich (apeljovich@bellsouth.net)
Co-authors: J. Candia, P. Ackerman; The Shepherd Center, Atlanta, GA USA

Introduction: Among the various criteria used in surgical decision-making for tetraplegia hand reconstruction is the assurance that the candidate’s neurological status is stable. The two variables that seem to have the greatest influence on neurological stability is time from injury and completeness of injury. One year from the date of injury is the traditional upper limit for which an individual with complete spinal cord injury (SCI) is expected to have made their fullest neurological recovery. No studies we are familiar with have looked at this using the International Classification for the Hand and Upper Extremity in Tetraplegia (ICH). We use the traditional concept of one year from complete SCI at the Shepherd Center, but are aware of centers that do not wait that long.

Purpose: The purpose of this pilot study is to evaluate whether the traditional concept of one-year for complete SCI is valid.

Methods: We pulled retrospective data from four randomly chosen adults with complete cervical SCI from the Shepherd Center database for whom we had complete manual muscle testing (MMT) data. We are now adding many more individuals to this pool. ASIA motor scores and ICH motor scores were calculated. We determined neurological stability based upon the earliest exam where the ICH scores remained unchanged. All four adults sustained complete injuries to the fifth/sixth cervical levels without any associated upper extremity injury including brachial plexus injury. ASIA motor levels varied from 4-6 on initial presentation for each arm. Similarly, initial ICH motor scores varied from 0-2 on initial. ICH-based neurological stability for these four individuals was achieved at an average of 161.3 days from injury (Std. dev. = 33.49 days). Three arms in four of the individuals experienced a one-grade improvement in both their ICH and ASIA motor scores within this average 161.3 day period. The ASIA scores improved an additional grade, from ASIA 5 to 6, two and four months, respectively, after the ICH scores remained fixed.

Results: The preliminary results indicate that individuals with complete SCI realize ICH score stability by an average of 5 – 6 months from injury. We therefore suspect that individuals can undergo hand/upper limb reconstruction much earlier than one year without fear of further significant neurological gain. The implications include the ability to capture individuals while they are still recuperating and motivated, as opposed to later in their course when additional treatments can seem as a large hurdle. In the United States, this also allows individuals to receive care while their primary medical insurance remains intact and their benefits and resources are more conducive to hand and upper extremity rehabilitation. If additional data supports our preliminary findings, we will proceed with a prospective study to evaluate the time to ICH – neurological stability with greater precision and analysis.
Level of improvement in motor and sensory function and prehension experienced by individuals with tetraplegia

Presenter:  I.M. Velestra  (inge-marie.velstra@paranet.ch)

Co-authors: H. Van Hedel, M. Baumberger, A. Curt.  Swiss Paraplegic Research, Nottwil, Switzerland; Spinal Cord Injury Center, Balgrist University Hospital, Zurich, Switzerland; Swiss Paraplegic Centre, Nottwil, Switzerland.

Introduction: The minimal clinically important difference (MCID) is the smallest difference in an outcome that a patient perceives as beneficial. The aim of the study is to determine MCID in motor function, sensory function and prehension in individuals with tetraplegia during rehabilitation based on the patients’ and the therapists’ rating of improvement.

Design: Prospective longitudinal multi-center cohort study

Setting: Spinal Cord Injury Units in eight rehabilitation centers across Germany and Switzerland

Methods: Manual muscle strength, sensibility and hand capacity are scored according to the protocol of the Graded and Redefined assessment of Strength, Sensibility and Prehension (GRASSP). The assessments are performed at baseline, one, three and six month’s post tetraplegia. Additional data from questionnaires for both patients and treating therapists regarding perceived change over time are recorded at one, three and six months post tetraplegia.

Analysis: Changes in motor function, sensory function and prehension are calculated between baseline and 1 month, 1 month and 3 months, 3 months and 6 months, as well as baseline to 6 months for each individual with tetraplegia. These changes are then related to the perceived change over time, as reported by the patient and rated by the therapist. Receiver-operating characteristic (ROC) curves will be used to determine the cut-off scores for changes in manual muscle strength, sensibility and hand capacity. Sensitivity and specificity values will be reported.

Results: This presentation provides some preliminary results about the MCID in motor and sensory function and prehension in individuals with tetraplegia during rehabilitation based on the patients’ and the therapists’ rating of improvement.
What are the elements that help a quadriplegic to decide to have surgery of the upper limb

Presenter: E. Toledano (elie.toledano@wanadoo.fr)

Co-authors: H. Tournebise, Y. Allieu; Centre de la Main - Toulon, Hôpital R. Sabran Giens, Institut Montpelliérain de la Main - Montpellier, France.

Introduction: If caregivers are convinced of the need to rehabilitate the upper limb of tetraplegic, few patients are operated. One reason is certainly the poor knowledge of this surgery. For patients who arrive at surgery consultation, we sought to analyze what were the elements that guided the patient to his decision.

Material and method: Using a retrospective questionnaire, we analyzed the information provided at the consultations by the various stakeholders and patient responses on the major factors leading them to make their decision.

The questionnaire involved 30 patients.

Results: Among the factors that lead a patient to have surgery:

- Have a specific goal. For example, catheterization or a gesture of making accurate self-hygiene.
- Meeting other surgical patients and satisfied
- The integration of the rehabilitation of upper limb in a more comprehensive life plan.

Negative Elements:
- Autonomy satisfactory.
- Too long duration of hospitalisations.
- Lack of family support.
- Poor image of the surgery. Saturation of medical cares

Conclusion: From this analysis we have made a “journey” of the patient to give him all the elements necessary for its decision: presentation of the intervention, meeting with patients operated on, discussions with the therapists, multidisciplinary preoperative consultation.
Getting a good grip on it: people with quadriplegia making decisions about upper limb surgery

Presenter: J. Dunn  (Jennifer.Dunn@cdhb.govt.nz)

Introduction: In New Zealand 59% of people with tetraplegia who are assessed for upper limb surgery have at least one surgical procedure performed to improve their arm or hand function. While the uptake of surgery is high compared to many other developed countries, it appears women and New Zealand Maori are less likely to have surgery.

Purpose: As part of a larger mixed methods study, we used in depth interviews to explore the decision making process for upper limb surgery in a group of people with tetraplegia.

Methods: Using an existing database, a purposive sample of men and women was selected to account for ethnicity and decision in relation to surgery (had or having surgery, not having surgery, undecided about surgery). Interim thematic analysis of the digitally recorded and transcribed interviews will be discussed; themes, illustrative quotes and preliminary interpretation of the decision making process will be presented.

Results: The preliminary findings suggest that many participants would like to know more about surgery, and for those who do not decide to have surgery at their initial assessment with the surgery the decision making process is dynamic and previous decisions may be re-evaluated. Clinically, this suggests that in New Zealand, those with tetraplegia might value an early opportunity to learn more about surgery from both health professionals and peers, and the opportunity to discuss surgery in the future when a person initially declines or is undecided may be valuable.
**Paper 5**

**Effect of neurotoxin dose and volume on muscle function**

**Presenter:** R. Lieber  (rlieber@ucsd.edu)

**Co-authors:** J. Hulst, V. Minamoto, S. Ward ; University of California, San Diego - USA.

**Introduction:** Therapeutic uses of Botulinum toxin A (BT-A) have rapidly expanded to include treatment for many disorders of abnormal muscular contraction. However, neurotoxin therapy is not completely benign. Adjacent and distal muscle weakness, antibody formation, and high cost of therapy are considerations in dosing. In an effort to minimize these undesirable side effects, issues of optimal dosing have become important to the practitioners who use BT-A. A priori, it might be argued that dose, volume, both dose and volume, or an interaction between the two based on anatomy, neuromuscular junction location, and injectate flow mediates the observed paralysis. The purpose of this study was to determine the effects of varying injection dose and volume on the functional and structural properties of injected muscles.

**Methods:** Male Sprague-Dawley rats (393.2 g ±1.8g, n=63) were housed two per cage at 20-23°C with a 12:12h dark-light cycle and randomly divided into nine experimental groups. Each group was subjected to a different dose or volume of BT-A (Botox®, Allergan, Irvine, CA, USA) injection: 6 units/kg in a 100µL volume (6u/100µL, n=6), 6u/20µL (n=6), 6u/4µL (n=6), 3u/100µL (n=6), 3u/20µL (n=6), 3u/4µL (n=7), 1u/100µL (n=6), 1u/20µL (n=6), and 1u/4µL (n=10). A tenth group of animals received saline injections to serve as controls for the anesthesia, handling, and injection procedures (CTL, n=4). One month after injection, under general anesthetic, ankle isometric dorsiflexion torque was measured as the indicator of maximum muscle strength. Then, muscles were flash frozen for morphometric analysis of muscle fiber area.

**Results:** Post-injection dorsiflexion torque of the treatment limbs was significantly decreased in all experimental groups compared with the saline controls (p<0.05) and there was a significant decrease in torque as a function of dose (p<0.05), but there was no effect of volume (p>0.2) and no interaction between dose and volume (p>0.3). Muscle fiber cross-sectional area results were similar to those of torque where dose had a significant effect on fiber size, but a significant interaction was observed between dose and volume (p<0.05). Although there may have been a significant effect of volume on fiber size, rigorous statistical analysis failed to demonstrate this relationship (p=0.06).

**Discussion:** These data demonstrate that the major factor that determines neurotoxin efficacy is the total number of units of neurotoxin injected into the muscle. This suggests that the ability for a specific injection volume to “hit” the neuromuscular junctions is not limited by diffusion within the muscle or the total volume of extracellular space in this model system. To the extent these results apply to humans, dosing of neurotoxin should be determinable based on the amount of neurotoxin required to treat a specific muscle rather than any type of critical concentration.
**Paper 6**

**Surgical treatment of spasticity in tetraplegia**

**Presenter:** C. Reinholdt (cirein@telia.com)

**Co-author:** J. Friden, National Center for Reconstructive Hand Surgery in Tetraplegia - Sweden.

**Purpose:** Patients with incomplete tetraplegia often suffer from spasticity, which can be general or focal in the upper extremities. There are numerous conservative ways of treating or reducing the unwanted problems caused by spasticity. Conservative treatment and botulinum injections may not always be sufficient. Improved surgical techniques and better knowledge of postoperative mobilization have resulted in a surgical treatment option for patients with tetraplegia and spasticity. The purpose of this study was to demonstrate the results of surgical treatment of spasticity in patients with incomplete tetraplegia.

**Methods:** 19 patients with incomplete tetraplegia and spasticity underwent surgical release or tendon lengthenings of spastic muscles in the hand or forearm. The patients started early active mobilization the 1st postoperative day. Grip strength, pinch strength, range of motion (ROM) of finger joints and wrist were measured. Canadian occupational performance measurements (COPM) were evaluated pre- and postoperatively.

**Results:** The COPM results showed that satisfaction and treatment goals were achieved with an increase of 3.5 scale steps. The patients reached a higher level of function. The patients improved their ROM and grip strength was not decreased.

**Conclusions:** The study shows that surgical treatment of spasticity in tetraplegia is beneficial for the patient. Spasticity surgery is a one-time treatment that is cost-efficient compared to other treatments.
**Purpose:** The aim was to evaluate if early activation after spasticity surgery would be a valuable adjunct in reducing the immobilization time after surgery and thereby enabling earlier use of the hand in multiple activities in daily life.

**Methods:** 23 patients underwent corrections of deformities and functional surgery aiming at reducing spasticity in the hand. Surgeries performed were different combinations of tendon lengthenings and releases. All patients started training the day after surgery, including range of motion training, individual movements of each finger to prevent adhesions, strength training of weak antagonists and finally relearning normal movement patterns of the arm and hand. After four weeks, patients were allowed to use the hand in all kinds of activities during daytime. They continued train strength of the antagonists and movement patterns to maintain and increase the opening of the hand for grasp function. Follow ups were made after 4 weeks, 2 and 6 months. After 6 months, satisfaction with the surgical outcome and goal oriented satisfaction and performance with specific tasks were evaluated according to the COPM protocol.

**Results:** All patients initiated active training within 24 hours post surgery and managed to improve finger extension, thumb abduction and wrist position control within the first 2-3 training sessions. No tendons ruptures were observed. Two patients had superficial wound infections that were successfully treated with antibiotics. No substantial edema that interfered with the training in daily activities was detected 4 weeks post surgery. At 6 months follow up the improvement was essentially retained. 3 patients were set up for new surgery to increase the function even more. 16 of the 23 patients listed their main goals with the surgery were rated with COPM and after 6 months the they had increased with on average 3.5 scale steps both in performance and satisfaction. 22 out of 23 patients operated would recommend the surgery to someone in the same position. An additional treatment effect was the overall improvement of the shoulder and upper extremity range of motion.

**Conclusion:** Surgical intervention and immediate post-operative activity training improves the overall function and ability for individuals with spasticity in the upper extremity after spinal cord injury.

**Acknowledgements:** This work was supported by Swedish Research Council (Grant 11200), University of Gothenburg and Promobilia Foundation.
Paper 8

First muscle and then tendon adapts after chronic stretch in a rabbit model of tendon transfer

Presenter: R. Lieber (rlieber@ucsd.edu)

Co-authors: M. Takahashi, S. Ward, J. Friden; University of California, San Diego USA.

Introduction: Donor muscles are often highly stretched in tendon transfer surgery. Despite literature reports that show serial sarcomere number adaptation to moderate stretch, little is known regarding adaptation to stretch outside of the physiologic range (commonly seen in clinical tendon transfer). In addition, in some tendon transfer models, significant tendon adaptation also occurs. Therefore, this study was performed to evaluate the entire muscle-tendon unit adaptation to tendon transfer surgery in an rabbit tendon transfer model.

Methods: Thirty-seven male New Zealand White rabbits were used in this study. The extensor digitorum muscle of the second toe (EDII) was transferred at a specific sarcomere length (Ls) of 3.7 µm, chosen to be near the end of descending limb of the rabbit Ls-tension curve, explicitly measured during tendon transfer by laser diffraction. Animals were sacrificed at five time points ranging from one to eight weeks, at which time complete muscle architectural analysis was performed as were tendon dimension, tendon water content and tendon cytokine transcript levels by quantitative PCR.

Results: As expected, since the muscle was stretched, a rapid increase in serial sarcomere number (4658 ± 154 for the transferred muscle compared to 3609 ± 80 for the control muscle), was achieved one week after surgery. From this time point until 8 weeks, this increased serial sarcomere number paradoxically decreased, with Ls remaining constant. Eventually, it reached the same value (3749 ± 83) as the control muscle (3767 ± 61) after 8 weeks. Thus, these data demonstrate a two-phased response to stretch—first sarcomere number increase and then a slow decrease. Tendon adaptation was delayed relative to muscle adaptation but no less dramatic. Tendon length (Lt) increase was 4.5 ± 1.1 mm over the 8-week time period, corresponding to a strain of 15.55 ± 4.08 % with upregulation of several collagen genes and other transcripts probably reflecting tendon inflammation and remodeling.

Discussion: This is the first report of a biphasic response after tendon transfer—serial sarcomere number adaptation followed by a tendon adaptation which indicates that muscle adapts more quickly than tendon. Taken together, these results illustrate a complex and unique interaction between muscles and tendons that occur during adaptation to stretched tendon transfer. Understanding the time-course of muscle-tendon unit adaptation can provide surgeons with information for postoperative care of tendon transfer surgery as well as guidelines for tensioning muscles during tendon transfer.

Acknowledgements: This work was supported by the Department of Veterans Affairs and NIH grants HD048501 and HD050837.
**Paper 9**

**Muscle architecture determines functional properties proportional to surgical release**

**Presenter:** S. Ward  (srward@ucsd.edu)

**Co-authors:** T. Winters, M. Lim, M. Takahashi, J. Friden, R. Lieber; Departments of Radiology and OrthopaedicSurgery, University of California, San Diego USA and Department of Hand Surgery, Goteborg University, Sweden.

**Introduction:** Specific release strategies for common donor muscles and objective methods to set muscle length are lacking. This has led to variable outcomes in patients undergoing tendon transfer surgery. Mobilization is necessary to optimize the line of muscle action, but risks disruption of neurovascular structures and muscle attachment sites. The goal of this study was to investigate the impact of muscle architecture on the active and passive tension-generating capacity of three muscles with differing architectures by quantifying their force producing capacities as they are released.

**Methods:** Male New Zealand White rabbits (mass = 2.64±0.49 kg), 9 tibialis anterior (TA), 5 extensor digitorum longus (EDL), and 12 extensor digitorum II (EDII) muscles were tested. Lower extremities were stabilized in a custom jig before the distal muscle tendons were released and attached to a servomotor at the myotendinous junction to measure passive and active isometric forces. Muscles were activated maximally via electrode stimulation of the peroneal (TA and EDL) or tibial (EDII) nerves. Myofascial and bony connections were disrupted from distal to proximal at 0%, 25%, 50%, and 75% of muscle length. Before release and at each release point, active and passive isometric forces were measured at muscle lengths of L0-10% to L0+10% in increments of 5% L0. Data are presented as percent decline in relative tension as a function of muscle release.

**Results:** When comparing peak active tensions as a function of release distance, the EDII declined more rapidly (0.40±0.03 %decline/%release, p<0.05) compared to EDL and TA (0.24±0.05 %decline/%release and 0.22±0.01 %decline/%release, respectively). When comparing passive tension as a function of release distance, both the TA and EDII declined more rapidly (both 0.09±0.03 %decline/%release P<0.05) than the EDL (0.02±0.01 %decline/%release).

**Discussion:** Active and passive force generating capacity changes as a muscle is released, indicating a tradeoff between muscle mobility and acute force generating capacity. Muscle architecture influences how release affects functional properties. Short fibered muscles have a larger fraction of fiber attachments disrupted, and therefore, less active force generating capacity. However, it appears that lateral force transmission is important in these short fibered muscles, as they still generate >75% of their pre-release activate tension when released 75% of their length. Passive tension decline did not share the same correlation with architecture, as all muscles lost more than 50% of their passive tension generating capacity when released 75%. Clinically, these data suggest that muscle release does not have a profound impact on active force generating capacity. However, short pennated muscles will be compromised more severely than long fibered muscles.

**Acknowledgements:** This work was supported by the Department of Veterans Affairs and NIH grants HD048501 and HD050837.
Using musculoskeletal modeling to identify factors that limit pinch force following Br-FPL transfer

Presenter: J. Mogk (j.mogk@northwestern.edu)
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Introduction: Loss of hand function is a disabling consequence of cervical spinal cord injury (SCI). Surgical transfer of the non-paralyzed brachioradialis muscle (BR) to the flexor pollicis longus (FPL) tendon can restore lateral pinch function and improve independence. Computer simulations suggest that surgical “tensioning” impacts the posture in which peak muscle force is produced, but reflected pinch force only if maximal activation of the transferred BR, and sufficient extensor muscle strength to balance the wrist and elbow was assumed. However, experimental data show significantly lower activation of the transferred BR during lateral pinch compared with elbow flexion, with distinct deficits in patients with weak elbow extension. We developed subject-specific biomechanical simulations to examine the effects of muscle strength and surgical attachment length on predictions of post-operative pinch force.

Methods: We augmented our previous surgical simulation of the BR-FPL transfer, and mathematically transformed BR muscle force to thumbtip force to predict lateral pinch force production. We included eight other muscles that often remain under voluntary control after C5-C6 SCI: two wrist extensors (ECRB and ECRL), the triceps (TRI, all three heads), the biceps (BIC, long and short heads) and brachialis (BRA). All other muscles were “paralyzed” by setting their activation to zero.

Simulations used EMG data and elbow, wrist and thumb joint angles recorded from five subjects with SCI and BR-FPL transfers during maximal lateral pinch efforts. EMG recorded from the BIC, TRI and ECRB defined the activation levels of the modeled elbow flexors, and elbow and wrist extensors. Simulations computed the highest BR activation, and resultant pinch force, without generating a net wrist or elbow flexion moment. Simulations were repeated using different strength levels and three surgical attachment lengths. “Non-impaired strength” assumed healthy muscle volumes in the tetraplegic limb. “Scaled strength” combined subject-specific BR volume data (from MRI) with measured wrist and elbow torque.

Results and Discussion: When simulations incorporated non-impaired strength, results were generally consistent with maximum activation of the transferred BR, and pinch force magnitude varied with surgical tensioning. In contrast, BR activation was submaximal and varied with tensioning in the simulations involving scaled strength, while pinch force varied little and differed mainly in the ratio of active and passive force. Overall, the magnitude of pinch forces simulated with subject-specific strength levels were less sensitive to tensioning than under non-impaired strength conditions. Personalized simulations suggest that tensioning does not dramatically alter the overall pinch force magnitude an individual with weak extensor muscles can produce. Rather, tensioning can modulate the level of voluntary control that one has over active pinch force following BR-FPL transfer.
Brachioradialis muscle volume and pinch force following tendon transfer

Presenter: K. Saul (krsholzbaur@gmail.com)

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Introduction: The maximum isometric force a muscle can produce is determined by its architecture; intersubject variability in isometric strength in the upper limb has been shown to significantly covary with muscle volume in young, healthy individuals. However, given the severity of the disability following cervical spinal cord injury as well as challenges in motor re-learning following tendon transfer, the relationship between muscle architecture and isometric strength may be obscured in the surgically reconstructed tetraplegic upper limb. For example, following surgical transfer of the brachioradialis (Br) to the flexor pollicis longus (FPL) to restore lateral pinch, weakness of the elbow extensors can limit the ability to fully activate the transferred brachioradialis. Thus, despite the strong relationship between muscle structure and muscle function, it remains unclear if the variability in the lateral pinch forces that subjects with Br-FPL tendon transfers generate are explained by intersubject variability in muscle volume.

Methods: Nine subjects with tetraplegia (9 arms, 29-60 years, C4-C7) who had undergone Br-FPL transfer (average 9 years since surgery) were studied. Magnetic resonance images of the brachioradialis were obtained using a 3D SPGR sequence. To calculate muscle volume and length, brachioradialis boundaries were segmented in axial images and a three-dimensional polygonal surface was created from the outlines. Subjects produced maximum pinch force under three conditions: unsupported, with elbow support, and with elbow and wrist support. Support was provided by padded stops to limit joint movement. All trials were in 60° of elbow flexion. A force sensor mounted on a custom grip recorded pinch force. We compared maximum pinch force among the conditions using paired t-tests, and investigated the relationships between muscle volume and measured pinch force using linear regression analysis.

Results: Pinch force was significantly correlated to brachioradialis volume (26.6 to 85.5 cm³, mean 61.7 cm³) for unsupported (p=0.02), elbow support (p=0.01), and elbow and wrist support conditions (p=0.01). The amount of variability in the pinch force explained by muscle volume increased with increasing support, with 58% of the variability in pinch force accounted for by muscle volume in the unsupported condition, 62% for elbow support, and 68% in the wrist and elbow support case.

Summary: Muscle volume was a significant predictor of maximum pinch force, but was most highly correlated to pinch force in the case when the elbow and the wrist were both stabilized. Even without support, nearly 60% of the variability in pinch force was accounted for by muscle volume. While other factors, such as strength of opposing muscles crossing the elbow and wrist, can limit pinch force generation, the volume of the transferred Br is an important indicator of pinch force strength in this population.
Introduction: Comparing interventions to restore hand function across patients, conditions and time requires reliable outcomes measures. Current metrics include maximal grip and tip strength, range of motion (ROM), and whole arm pick-and-place tasks. Additionally, several ‘dexterity’ tests quantify performance on standardized tasks relevant to activities of daily living. There are known limitations to available test, like the fact that maximal force and ROM are not often needed in everyday life ‘maximal’ values can be unreliable, for instance, in painful hands whole arm ‘dexterity’ tests allow adaptive strategies and ‘time spent’ is insensitive to adaptations that hide or falsely suggest improvement in task performance.

Purpose: These limitations—and the lack of tests that focus on dynamic finger function at low force magnitudes—led us to develop the Strength-Dexterity (SD) test.

Methods: The SD test quantifies the (directional) control of finger and thumb force vectors during the compression of unstable springs. A patient is simply asked to compress and hold the spring as fully as possible without buckling.

Results and discussion: Prior work showed the SD Test has good test-retest reliability, shows no learning effects, and has low correlation with measurements of maximal force. In addition, it can distinguish across patient populations and developmental stages in children. We now take the necessary steps to enable its wide-ranging clinical use and report SD Test results from using a new stand-alone tabletop system in a large group of healthy adults in both dominant and non-dominant hands. We simultaneously collect standard clinical tests to establish its relationship to current outcomes measures. We also compare these norms to SD Tests in a few patients with tetraplegia. These SD Test results provide a norm to compare against patients at different stages of treatment at our departments.
Paper 13

Restoring function in tetraplegia using innovative methods from peripheral nerve injury

Presenter: A. Gohritz (andreas_gohritz@yahoo.com)
Co-authors: P.M. Vogt, J. Friden; Hannover, Germany and Goteborg, Sweden

Dr. Gohritz has graciously agreed to combine the 3 following abstracts into a single presentation.

A. Nerve transfer of the supinator muscle branches to restore thumb and finger extension (C7-Th1) in tetraplegia with intact C6 function – anatomical investigation of feasibility

Introduction: Many patients after cervical spinal cord injuries (SCI) lack finger and thumb extension, but have supinator muscle function (supplied by the C6 root) which is expendable due to preserved supination force by the biceps brachii (C5/6). The supinator muscle has been neglected as a donor for tendon transfer because of its unfavourable architecture and direction; however, it has recently been described as donor for nerve transfer in 2 cases of lower brachial plexus (C7-Th1) injuries.

Objective: This study explored the theoretical concept and anatomical feasibility of reconstructing finger and thumb extension by supinator muscle branches (SMB) nerve transfer to the posterior interosseus nerve (PIN) after SCI.

Methods: Anatomical dissections were undertaken in 7 upper extremities of 4 embalmed cadavers (3 female, 1 male, mean age 68 years) to explore the anatomical relation of the donor and recipient nerve including measurements of the length, diameter and distance between the respective branches under loop magnification using calipers.

Results: The SMB were always found near the proximal border of the muscle, a dual supply was present in all but 1 specimen (only 1 branch detectable) with one medial branch to the superficial and one lateral branch to the deep muscle belly, their length averaged 28mm and 26mm, respectively. Coaptation of both SMB to the PIN was always feasible without interposition graft. The calibre of the medial and lateral motor branches averaged 1.6 and 1.3 mm, respectively and the ratio between both SMB together and the PIN as recipient ranged between 50-72 (mean 66%).

Conclusion: Direct transfer of the supinator motor nerves to the posterior interosseus nerve is anatomically feasible and may restore thumb and finger extension in patients with SCI below C6 level (IC groups 2-10). Theoretically, this procedure satisfies important requirements of a neurotization: 1. expendable axon donor, 2. vicinity of donor to recipient (short regeneration time), 3. high motor axon content of both nerve, 4. direct coaptation without nerve graft and 5. adequate calibre match. Candidates may be tetraplegic patients with intact C6 function with preserved or restored thumb and finger flexion, but weak or absent hand opening.
B. Restoring Function in Tetraplegia using Innovative Methods from Peripheral Nerve Injury – Literature Review and Theoretical Concepts

Introduction: New methods to improve the results after peripheral nerve injury (PNI), especially of the lower brachial plexus (C7-Th1), have not been applied in patients after tetraplegia due to spinal cord injury (SCI) - although they might be equally or even more useful in these individuals.

Objective: This paper provides a review of innovative techniques in PNI illustrated by own anatomical dissections to initiate a discussion how they could be applied in tetraplegic patients.

Results: These nerve transfers would be available in patients with intact C6 level:

2. Supinator nerve branches (C6) to posterior interosseus nerve for thumb and finger function (C7-Th1) (Bertelli et al. 2009, 2010)
3. Axillary nerve (C5/6) to triceps branch of radial nerve (C7) (Bertelli et al. 2009, Gohritz et al. submitted 2010)
4. Spinal accessory nerve (SAN) for shoulder or arm function (Vathana et al. 2007)
5. Superficial radial nerve (C6) or lateral antebrachii cutaneous nerve (C5/6) for sensory restoration of the median nerve (1st web space) in patients categorized as 0 (ocular control) (Brown and Mackinnon 2008)

These muscle transfers proved effective after PNI and may increase ability also after SCI below C5/6 level:

1. Brachialis muscle (C5/6) transfer to wrist extensors or thumb flexor (Bertelli et al. 2005)
2. Supinator muscle (C6) transfer to thumb and finger extensors (Bertelli et al. 2010)
3. Biceps (C5/6) tendon (prolonged by fascia lata) to deep finger flexors (Oberlin 2009, Goubier and Teboul 2009)
4. Lower trapezius (SAN) to triceps muscle for elbow extension (Bertelli et al. 2009) Theoretically, nerve transfers in SCI may even be more effective compared to PNI:

1. Recipient muscles with intact lower motoneuron preserve reflex arcs and do not become refractory to reinnervation / external stimulation after 18-24 months as after peripheral palsy,
2. axon transfer to the intact donor nerve may allow highly selective neurotization by intraoperative fascicle stimulation of the intact recipient nerve, 3. this may minimize the distance between donor and recipient and regeneration time.

Conclusion: Innovative procedures of muscle and nerve transfer used after PNI could also improve key muscle functions and sensory protection after SCI, especially in groups with very limited resources (such as IC groups 0-3). Further research should be directed at combining traditional algorithms with these new approaches.
C. Axillary to Radial Nerve Transfer to Restore Elbow Extension in Tetraplegia – Theoretical Considerations and Anatomic Feasibility

Introduction: Active elbow extension is of utmost importance for tetraplegic patients and usually restored in patients with intact C5 level by transfer of either the posterior deltoid or the biceps brachii muscle. Although time-proven and effective, these procedures are not without drawbacks, such as demanding technique, complicated and lengthy immobilization and after-treatment and potential functional loss over the long-term due to graft lengthening with diminished extension and power.

Objective: This study investigated the anatomical feasibility of restoring elbow extension by nerve transfer of the posterior deltoid branch of the axillary nerve (PD-AX) to the adjacent radial nerve branch to the lateral head of the triceps (LAT-RAD).

Methods: Anatomical dissection were performed in 8 upper extremities of 2 fresh and 2 embalmed cadavers (2 female, 2 male, mean age 63 years) to elucidate the anatomical relation of donor and recipient nerves by measuring the length, diameter and distance between the respective branches using loops magnification and caliper.

Results: The PD-AX always emerged from the axillary nerve in the quadrangular space as a single branch in 6 and with 2 branches in 2 cases, its length averaged 48 mm while the LAT-RA arborized from the radial nerve stem and had an average length of 40 mm. Tension free direct coaptation of the PD-AX donor and the LAT-RAD recipient branch was accomplished in all cases with an average surplus length of 14 mm in shoulder adduction and 8 mm in 90° abduction position. Caliber of both donor and recipient nerve branches matched adequately with 2.1 and 1.8 mm, respectively.

Conclusion: Restoration of elbow extension by axillary-to-radial nerve transfer using the LAT-RAD and PD-AX can be easily performed anatomically and theoretically fulfills important requirements of a neurotization procedure:

1. expendable donor nerve,
2. high motor axon density of donor and recipient nerves,
3. good caliber match and
4. short regeneration distance.

Nerve transfer may be promising in tetraplegic patients and overcome disadvantages of conventional muscle transfer.
Involuntary, electrically excitable nerve transfer for denervation: results from an animal model

Presenter: D. Master  (daniel.mastermd@gmail.com)
Co-authors: T. Cowan, S. Narayan, R. Kirsch, H. Hoyen. University Hospitals Case Medical Center, Department of Orthopaedic Surgery, Cleveland, OH; Case Western Reserve University, Department of Biomedical Engineering, Cleveland, OH; Case Western Reserve University School of Medicine, Cleveland, OH; Metrohealth Medical Center, Department of Orthopaedic Surgery, Cleveland, OH.

Purpose: Evaluate the efficacy of “paralyzed” nerve transfer (i.e. transfer of an involuntary, non-degenerated, electrically excitable nerve onto an involuntary, degenerated, non-electrically excitable nerve) and functional electrical stimulation (FES) for re-innervation. We hypothesized that lower motor neuron (LMN) cell body continuity with the motor cortex, via intact upper motor neurons, is not necessary for re-innervation of the extremities.

Methods: Fischer 344 rats underwent lower thoracic SCI followed by unilateral tibial nerve transection and delayed peroneal (“paralyzed”) to tibial nerve transfer (Group A) or primary neurorrhaphy (Group B). Control groups underwent SCI and a unilateral hindlimb approach only (Group C) or a unilateral hindlimb approach and transection of both the tibial and peroneal nerves (Group D). Three months following surgery, the proximal peroneal (Group A) or proximal tibial (Groups B, C, and D) nerves were electrically stimulated in vivo and gastrocnemius force production was measured on both the operative and non-operative hindlimbs. In addition, the distal tibial nerves from the both the experimental and control-side hindlimbs were sectioned and stained with anti-Neurofilament protein to determine total axon counts.

Results: Mean gastrocnemius force return and mean axonal regeneration was 47% (95% CI: 41, 53) and 51% (95% CI: 46, 56) for Group A animals (N=9), 68% (95% CI: 65, 70) and 73% (95% CI: 71, 75) for Group B animals (N=4), 97% (95% CI: 96, 98) and 99% (95% CI: 97, 100) for Group C animals (N=4), and zero and 2% (95% CI: 1, 2) for Group D animals (N=4). A one-way ANOVA for independent samples revealed significant differences (p < 0.01) between groups A, B, and C for gastrocnemius force return and between all groups for axonal regeneration.

Conclusions: Paralyzed nerve transfer produces a mean of approximately 50% return of gastrocnemius force and axonal regeneration. Paralyzed nerve transfer combined with FES is a viable method for re-animating denervated motor units in the setting of SCI.
A networked neuro-prosthetic system

Presenter : K. Kilgore (Kilgore-klk4@case.edu)

Co-authors : M.Keith, H.Hoyen, A.Bryden, P.Peckham; MetroHealth Medical Center, Case Western Reserve University, Cleveland, OH, USA.

We have developed a new implantable neuroprosthetic system, the networked neuroprosthetic system (NNPS), that is sufficiently flexible to meet the technological needs for use in many different disabilities. We developed functional and technical specifications for the proposed neuroprosthetic system based on our analysis of the anticipated clinical applications and our clinical experience in the deployment of multiple neuroprosthetic systems providing motor control. An abbreviated summary of the system specifications includes: no external components required during functional use, flexibility in the configuration of stimulus (output) and sensor (input) channels, ability to upgrade system after initial implantation without component removal, scalable to efficiently meet the needs from simple to advanced system requirements, and ease of replacement of failed components. Technical specifications included: 1 to 68 stimulation channels and 0 to 25 sensor inputs in any combination from multiple modalities, capacity for multiple wireless inputs from external sensors.

The NNPS utilizes small implanted modules distributed throughout the body which are connected to a central power source. Each remote module contains local processing capabilities in order to minimize the communication rate between modules, and can be programmed through a transcutaneous wireless link. The modules are connected to a network through using a single two conductor lead that both distributes power and provides a data communication link between each module, thus simplifying clinical implementation by minimizing lead routing through the body. Network communication utilizes the industrial standard “controller area network” (CAN) protocol. The NNPS receives its power from implanted lithium ion batteries that are rechargeable through a central transcutaneous inductive link. The open networked architecture allows the NNPS to be applied equally well to modest disabilities using a few components or severe disabilities requiring many more components. This novel architecture also facilitates system expansion, technical upgrades, and functional enhancements. The use of implanted power storage, fully implanted sensors, and high performance internal processors frees the user from all external devices during normal operation while also allowing the implementation of much more sophisticated and functional control algorithms. Thus, we believe that the NNPS is both a fundamental breakthrough in the design of neuroprostheses as well as being an enabling technology that provides a platform upon which clinical applications can be developed for a multitude of neurological disorders.
Paper 16

Saggital plane strength characteristics of people with tetraplegia

Presenter: S. Gooch (shayne.gooch@canterbury.ac.nz)


The purpose of this study is to evolve a method for quantitatively demonstrating the differences in strength and function for people with C5, C6 and C7 tetraplegia. The information has the potential to assess the outcomes of surgical procedures and can be used to help better prescribe, adjust and design assistive devices for people with tetraplegia.

A test rig for measuring upper body strength has been built. The participants apply a horizontal force onto two hand supports incorporating calibrated compression load cells. Results were recorded onto a computer along with the position of the hand supports. The subject’s strength can be measured at any point and in any direction in the sagittal plane.

Force measurements were recorded for four able bodied participants (22 to 60 year old males) over their full range of motion and force contour maps were created. While the magnitude of the forces varied, the force contour maps showed a clearly recognisable pattern from which human force and function could be characterised.

Force contour maps were created for three people with tetraplegia. The first participant had C5/C6 tetraplegia and no active arm extension. The second participant had C6 tetraplegia and had received the posterior deltid to triceps transfer (D-T) procedure for arm extension. The third participant had C7 tetraplegia and active triceps for arm extension. The results of strength measurements for the participant with C6 tetraplegia and D-T procedure showed an asymmetric strength profile. This result was consistent with anecdotal evidence which suggested that this participant had a markedly more successful surgical outcome on his right side than on his left side. The force contour maps were useful in terms of assessing whether or not a particular posture will be suitable for a particular activity. From contour map for the participant with C5 tetraplegia it could be seen that changing the seat height by approximately 100mm would be likely to result in improved wheelchair propulsion ability.

The people in each group tested have particular motor and sensory function and this was illustrated in the distinctly different force contour maps obtained. Given that the people with normal motor and sensory function were found to have similar force contour maps, it is likely that people tested with tetraplegia are representative of other people with similar injuries.

This paper presents a novel method of characterizing human strength capability while seated. For individual participants, the maps can be used for assessing strength, function and ability to perform particular tasks. In the future the method may be used to characterise strength and function for people with specific spinal cord injuries.
Paper 17

Mechanical feasibility of immediate mobilization of the brachioradialis muscle after tendon transfer

Presenter: J. Friden (jan.friden@orthop.gu.se)

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Purpose: The purpose of this study was to measure the Brachioradialis (BR)-to-flexor pollicis longus (FPL) tendon tension across a range of wrist and elbow joint angles to determine its acute vulnerability to joint motion.

Methods: BR-to-FPL tendon transfers were performed on fresh frozen cadaveric arms (n=8) and the BR-FPL tendon was instrumented with a buckle transducer. Arms were ranged over 4 wrist angles from 45° of flexion to 45° of extension and 8 elbow angles from 90° of flexion to 0° of flexion during which BR-FPL tension was measured. Subsequently, the BR-FPL tendon constructs were elongated to failure.

Results: Over the normal wrist and elbow range of motion, BR-FPL tendon tension was under 20 N. Two-way ANOVA with repeated measures revealed a significant effect of wrist joint angle (p<0.0001) and elbow joint angle (p<0.0001) with significant interaction (p<0.0001). Since the failure load of the repair site was measured as 203±19 N, over 10 times the loads that would normally occur at the repair site, this demonstrates that the attachment has a safety factor of ~10.

Discussion: These tendon force measurements support the assertion that the BR need not be immobilized after use as a donor muscle in tendon transfer. This is based on the fact that maximum passive tendon tension was only ~20N and was typically, well under 10N. As a result of this finding, we suggest that it is possible to initiate immediate and full postoperative mobilization of the BR-FPL muscle-tendon complex. This treatment protocol is believed to be beneficial to the patients by decreasing adhesions, hastening rehabilitation, decreasing muscle atrophy, and improving neural retraining.
A multi-center assessment of surgical tensioning of the brachioradialis to flexor pollicis longus tendon transfer

Presenter: V. Hentz (vrhentz@stanford.edu)

Co-authors: W. Murray, J. Lee, M. Johanson, J. Boakes, M. Bednar, J. Friden, H. Hoyen, M. James, M. Keith, S. Kozin; VA Palo Alto HCS

Introduction: It is commonly accepted that surgical technique has an important influence on the outcome of tendon transfer. A surgeon controls a donor muscle’s length intraoperatively when attaching it to a paralyzed muscle. Surgeons select attachment lengths qualitatively. The most commonly employed technique is based on tactile feedback, in which a surgeon relies on the relationship between muscle length and passive muscle force. The desired level of passive tension in a donor muscle and the attachment length that results is assessed qualitatively, is learned through experience, and is not easily taught. We hypothesize that different surgeons performing the same tendon transfer choose different attachment lengths.

Methods: Five centers from North America and one center from Sweden contributed data to this ongoing, prospective study. Here we summarize initial analysis, including data collected from 22 limbs with tetraplegia undergoing transfer of brachioradialis to flexor pollicis longus. Each surgeon’s technique was quantified intraoperatively using laser diffraction. The surgeon directed a 5 mW He-Ne laser through a small bundle of muscle fibers and measured the distance between the 2nd order diffraction bands, observable on a frosted glass slide attached to the laser, using an electronic caliper tool. Six measurements were collected per limb, three were performed in situ and three were performed following transfer.

Results: The length of the brachioradialis following transfer to FPL was not significantly different from its in situ length in these 22 limbs (p = 0.1198). The average distance between the 2nd order diffraction bands following transfer was within 1 mm of the average in situ length, suggesting the length of the transferred brachioradialis was within 0.1 \( \mu \text{m} \) of its in situ length. When transferred and in situ data were pooled, significant differences in the mean length of the brachioradialis were observed among specific sites (p < 0.05). The maximum difference observed at any two sites was ~5 mm for the mean distance between the 2nd order diffraction bands, which is consistent with a difference in sarcomere length on the order of 0.4 \( \mu \text{m} \). When just the in situ lengths from these two sites were compared, a similar difference was also observed.

Conclusions: Despite the qualitative nature of surgical tensioning and previous work that describes obvious differences in surgical approaches, our data suggest that, with regard to muscle sarcomere length, these surgeons made remarkably similar tensioning choices intraoperatively during Br-FPL transfer. Sarcomere lengths following transfer were not significantly different than the in situ length of the brachioradialis. At this point, differences observed among sites appear to be related to either factors associated with inherent differences in the in situ lengths of the subjects evaluated at each center or variability in implementing the measurement method among centers.
Shoulder Range of Motion and Strength in Tetraplegia

Presenter: Anne Bryden (anne.bryden@case.edu)

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Purpose: The purpose of this study was to examine the differences in shoulder range of motion and strength in people with tetraplegia, as classified by the American Spinal Injury Association (ASIA) Classification and the International Classification for Surgery of the Hand in Tetraplegia (IC).

Background: Cervical spinal cord injury imposes limitations on shoulder range of motion and strength. Current classification systems for tetraplegia do not include specific strength and range of motion data for the shoulder. As a result, there is a lack of normative data for this population. Existing classifications serve the purpose of guiding rehabilitation expectations and options for treatment, including reconstructive surgery for the upper extremity. Determining if there are differences in shoulder function across ASIA classification levels and IC levels may result in more definitive recommendations for reconstruction.

Methods: Active Range of Motion (AROM), Passive Range of Motion (PROM) and Manual Muscle Test (MMT) data were retrospectively reviewed from individuals with C4 or higher, C5 or C6 tetraplegia (IC groups 0-3). These individuals were evaluated for inclusion in IRB-approved research studies being conducted from 1990 through 2008.

Results: Muscle strength data was collected on 101 arms (54 participants). AROM/PROM was collected on 92 arms (53 participants). Significant differences (p<0.05) were found in strength across all three ASIA classification levels (C4 or higher, C5 and C6) for the following muscles: deltoid, latissimus dorsi, pectoralis major, external rotators and internal rotators. For trapezius and serratus anterior, differences were either not significant, or only significant within 2 levels (eg. C4 vs. C6). Significant differences in AROM were found across all ASIA levels for the following shoulder movements: flexion, abduction, extension, horizontal adduction, internal rotation. Comparing strength across all IC levels (groups 0, 1, 2, 3) no muscle showed significant differences across all four of the groups. Posterior deltoid strength was significantly different between groups 0 and 1 and groups 1 and 2. The remaining muscles showed significant differences between either groups 0 and 1 (upper trapezius, latissimus dorsi, external rotators) or groups 1 and 2 (internal rotators, anterior deltoid, pectoralis major). AROM results classified by IC were similar, with significant differences seen in shoulder extension and horizontal adduction.

Conclusion: Significant differences in shoulder function were observed across ASIA levels, whereas significant differences were not observed across all IC levels. However, the significant differences in shoulder extension (posterior deltoid) and horizontal adduction (pectoralis major) between groups 0 and 1 and groups 1 and 2 may contribute to decision making regarding type of reconstructive surgery performed, such as posterior deltoid versus biceps transfer to triceps.
Shoulder muscles in traumatic tetraplegia

Presenter: K. Mohammed (kmortho@xtra.co.nz)
Co-authors: B. Campbell, A. Rothwell, K. Dalzell; Burwood Spinal Injuries Unit, Christchurch, New Zealand

Aim: The aim of this study was to determine the activity of shoulder girdle muscles in traumatic tetraplegia and relate the pattern of shoulder muscle activity to the international forearm classification.

Method: We examined 50 upper limbs in 25 male subjects with traumatic tetraplegia. Forearms were graded according to the international classification system. Strengths of 9 shoulder movements were recorded according to the MRC system. Surface EMG activity was recorded in 9 shoulder girdle muscles.

Results: Absence of voluntary EMG was only seen in Latissimus Dorsi and only in very high cervical lesions. 3 of 20 patients with a forearm classification of 0 or 1 had absence of Latissimus Dorsi voluntary EMG. Lower motor neurone denervation signs of infraspinatus and latissimus dorsi were seen in most patients with forearm grade 4 or less. Adduction then external rotation tended to be the weakest movements.

Conclusions: Only patients with very high level lesions showed complete denervation of any shoulder girdle muscles and only latissimus dorsi. This has implications with muscle imbalance and rehabilitation of the shoulder.
Systematic Review of Rotator Cuff Repair in Spinal Cord Injury

Presenter: F. Mirza (fmirza@stanford.edu)

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Objective: To perform a systematic review of the literature on rotator cuff repair outcomes in patients with spinal cord injury.

Data Sources: An exhaustive search of the literature utilizing the following sources was performed – PUBMED, OVID, COCHRANE. Results from 1986 to April 2010 were utilized in the English language. The following search terms were used: (spinal cord injury OR tetraplegia OR paraplegia OR quadriplegia OR paralysis) AND (shoulder surgery OR shoulder reconstruction OR shoulder repair OR rotator cuff surgery OR rotator cuff reconstruction OR rotator cuff repair OR rotator cuff debridement). This search was supplemented with manual searches of the bibliographies of retrieved articles.

Study Selection: Inclusion criteria were any articles that described rotator cuff repair in patients with spinal cord injury. Exclusion criteria were other surgeries such as tendon transfers, arthroplasty or fractures. First, the title and abstract of each citation were reviewed and most reports were excluded in that preliminary round. The remaining articles were checked for inclusion and exclusion criteria by two physicians who treat upper extremity problems in patients with spinal cord injury. Any differences between reviewers were resolved through consensus. Due to the paucity of literature on this particular topic, there were no restrictions on methodology or study design. The preliminary round identified 774 articles from which only 11 were reviewed in detail by the reviewers; with only 3 meeting our criteria (0.4%). We also pooled unpublished data from our center on shoulder surgery performed on spinal cord injury patients from 1991-2001.

Data Extraction: Data was extracted based on reported outcomes and details supplied by the published articles along with our data. Detailed analysis identified the similar variables and was used in the final assessment. No single outcome measure was comparable and therefore a general impression provided by the authors was used in defining our pooled outcome measures (Improved, Same, Worse). We inferred outcome based on reported ability to transfer, perform independent activities of daily living and patient satisfaction.

Results: Only 3 articles met all our criteria from which the extracted data was pooled with the 3 rotator cuff repairs performed at our center to provide a total case load of 18 rotator cuff repairs in 15 patients. The mean age was 55 years consisting of injuries from C5 to L1, with only one tetraplegia. Sixty-one percent improved (11/18) and 11% got worse (2/18). Positive predictors of a good outcome were tear size <3cm (100% of subjects improved) and preoperative abduction >100° (89% improved).

Conclusions: There is very little published data on rotator cuff tears and surgical repair in patients with spinal cord injury. Although the identified studies were heterogeneous in many factors as well as having small numbers, this systematic review reveals evidence that rotator cuff repair may improve outcomes in this population based on the size of the tear and the subject’s preoperative abduction range of motion. Further research is warranted and needs to be explored.
A CASAM study on the feasibility of developing a pre-operative test for evaluating the strength of the individual wrist extensors in tetraplegia

Presenter: A. Kerver (erikwalbeehm@mac.com)

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Tendon transfer remain the most important modality of reconstruction of hand function in tetraplegic patients. An essential pitfall is whether the extensor carpi radialis brevis (ECRB) muscle is sufficiently strong to allow transfer of the extensor carpi radialis longus (ECRL) muscle.

There is no reliable clinical test to evaluate these two muscles independently. Prior to biceps to triceps transfers it is good practice to temporarily paralyse biceps with marcaine, in order to test residual strength in the brachialis and brachioradialis muscles.

The goal of this project is to describe the anatomy of the muscle bellies of ECRL and ECRB and brachioradialis, as well as the innervation points, and describe the feasibility of injecting either ECRL or ECRB with marcaine to test the remaining strength in the other muscle, as a pre-operative clinical test.

Twenty arms were evaluated with the elbow in 90 degrees flexion, and the forearm in neutral. The lateral- and medial edges of the muscle bellies of brachioradialis, ECRL and ECRB were dissected, measured and photographed, together with a number of fixed anatomical landmarks. Subsequently the innervation points of all muscles were mapped and classified.

A novel method, CASAM (Computer Assisted Surgical Anatomy Mapping) was used to visualise and evaluate all data. With this method muscle bellies and innervation points can be shown in a calculated average arm.

In all cases the ECRL muscle belly was proximal to the ECRB, with a large overlapping area. By means of CASAM areas could be identified of ECRL and ECRB that were unique to either muscle, in all 20 arms.

The ECRL area was situated at 16% of the distance between the lateral epicondyle and the deltoid muscle insertion. The ECRB area was 5 times bigger then the ECRL area and was found at 40% of the distance between the lateral epicondyle and the radial styloid process.

The ECRL and brachioradialis showed 1 to 3 innervation points. The ECRB 1 to 4. In 47% of the cases there was a nerve branch innervating both ECRL and ECRB. Based on the CASAM generated data it seems anatomically feasible to inject either the ECRL or the ECRB with a temporarily paralysing substance. Subsequently the remaining force can be tested. Although the unique ECRL area is smaller then the unique ECRB area, it appears more practical to inject the unique ECRL area, since this provides direct information on the remaining force of ECRB.
Motor branch of ECRL: anatomic localization for selective motor branch block: a useful technique before muscle transfer in tetraplegia

Presenter: F. Genet (francois.genet@rpc.aphp.fr)
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Introduction: Extensor carpi radialis longus (ECRL) is frequently transferred in order to improve function in patients with tetraplegia. It is not easy to assess before surgery, and mainly when GIENS Score is between 2 and 3, the isolate strength of the extensor carpi radialis brevis (ECRB) to maintain effective active wrist extension after surgery.

Purpose: The aim of this study was to localize the ECRL motor branch, its motor point, and to precisely identify its coordinates in relation to anatomical surface landmarks. This can allow the practice of selective motor nerve block before ECRL transfer in tetraplegia.

Intervention: Anatomic dissections of twenty adult cadaver limbs were done to localize the ECRL branch of the radial nerve.

Mean Outcome Measure: Three measurements were taken of the position of the motor branch: the distance from the lateral epicondyle (proximo-distal (mm)) and the ratio between the distance corresponding to the nerve depth (measured on a needle which was inserted transversely in the forearm from the lateral epicondyle, until it contracted the nerve (mm)) and the intercondylar distance (mm).

Results: The radial nerves of 4 males and 6 females (age ranged 59 to 80) were identified between brachioradialis and ECRL and traced proximally to the lateral epicondyle of the humerus. The point of injection is between the lateral epicondyle posteriorly and the wrist extensor group anteriorly. Direction is perpendicular to the axis of the forearm axis. Mean depth was 35.6 mm (24; 58 +/- 9). Ratio between nerve depth and intercondylar distance 0.46 (0.37; 0.53 +/- 0.05).

Conclusion: We propose anatomical landmarks for selective motor nerve block of the ECRL branch. This could be a useful tool and innocuous technique for testing the capacity of ECRB to extend the wrist alone and to assess the residual tenodesis effect, command and overactivity of the antagonist (wrist flexor) before functional surgery.
Grip reconstruction in a one stage procedure

Presenter: Reinholdt (cirein@telia.com)

Background: Reconstructing the grip in patients with tetraplegia is a surgical and physiotherapeutical challenge. Previously patients underwent surgical procedures in two stages in order achieve both finger flexion and extension. By adding tenodesis procedures to the flexor reconstruction phase it is possible to restore both active flexion and passive extension. The current study was undertaken to investigate the applicability of this combination of surgical procedures.

Methods: 12 patients classified OCu 3-4 underwent tendon transfers for finger and thumb flexion and tenodesis procedures of modified House’ procedure for finger extension, EPL tenodesis for thumb extension and ECU tenodesis to correct radial deviation in the wrist. Rehabilitation was focused on early mobilization. The range of motion (ROM) of finger flexion and extension were measured.

Results: Passive extension of the thumb and fingers was created with increased ROM in the metacarpal phalangeal joints. Finger flexion was satisfactory. The radial deviation deformity in the wrist was corrected.

Discussion: Grip reconstruction including active finger flexion and passive extension is possible to restore in a one-stage procedure. Patients were satisfied with the extension range and felt no need for active extension reconstruction. The study shows the importance of early mobilization to reduce the risk of adhesions.
Paper 24

Opponensplasty and extensor carpi radialis longus to flexor digitorum profundus transfer in the treatment of the tetraplegic hand: objective functional outcome

Presenter: F. Dachs (alexdelarco2502@hotmail.com)

Co-authors: A. DelArco, M. Ochoa, L. Ledesma, J.E. Prim, J. Vidal; Institut Guttman, Spain

Introduction: Our purpose is to perform an objective evaluation of the surgical treatment (Opponensplasty and tendon transfer of extensor carpi radialis longus to flexor digitorum profundus) and rehabilitation program in tetraplegic patients.

Methods: We conducted a study on 11 consecutive patients operated on from December 2007 to February 2009. They are all tetraplegic patients with functional neurological level 4 and 5 according to Giens Classification. 3 patients were operated bilaterally, so we collected 14 cases. A unique surgical procedure was performed in all cases: Opponensplasty (Braquiorradialis to thumb oponent in most cases) and ECRL to FDP transfer to achieve voluntary flexion of the triphalangeal fingers and the clamp of the thumb. The same rehabilitation program was applied: Patients performed 4 weeks of immobilization and 12 functional rehabilitation, contributing to the elastification of scars and musculature and passive mobilization on the first phase. At six weeks, begins BR functional electrostimulation, and since this moment reinforcement of functional patterns and training of daily life activities.

The clinical assessment battery consists of: ARA Review, NHPT, dynamometry, SCIM and videotaping. These tests have been performed preoperatively, at 4 months and one year postoperatively.

Results: We found a clear functional improvement of both the skills acquired and scores on different tests: ARA test goes from 17.57 to 36.31, dynamometry improves from 0.393 kg to 6.2 kg. The improvement is statistically significant. The sample NHPT shows functional improvement but not statistically significant.

As complications we encountered only one case of insufficient thumb pinch, which required surgical reintervention. There have been no surgical infections.

Conclusions:

1. Opponensplasty and ECRL to FDP transfer is an effective and predictable procedure for the treatment of tetraplegic hand Giens 3, 4 and 5.

2. The use of functional scales offers an objective analysis of the clinical outcome of patients, facilitates the detection of technical errors, and comparison of results between different series.
Arthrodesis or conservation of the carpometacarpal joint when constructing a key-grip in tetraplegic patients: a comparative study on 40 key grips

Presenter: B. Coulet  
(bertrand-coulet@wanadoo.fr)

Co-authors: J. Teissier, C. Fattal, D. Lumens, Y. Allieu, M. Chammas; Hand and Upper Limb Surgery Department Propara Center, France.

Introduction: Constructing a “key grip” (KG) is the final aim of any functional surgery program for the upper limb in tetraplegic patients. Three stages are required: activating the pinch, simplifying the polyarticular chain and positioning the thumb column. For the latter, 2 options are possible for the carpometacarpal joint (CMC): either arthrodesis or preserving the joint with a possible associated intervention on the soft parts. Our study compares these 2 techniques.

Materials and methods: 40 KGs were reviewed at 7.4 years’ mean follow-up. There were 17 KGs with CMC arthrodesis, 11 of which were active, and 23 without CMC arthrodesis, 7 of which were active. At review, both groups of active and passive KGs, according to the different positioning techniques were statistically comparable, regarding median ASIA motor scores, wrist extension strength and elbow flexion.

Results: Active KGs are significantly stronger (p=0.05) after CMC arthrodesis with a mean « pinch » of 2.6 kg against 1.3 kg. For passive KGs, the difference is not significant with 1.1±0.6 kg after fusion versus 1.0±0.9kg without.

Regarding opening, the mean distance between the thumb pulp and index was 4.0 cm for active KGs after CMC arthrodesis by a tenodesis effect and 5.8 cm for grasping large objects whereas without it, when the CMC was preserved, these values were 3.4 cm and 6.8 cm respectively. For passive pinches these same values were 2.2 cm and 3.5 cm after CMC arthrodesis compared with 2.4 cm and 6.9 cm without.

23.5 % of pinches were unstable with CMC arthrodesis compared with 30.4% without.

Discussion: CMC arthrodesis gives the active KG more strength to the detriment decreased opening when grasping large objects. However, for passive KGs, CMC arthrodesis significantly limits passive opening, with no significant gain in strength. Regarding pinch stability, neither technique has proved superior.
Mechanical strength of the side-to-side versus weave tendon repair

Presenter: R. Lieber (rlieber@ucsd.edu)
Co-authors: S. Brown, E. Hentzen, S. Ward, R. Lieber; University of California, San Diego USA.

Introduction: Early remobilization after tendon transfer is desirable in order to avoid adhesions, muscle atrophy and neural detraining. To accomplish this, the side-to-side (SS) tendon suture technique was designed to permit immediate post-operative activation and mobilization of a transferred muscle. The current study was designed to test the strength and stiffness of the SS technique against a variation of the weave (WV) repair technique.

Methods: Flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) tendons were harvested from four fresh cadavers and used as a model system to compare suture methods under controlled conditions. Seven SS and six WV repairs were performed using the FDS as the donor and the FDP as the recipient tendon. For SS repairs, the FDS was woven through one incision in the FDP, and was joined with four cross-stitch running sutures down both sides, and one double-loop suture at each tendon free end; for WV repairs, FDS was woven through three incisions in FDP, joined with a double-loop suture at both ends of the overlap, and four evenly spaced mattress sutures between the ends. Tendon repairs were placed in a tensile testing machine, pre-conditioned and tested to failure.

Results: There were no statistically significant differences in cross-sectional area (p=0.99) or initial length (p=0.93) between SS and WV repairs. Therefore, all comparisons between methods were made using measures of loads and deformations, rather than stresses and strains. All failures occurred in the repair region, rather than at the clamps. However, failure mechanisms were different between the two techniques—WV repairs failed by the suture knots either slipping or pulling through the tendon material, followed by the FDS tendon pulling through the FDP tendon; SS repairs failed by shearing of fibers within the FDS. Load at first failure (p < 0.01), ultimate load (p < 0.001), and repair stiffness (p < 0.05) were all significantly different between SS and WV techniques; in all cases the mean value for SS was higher than for WV.

Discussion: The SS repair, using a cross-stitch suture technique, was significantly stronger and stiffer compared to the WV repair using a mattress suture technique. This suggests that using SS repairs could enable patients to load the repair soon after surgery. Ultimately, this should reduce the risk of developing adhesions and result in improved functional outcome and fewer complications in the acute post-operative period. Future work will address the specific mechanisms (for example, suture-throw technique, tendon-weave technique) that underlie the improved strength and stiffness of the SS repair.

Acknowledgements: This work was supported by the Department of Veterans Affairs and NIH grants HD048501 and HD050837.
Paper 27

A comparison of dacron and hamstring grafts in deltoid to triceps transfers in traumatic tetraplegia

Presenter: K. Mohammed (kmortho@xtra.co.nz)

Co-authors: A. Rothwell, J. Dunn; Burwood Spinal Injuries Unit, Christchurch, New Zealand

Introduction and Purpose: The Burwood Spinal Injuries Unit initially used tibialis anterior as an intercalary graft for deltoid to triceps transfer. In 2001 we changed to a dacron graft and accelerated our rehabilitation program. Because of concerns with early failures and complications we changed our graft choice to hamstrings autograft, with no change in the rehabilitation program that we had used with the Dacron graft patients. This presentation reviews these 2 sequential groups of patients operated on by the same surgeons with the same rehabilitation program by the same therapists.

Method: Between July 2001 and September 2003 17 deltoid to triceps transfers were performed in 9 patients using a dacron graft. Since then, 21 deltoid to triceps transfers were performed in 12 patients using hamstrings autografts. The rehabilitation in the two groups was the same.

Results: There were 5 early failures in the dacron group where the dacron prosthesis had avulsed from the deltoid. There were 2 reoperations in the dacron group. There were no early failures or reoperations in the hamstrings group. Movement and strength data will be presented.

Conclusions: We experienced early problems with dacron grafts in our unit which we have not experienced with the use of hamstring grafts. Hamstrings autograft is a reliable graft choice for deltoid to triceps transfer and can be harvested through a small incision with minimal morbidity.
Revision surgery for failed biceps to triceps transfer

Presenter: D. Zlotolow (dzlotolow@yahoo.com)

Co-authors: C. Sylvan, D. Hutchinson, S. Kozin - Shriners Hospital for Children of Philadelphia.

Introduction: Restoration of active elbow extension has been shown to dramatically improve upper extremity function in patients with spinal cord injury. The biceps to triceps transfer has been demonstrated to provide reliable anti-gravity elbow extension in the majority of patients, and has advantages over the more traditional posterior deltoid to triceps transfer. However, we have experienced a nearly 10% rate of rupture with these transfers that has been consistent despite refinements of the technique. We present our experience with revision biceps to triceps transfers.

Methods: Six male patients with spinal cord injuries varying from C5 to C6 level underwent bilateral biceps to triceps transfers along with concomitant procedures for pinch and/or grip. The age at initial injury was an average of 16 years (range 12-17) and age at index surgery was 18 (range 14-19). Four patients were right handed, one was left handed, and one was ambidextrous. Patients who failed to progress with therapy comparable to the contralateral side, experienced an extensor lag, or regressed during therapy were evaluated for a possible rupture of the transfer.

Results: Five patients were found to lag behind the contralateral arm in elbow extension strength, and did not achieve strength beyond 2/5. One patient was progressing with therapy until they felt a pop. All patients had a failure of their non-dominant extremity, except for the ambidextrous patient, who had a rupture of the left transfer. All patients were found to have the biceps detached from the olecranon bone tunnel. One patient had a tendon autograft placed to augment the atrophied biceps tendon. Four patients had their biceps tendon reinserted into the olecranon and sutured to the triceps tendon, three of these with the addition of an interference screw into the olecranon bone tunnel. In two patients, the tendon was sutured to the triceps tendon only. Most patients were able to achieve anti-gravity elbow extension postoperatively. One rerupture occurred.

Discussion: All patients except for the one which is ambidextrous had a failure of their non-dominant side, with avulsion of the biceps tendon from the olecranon bone tunnel. Our suspicion is that co-contraction of the biceps and brachialis may be more difficult to prevent in the non-dominant side, and this may be causing the failures. The tendon/bone healing and the fixation of the tendon insertion may be another cause for failure, and perhaps should be modified as new technologies become available.
CMC fusion by shape memory staples in tetraplegia

Presenter: G. Kantunakis

Co-Authors: G. Caserta, A. Pellacani, A. Landi; Unit of Hand Surgery and Microsurgery, Policlinico of Modena, Modena, Italy.

The authors present their experience in CMC fusion by shape memory staples. CMC good positioning is necessary in treatment of unfavourable groups to obtain a good quality of tip to tip and tip to side pinches. Authors initially achieved CMC fusion by two K wires, then by one K wire and one staple and in the last four years by two shape memory staples. This technique provides immediate CMC stability without disadvantage of hardware removal and minimizing infection risks and immobilization.

Usually half cast immobilization is kept in the first 15 days, after which thumb tendon transfer rehabilitation is carried out and a new custom made plastic cast is maintained for an overall period of 35 days.

10 out of 10 patients treated (2 of which bilaterally) by the new technique achieved CMC X-rays fusion at 45 days without complications.

This surgical technique provides a better quality of life to tetraplegic patients reducing immobilization time and with earlier transfer rehabilitation.
A case of triceps tendon dislocation as a sequelae of deltoid to triceps transfer

**Presenter**: L.G. Conforti (gmrconforti@gmail.com)

**Co-authors**: MP. Tarello, PL. Tos, B. Battison. Traumatological and Microsurgery Ward, C.T.O. Hospital, Torino, Italy

Deltoid-to-triceps transfer was performed in July 2008 on a young quadriplegic patient (ASIA B, FIM 4/5, IC 1). The technique used was the fascia lata interposition with transolecranic bone tunnel.

**Postoperative treatment**: POP for 4 weeks followed by progressive active flexion and articular elbow recovery. In 2 months he developed full elbow extension with good strength (M3/4) and he started to use it freely to the point that he was playing at boxing with everybody passing near by him. Four months after operation he developed progressive loss of strength. The cause was a medial dislocation of the fascia lata. A new operation was performed in April 2009 to construct two pulleys for the fascia lata with complete recovery.
Rupture of the extensor carpi radialis brevis following tendon transfer in a tetraplegic patient

Presenter: G. Jacquemin gjacquemin@yahoo.com

Co-authors: I. Robidoux, A. Delure, P.G. Harris, T. Moser, A.M. Danino; Montreal Gingras-Lindsay Rehabilitation Institute, Université de Montréal’s Hospital Center, Notre-Dame Hospital, Canada.

Study Design: Case-report of a 45-year-old tetraplegic man who sustained a rupture of the extensor carpi radialis brevis following tendon transfer of the extensor carpi radialis longus on the flexor digiti profundus and the flexor pollicis longus.

Objective: To report a potential complication associated with this type of tendon transfer and discuss the appropriate diagnosis and treatment option for this complication.

Background data: Complications of tendon transfer surgery do include the rupture of the tendon transferred.

Methods: To our knowledge, this is the first report of a rupture of a non-transferred tendon following this surgery.

Results: This patient had a C7 tetraplegia. He had complained of wrist 3 months after his spinal cord injury. He did not report any pain previous to his injury. An x-ray failed to reveal any abnormality. A CT-scan showed slight degenerative changes of the third carpo-metacarpal joint. The patient received hyaluronic acid injection and was not complaining of any wrist pain when we evaluated him for the tendon transfers, a year and a half later. He underwent the first surgery for this extensor phase of the grasp restoration with no problem. Five months later, he underwent transfer of the ECRL on the finger flexors. After the immobilization period, we noticed a weakness of the wrist extensor. An ultrasound and an MRI were performed and demonstrated complete rupture of the ECRB. Surgery was performed and demonstrated a synovitis and degenerative lacerated tendon. Repair was done with transposition of a graft from the flexor hallucis longus. The patient underwent immobilization and rehabilitation was continued thereafter.

Conclusion: It is possible that this patient had a degenerative tendon before tendon transfer surgery. If a pathology of the wrist is suspected, a complete evaluation of the tendon integrity, including MRI should be performed.
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I want to drive my car and win races. Don’t give up

**Presenter**: I. Turcsanyi  (turcsanyii@chello.hu)
Department of Orthopaedics, Nyíregyháza County Hospital, Hungary.

**Introduction**: Although effectiveness of functional surgery based on remaining motor function of upper limb in tetraplegia is very important, it requires the patient’s motivation and personal capacity to pursue surgery and postoperative rehabilitation too.

**Patient and Method**: A 29 year old hungarian care racer had car accident and sustained C5-6 fractures and became tetraplegic in 1997. He was classified as OCu5(Tr+) according to the international classification. In his rehabilitation surgical treatment included restoration of active grasp (ECRL to FDP II-IV, Zancolli-lasso plastic), active key pinch (Split thumb tenodesis, BR to FPL) and reconstruction of thumb abduction (EDQ to APB) on his dominant right hand.

**Results**: Grasp of 6.2 kg and key grip of 3.9 kg could be restored. Active opening of the first web space increased of 13 cm. He returned to care race and won 8 hungarian races from 13 in 2005.

**Conclusion**: If you restore the function of the upper extremity in tetraplegic patients you can give them the purpose to live.
Fifty-two year follow-up of Bunnell’s procedure—Tribute to Jenő Manninger in Hungary

Presenter: I. Turcsanyi (turcsanyii@chello.hu)
Department of Orthopaedics, Nyíregyháza County Hospital, Hungary.

Introduction: Sterling Bunnell recognized in 1949 that, for the tetraplegic patient the wrist is the key joint of the hand. He recommended a flexor tenodeses procedure for the tetrapleg patient who has retained the ability to extend the wrist actively.

Patient and Method: Fifty two years after performing this procedure in Hungary the functional outcomes were retrospectively evaluated. A seventeen year old girl fell from gymnastic bars and suffered a spinal cord injury from level C5 to C6 in 1954. She became tetraplegic and according to the international classification she could be classified as OCu5(Tr). In 1958 she was offered a hand reconstruction procedure on her dominant left hand. Finger and thumb flexor tendons were tenodesed to the radius according to Bunnell’s recommendation. The triceps has not been reconstructed. Later on her right hand has been a similar tenodeses performed.

Results: Her grasp and key pinch strengths increased significantly, she became almost independent. She is alive now and a grandmother.

Conclusion: Fifty two year after surgery it can be confirmed that Bunnell’s recommended procedure gave a useful grasp and key pinch for those tetraplegic patients who has retained the ability to extend the wrist actively.
Multi-center survey of rehabilitation protocols after tendon transfer to restore pinch in tetraplegia

Presenter: E. Johanson (johanson@VA51.stanford.edu)


Introduction: Multi-center trials and systematic literature reviews have become important methods for establishing evidence based clinical practice guidelines. Tendon transfer procedures are widely reported to improve upper limb function in tetraplegia, however, small subject numbers, potential variability in surgical procedures, undocumented rehabilitation protocols, and lack of consensus in meaningful outcome measures can limit the ability to combine data sets from multiple sources. The purpose of this study was to determine if postoperative care is variable across multiple SCI Centers.

Methods: Standard postoperative management and rehabilitation protocols were surveyed in 7 SCI centers following tendon transfer as part of an ongoing Multi-Center trial. The subjects (to date) include 29 individuals, injury level cervical 4-7, who underwent transfer of the brachioradialis to flexor pollicis longus to restore lateral pinch between 2007-2009. The participating centers were instructed to complete a checklist documenting the key components of patient care following tendon transfer procedures. Information was recorded for duration and limb position for postoperative casting and splinting, therapeutic interventions (including initiation of passive and active mobilization, strengthening, and muscle re-education), and the utilization of home exercise programs.

Results: Immediately following tendon transfer procedures, care is directed to protecting the integrity of the transfer. One center allowed early mobilization of the transfer. The average days until all splints were removed after surgery was 79 days (range 48-146). Only 3 of 29 subjects used electrical stimulation or biofeedback for muscle re-education. Permitting active pinch postoperatively was variable (range: 1–91 days) and time to performing light activities from the time of surgery averaged 32 days (range 4-48). Strength training was prescribed in all centers and varied on its intensity. The ability to self-propel a manual wheelchair without splints averaged 76 days (range 27-116). The postoperative rehabilitation often did not occur in the same center as the surgery and muscle re-education became a primary responsibility of the patient by practicing functional tasks in the home.

Conclusions: Surgical outcomes following tendon transfer procedures have the potential to be significantly influenced by postoperative therapy. In the Centers we surveyed, similar protocols were followed during the immediate postoperative period with a large degree of uniformity for initiating light activities and more aggressive functions such as wheelchair propulsion, however there was variability in the timing, intensity, and focus of the rehabilitation programs. This study emphasizes the need for developing a standardized prescription for conventional postoperative care following tendon transfer procedures to serve as a baseline for studies of how postoperative rehabilitation affects surgical outcomes.
Early active training of deltoid to triceps transfers: a controlled study

Presenter: A. Lamberg (ann-sofi.lamberg@vgregion.se)
Co-authors: J. Friden; Department of Hand Surgery, University of Gothenburg, Sweden

Purpose: The aim of the study was to investigate the effect of early postoperative activation on elbow extension strength and elbow joint range of motion after reconstruction of posterior deltoid to triceps compared to a control group.

Methods: Fourteen individuals underwent early activation after surgery. They were matched to a control group (n = 14) regarding age at injury, ASIA motor score, and international classification of the hand. Pre- and postoperatively muscle strength, range of motion and international classification were assessed by a hand surgeon. Both groups adhered to same standard protocols after reconstruction elbow extension except for early activation in one of the groups. Those who had early isometric activation started with training of elbow extension in the cast on the first day after surgery. The purpose was to identify and activate the elbow extension. They trained four times per day with 3 sets of 5 repetitions and with shoulder in 80° of abduction. After four weeks they started to train the elbow extension in the range of motion that were allowed by the adjustable splint (starting with 40° of flexion to full extension with increased flexion by 15 degrees every second week). They continued with isometric activation in maximum extension of the elbow. After 3 months the adjustable splint was removed and they started using the hand in daily activities. The training focused on exercising full elbow extension in all planes of the shoulder joint. Throughout the entire rehabilitation patients exercised the contralateral arm.

Results: There were no differences between the groups regarding age, ASIA motor score or international classification or preoperative extension of the elbow. Those who underwent early activation demonstrated a significant increase in elbow extension range of motion both passively and actively after surgery. Of those who trained actively, 8 individuals had the same range of motion in elbow extension and 6 increased in elbow extension postoperatively compared to the control group where 9 individuals had no change, 3 decreased in elbow extension and 2 increased in elbow extension. There was also a significantly difference between the groups regarding postoperatively strength (p=0.036) were the individuals in the early activation group generated more power in elbow extension.

Conclusion: Early activation after reconstruction of Posterior Deltoid to Triceps is safe and may, in some cases, reduce elbow extension deficits.

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Enhanced postoperative training after grip reconstruction facilitates return to critical functions

Presenter: A. Lamberg (ann-sofi.lamberg@vgregion.se)
Co-authors: J. Wangdell, C. Reinholdt, J. Friden; Department of Hand Surgery, University of Gothenburg, Sweden

Purpose: This study investigated whether increased postoperative activity can reduce the time of relative immobilization and positively affect outcome after reconstruction of the grip and thumb flexion.

Methods: 11 patients who underwent 12 complete grip reconstructions were included in this study. 6 of the patients (7 arms) were trained according to our standard protocol including static hold activation of the thumb day after surgery but with extensive restrictions in range of motion of the fingers, thumb and wrist and fewer repetitions. Hand was tightly bandaged to prevent edema and a volar splint was used between training sessions during the first 4 weeks. Patients were not allowed to use the arm and hand for support during daily activities.

5 other patients started their training on the day after surgery and the goal was to recruit and activate the BR-to-FPL-powered thumb flexor. Activation comprised entire range of motion of the thumb flexion in the MCP joint with gradually increased number of repetitions in different positions of the forearm. Hand was bandaged with minor compression to allow unloaded activity during training but with considerable compression at rest in the splint for the first 4 postoperative weeks. Patients were encouraged to use the hand for support during daily activities.

The patients’ ability to use the new functions in daily activities (Yes/No) 4 weeks post surgery and their ability to activate the thumb flexion in full range of motion (Yes/No) was examined. Edema was evaluated 4 weeks postop from the perspective of whether it restricted training (Yes/No).

Results: After four weeks, one out of seven in the group training according standard protocol managed to reach the index finger with the thumb. The corresponding value for the activation group was five out of five. Whereas the patients in the activation group could focus on using their new functions in daily activities and modulating power of the grip, the patients training according the standard protocol had to focus on training range of motion at the corresponding time. Edema was never a training-restricting issue in the activation group while 6 out of 7 patients had edema-related problems in the standard group.

Conclusion: Early and rigorous range of motion activation after grip reconstruction, allows for earlier training of the new functions in daily activities.
Evaluation of the long term results of functional surgery of the upper limbs in tetraplegic individuals

Presenter: T. Albert  (talbert@ugecamidfr.fr)

Introduction: Postoperative evaluation of tetraplegic patients following rehabilitative surgery of the upper limbs and appropriate therapy shows, in the vast majority of cases, a satisfactory outcome, with improvement of prehensile capacities, and of activities of daily living. But very few studies have evaluated the results in the long term.

Goal: To evaluate the outcomes of rehabilitative surgery of the upper limbs after a minimum of five years

Methods: All tetraplegic patients having undergone rehabilitative surgery of the upper limbs more than five years ago at our centre were called in for reevaluation, regardless of the level of the tetraplegia, and of the surgical procedures performed. Evaluation involved a team assessment (successive examination by physiatrist, physical therapist, and occupational therapist.), and involved

1. Evaluation of the general health status (neurological status: ASIA; possible clinical complications; unrelated affections)
2. Standard analytic measurements of the upper limb: range of motion, muscle strength (BMRC), and sensory evaluation
3. Assessment of different types of prehension according to our standardized protocol
4. Functional independence: based on our own system of measurement (modified FIM), as well as on more recent tools (SCIM, Quick DASH)
5. Patient’s satisfaction: VAS, and a satisfaction questionnaire

Results: 68 patients were operated more than 5 years ago (1989 to 2005) by a single surgeon, and rehabilitated at a single centre. Nine patients were deceased, 38 were called in for review, 23 answered, and 19 agreed to return to the centre for a one-day re-evaluation. Up to date 11 patients have been reviewed, and the remaining 8 are programmed for a review within the next 3 months. Results on the first 11 patients show a stability of the neurological status. Performances in terms of prehension and functional independence have remained basically identical to the short term; In one case however the functional results deteriorated, along with the development of a syringomyelia. Patients confirmed on the long term their previously high satisfaction with the procedures, and would recommend this surgery to similar patients.

Discussion: Only 38 patients out the 59 / 68 still alive were called in, because the remainder either live abroad, or could not be called in for administrative and/or financial reasons. The preliminary results of this study show stability in the long term, both analytically and functionally. Upon completion of this first review, we intend to further extend it by contacting (by telephone, internet and a written questionnaire) all those patients who could not or would not come back for evaluation, in order to exclude any possible bias.
Posterior deltoid to triceps reconstruction after C4-C6 spinal cord injuries: a retrospective review of outcomes

Presenter: A. Lamberg (ann-soft.lamberg@vgregion.se)

Co-authors: J. Friden; Department of Hand Surgery, University of Gothenburg, Sweden.

Purpose: The purpose of the study was to retrospectively review the outcome after reconstruction of posterior deltoid to triceps and secondly point out the preoperative factors that affect the outcome.

Methods: Data were retrospectively reviewed from 34 individuals (48 arms) undergoing elbow extension surgery during the period of 1996 to January 2009 at National Center of Reconstructive Hand Surgery in Tetraplegia. Data collections were made from a database for reconstructive hand surgery of tetraplegic patients and from the hand surgeons’ medical records. Preoperative muscle strength, range of motion, ASIA classification, ICSHT classification, elbow extension strength and range of motion after reconstruction were reviewed.

Results: The subjects who underwent surgery had a spinal cord injury motor level from C4 to C6 and all except one were complete injuries. According to the ICSHT they were classified from O0 to OCh4.

Results: 75% of the arms measured grade 3-4 in elbow extension after reconstruction, 14.6% was grade 2, and 10.4% could not extend fully and were graded 1. Of those 5 subjects who did not receive full extension, 3 had medical problems that affected the outcome. The factors that demonstrated the highest correlations to postoperative strength in elbow extension were ASIA motor score, muscle strength of wrist extensors and Anterior Deltoid. Regarding passive range of motion, 25 out of 48 had no change in elbow extension after surgery, 14 out of 48 increased in extension and 9 of 48 decreased in elbow extension.

Conclusions: Reconstruction of posterior deltoid to triceps is a reliable procedure to power elbow extension. The expected outcome after surgery depends on level of injury but should never be less than grade 2 for an individual with C4 injury and grade 4 for a C5-C6 injury.

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Long term patient satisfaction after reconstructive upper extremity surgery to improve arm-hand function in tetraplegia

Presenter: Jaspers Focks-Feenstra (R.JaspersFocks@Roessingh.nl)
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Introduction: There is limited data available in the literature about patient satisfaction after reconstructive surgery to improve arm and hand function in tetraplegics. The current literature mainly describe functional outcomes.

Objective: To evaluate long term patient satisfaction after reconstructive upper extremity surgery in tetraplegics.

Setting: Two rehabilitation centers in the Netherlands with an active ongoing upper extremity reconstruction surgery program for improvement of hand function in tetraplegics.

Method: The study was carried out using a questionnaire that was originally used by Stroh Wuolle et al(1). Part 1 of the questionnaire in this study was divided into 3 parts and consisted questions about satisfaction, activities and occupation. Participants had to react to several statements on a 5-point Likert scale. Part 2 consisted of questions about changes in the ability to function after surgery and the willingness to undergo the surgeries again. In part 3 participants were asked to list activities in which the surgery was helpful and to give general comments on the surgery. Internal reliability of the questionnaire was verified by factor analysis and calculation of Cronbach’s alpha for the three factors. All data were statistically analyzed by means of descriptive analysis, Pearson correlation coefficients (two-tailed) and one-way ANOVA.

Results: In total 39 of 55 patients (70.9%) returned the questionnaire and participated in the study. The participants’ responses to questions about satisfaction were positive in 73.5%, to questions about activities were 67.6% positive and that relating to occupation were positive in 35.0%. Regarding the change of ability to function after surgery, 80.6% of the responses were positive. Sixty-five percent of the participants who underwent elbow extension surgery and 77.1% of the participants who underwent hand/wrist surgery expressed that they would choose to have surgery again. Correlation between participants’ readiness to have surgery again and their mean scores regarding activities and occupation (p) were: activities-elbow extension 0.68 (p=0.001), activities-hand/wrist 0.663 (p<0.001), occupation-elbow extension 0.63 (p=0.005), occupation-hand/wrist 0.65 (p<0.001). Differences in scores between the group who want to have surgery again and the group who would refrain were also significant; one-way ANOVA for activities (F=9.54, p<0.01) and for occupation (F=6.60, p<0.02).

Conclusion: In the Netherlands, the majority of tetraplegics who underwent reconstructive upper extremity surgery were satisfied with the results. Participants who responded that they would not choose to have surgery again had significantly lower scores on the factors activities and occupation.
Functional outcomes after implantation of a myoelectrically-controlled neuroprosthesis in people with tetraplegia

Presenter: Anne Bryden (anne.bryden@case.edu)

Purpose: The purpose of this study was to determine the functional outcomes after implantation of a myoelectrically controlled neuroprosthesis in people with tetraplegia.

Background: A second-generation implantable neuroprosthesis was developed for individuals with cervical level spinal cord injury. A key feature of this system is the implantation of both the control and the stimulation source, which reduced the external components by 50%. The IST-12 consists of 12 stimulation channels and two channels of myoelectric signal recording acquisition. The user generates myoelectric signals from muscles under voluntary control to activate stimulation to the paralyzed muscles in the arm. This results in functional hand grasp patterns including activation of shoulder and scapular muscles. Overall, 14 devices have been implanted in 10 participants with C5-C6 motor level SCI. This includes three participants with bilateral hand systems, and one participant with a system for hand and trunk function. The remaining participants have unilateral hand grasp systems. The International Classification of Functioning, Disability and Health (ICF) was used to structure measurement of functional outcomes.

Methods: Participants completed evaluations prior to surgery and again at three months, six months and one year post-surgery. Measures of body functions and structures include range of motion and grasp strength. Measures of activities include The Grasp and Release Test (GRT), The Capabilities of the Upper Extremity Survey (CUE), The ADL Abilities Test (ADLAT) and the Canadian Occupational Performance Measure (COPM). The primary measure of Participation is the Craig Handicap Assessment and Reporting Tool (CHART). Additionally an assessment of satisfaction with the neuroprosthesis was conducted at one year post-implantation.

Results: Lateral grasp strength increased with the neuroprosthesis. Median lateral grasp strength with the neuroprosthesis was 4.01 lbs. (1.74-6.27) compared to 0.77 lbs (0.35-5.40) without the neuroprosthesis. Participants were able to acquire and move a median of 6 out of 6 objects (5-6) with the neuroprosthesis compared to a median of 2 out of 6 (0-4) without. Everyone improved performance of at least one ADL with the neuroprosthesis. Overall, performance improved with the neuroprosthesis in an average of 75% of the activities tested per person (range 33%-100%). COPM Performance scores increased after neuroprosthesis implantation for all participants except for one, whose score stayed the same. Overall, participants were satisfied with their neuroprosthesis, and would recommend it to others with tetraplegia.

Conclusion: These results indicate that implanted myoelectric control is an effective control option for neuroprostheses and for restoring function to individuals with cervical level spinal cord injury.
Implanted neuroprostheses for high tetraplegia: A two patient review

Presenter: Anne Bryden (anne.bryden@case.edu)


The Cleveland FES Center, Case Western Reserve University, MetroHealth Medical Center, The Louis Stokes Cleveland VA Medical Center, Cleveland, OH, USA.

Purpose: To determine the feasibility of restoring arm and hand function in two participants with high level tetraplegia using implanted myoelectrically controlled neuroprostheses and advanced electrode technology.

Background: Individuals with high tetraplegia (ASIA classification C4 or higher) have few options to restore upper extremity function. They are not candidates for traditional tendon transfers due to the lack of voluntary muscles available. The Cleveland FES Center has been implanting neuroprostheses for hand function in people with mid-level tetraplegia for decades. Advancements made in implanted neuroprosthetic technology have now allowed us to stimulate shoulder, arm and hand muscles in people with high level tetraplegia. The advancements that make this possible include the use of nerve cuff electrodes for stimulation and implanted myoelectric electrodes for controlling the system. This report reviews the successes and challenges experienced in the implementation of two individuals with high tetraplegia.

Methods: Two participants were implanted with dual IST-12 neuroprostheses. Each participant has 24 stimulating channels and four myoelectric channels for controlling the neuroprostheses. The systems were implanted in 2-3 surgical procedures. Participants’ arms were immobilized for three weeks following the procedure. After the immobilization period, participants returned for follow up visits to address programming and functional training with the system.

Results: Both participants successfully use MES electrodes to control shoulder horizontal abduction/adduction, shoulder flexion/extension, shoulder internal/external rotation, elbow flexion/extension, forearm pronation/supination, wrist flexion/extension and hand opening/closing (one or two modes). Use of a mobile arm support (MAS) is necessary to reduce the effects of gravity. The first participant is able to use the system for eating finger foods and eating with a utensil. The second participant is still receiving training in functional activities, but was able to reach out and hug his children after his initial training. Challenges to implementing this system include upper extremity spasticity for participant one and difficulty refining the MAS for participant two.

Conclusion: Two participants have been successfully implemented with myoelectrically controlled neuroprostheses. Refinements of the systems continue to be made; however, both participants are able to do activities that were impossible prior to receiving their system.
**Perceived activity performance is not correlated with functional factors**

**Presenter**: Johanna Wangdell (johanna.wangdell@vgregion.se)

**Co-author**: J. Friden; Department of Hand Surgery, University of Gothenburg, Sweden.

**Purpose**: The purpose of this study was to investigate the relationship between perceived activity performance and specific physical determinants after grip reconstruction. Particularly, we explored whether the degree of physical improvement of hand function might have impact on the individual’s perceived ability to perform prioritised activities.

**Methods**: 48 persons (33 men and 15 women) with tetraplegia who underwent tendon transfer surgery in the hand between 2002 and 2008 were included in the study. Age at surgery was on average 40 years (20-74) and year after injury was 7.6 (1-36). In order to collect the patients’ activity goals and their performance of these activities, the Canadian Occupational Performance Measurement (COPM) was used. Difference between preop and 1 year postop COPM scores indicated activity change. Changes were divided into 3 groups depending of the magnitude of the difference; [A] No or minor clinical improvement (-1 - 1.9 scalesteps), [B] improvement (2 – 3.9) and [C] major improvement (4 - 9). The physical functions as measured one year after surgery were collected from our database. Data included grip strength, key pinch strength, sensibility (thumb), maximal distance between thumb and index finger, pulp-to-palm distance, hand dominance and wrist flexion and extension range of motion.

**Results**: Grip and pinch strength at 1 year was 7.5 and 2.1 kg, respectively. Distance between thumb and index finger was 5.5 cm (0-15). The expressed activity goals were spread over a wide range of activities. Average activity improvement for each person was 3.3 scalesteps (-0.7 - 7). There were no strong or significant correlations between patients’ perceived performance with their activity goals and any of the functional outcomes. Interestingly, persons operated on dominant side as well as those who had sensibility in the operated hand were assigned group B. Those who had surgery on non-dominant side or were operated in a hand that lacked sensibility assigned equally divided among A, B and C groups. In group A, all patients belonged to OCu4 or “worse”. Patients with OCu5 or “better” were allocated to group B.

**Discussion**: There are important improvements in both physical and activity perspective but the correlations between those dimensions are non-existing or low. The lack of correlation could be explained by the fact that individuals living with tetraplegia still, even after a grip reconstruction, have to perform many of their activities in an adjusted way, especially if the injury is high. They are forced to develop new adapted ways to optimise their new possibilities in activity. If the surgery is done in non-dominant hand or a hand without sensibility the relearning process is even more challenging.
Assessment model of tendon transfer in cervical spinal cord injury

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Introduction: Neurorehabilitation surgical treatment of tetraplegic hand is characterized by well-defined criteria, however, the final evaluation is still based on patient satisfaction and intuitive assessment of functional improvement by the clinical team. The purpose of this paper is to introduce a systematic assessment of functional outcome to objectively evaluate individual’s patient clinical outcome and compare it to that of other patients.

Objectives: To assess the neurorehabilitation program in individuals with cervical spinal cord injury with tendon transfer extensor carpi radialis longus and the flexor digitorum profundus opponent plasty, through a comprehensive test battery.

Materials and methods: The proposed comprehensive test battery includes Action Research Arm Test (ARA Test; Van der Lee, 2001), Nine Hole Peg Test (NHPT; Mathiowetz, 1985), dynamometry, Spinal Cord Injury Measurement (SCIM II; Catz et al., 2002) and videotape recording of six hand movement tasks (e.g. grasping of a glass). The assessment was performed at baseline prior surgery, 4 months post-surgery, and one year post-surgery. Data have been collected since December 2007 at Guttmann Institute. This is an ongoing study and here we are reporting results from the first 7 operated hands.

Patients underwent a 4-month neurorehabilitation program (4 weeks of immobilization and the remaining weeks of functional rehabilitation).

Results: Data were submitted to Wilcoxon Rank Sum test to identify potential for changes on each assessment between the three time points (baseline (T0), 4 months post-surgery (T1), one year post-surgery (T2)). Results revealed significant statistical differences of mean scores in the ARA test between T0 and T1 [Z = -2.94; P = 0.003] and between T0 and T2 [Z = -2.37; P = 0.018], in the lateral pinch dynamometry (T0 and T1: [Z = -3.20; P = 0.001]; T0 and T2 [Z = -2.38; P = 0.017]), in the grip dynamometry (T0 and T1: [Z = -3.18; P = 0.001]; T0 and T2 [Z = -2.37; P = 0.018]) and finally in SCIM test (T0 and T1: [Z = -1.97; P = 0.049]; T0 and T2 [Z = -2.21; P = 0.027]). These significant changes suggest that patients improved with time on each of these tasks.

For the NHPT, there was a trend of changes suggesting an improvement. Further testing is warranted to investigate whether patients would eventually improve as this task requires a more complex and fine hand movement.

Conclusion: Findings of the present study show an improvement of hand grip strength and functional outcomes at four months and one year after surgery compared to prior surgery. As a result, a functional independence (daily life and instrumental activities) is improved. The test battery used here provides an objective individual patient functional outcome that can be compared to outcomes from other patients.
Self-catherization acquisition after hand reanimation protocols in C5-C7 tetraplegic patients

Presenter: B. Bernuz (b.bernuz@leonberard.com)
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Study design: Retrospective study of patient files and phone surveys from a prospectively acquired database. OBJECTIVES: To assess the efficacy of Upper Limb Reanimation (ULR) protocols on acquisition of Intermittent Self Catheterisation (ISC) in C5 to C7 (ASIA) tetraplegic patients.

Setting: University Hospital, Paris, France.

Method: A prospectively acquired database of 152 tetraplegic patients followed in ULR consultation between 1997 and 2008 in a rehabilitation unit was studied. N=20 patients met the inclusion criteria which main are: traumatic patients unable to perform ISC, who benefited from ULR with the objectives of improving hand abilities and ISC acquisition through the urethral orifice for males or via a continent urinary stoma for females. Main outcome measure: ISC acquisition (ISC+) rate. Secondary outcome measures: relation of ISC acquisition to epidemiological and surgical data, key-grip strength, Patient Glogal Improvement score (PGI), activities of daily living (ADL) and Quality of Life (QoL) (Wuolle questionnaire, VRS).

Results: ISC+ rate was 75%. ISC+ depends on key-grip strength (p<0.05) and leads to a statistically significant improvement of urinary status compared to ISC- patients (p<0.01), with improvement in ADL and QoL. Even in the ISC- group, ULR improved patients’ abilities and QoL.

Conclusion: ULR protocols allow ISC in most of C5-C7 tetraplegic patients. Multidisciplinary care with surgeons and PRM physicians improves the vital and functional prognosis of these patients by changing their urological-management method.
Subsequent to the International Meeting on Upper Limb in Tetraplegia & Upper Limb Surgery in Philadelphia in 2007, an international working party was formed to address the issues of measurement of upper limb functional outcomes for persons referred to upper limb surgical teams or in clinics around the world. The outcomes of interest include both persons who undergo reconstructive surgery and persons who meet the criteria for surgery, but for whatever reason, do not have surgery. The pre-conference workshop “Whose outcome is it anyway?” was a catalyst for this project and it was agreed that New Zealand (NZ) would take the lead co-ordination role. The primary aims of this effort are to establish an international baseline of functional performance and then to determine the relative effectiveness of reconstructive hand surgery, and conventional follow-up care. In the first instance agreement was reached that the International Classification of Function, Disability and Health (ICF) would remain as the framework on which to base interpretation of measures. Second, the Canadian Occupational Performance Measures (COPM), agreed upon at the Christchurch meeting in 2001, would remain within the battery of measures. Finally, it was agreed that data ought to be collected and where possible shared internationally.

Select centres were then asked to use additional outcome measures in a pilot feasibility study to determine their practicality and clinical value. This presentation will firstly outline the process of international agreement and consensus. Secondly, the outcome measures chosen for the clinical utility and feasibility exercise in NZ and Sweden will be described and defended in light of current literature. The status of the feasibility exercise will be reported. Next the development of the database will be reported. Finally, justification for the development of a multi-centre quasi experimental clinical trial will be given.
Measuring functional outcomes after upper extremity reconstructive surgery: Developing a prospective case control study

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For more than four decades, surgical techniques have been established and used to increase upper extremity function and independence for people with tetraplegia. Surprisingly, the effects of these interventions in comparison to more traditional rehabilitation for restoring arm and hand function have not yet been comprehensively studied. Connolly et al. reported the following limitations based on a systematic review of the literature pertaining to upper extremity reconstructive surgery: 1) Standard measures were not consistently used, 2) Measures used were either not available or not easily used in clinical settings, 3) Measures were developed for specific study, 4) Measures were based only on subjective reports of satisfaction. Such reports contribute little to the base of evidence required to support the provision of these surgeries for the tetraplegic population.

In response to this problem, there has been increased attention toward measurement issues in the past two International Meetings on Upper Limb Surgery in Tetraplegia (2004, 2007). Sinnott and colleagues lead an international working group and a multi-center study developed to ensure an international baseline through the agreement in use of The International Classification for Hand Surgery, hand strength measured in newtons and three standardized outcome measures [The Capabilities of the Upper Extremity (CUE), The Canadian Occupational Performance Measure (COPM), and the Personal Wellbeing Index (PWI)]. Key elements of this study include the use of a control group and use of evaluator blinding techniques as appropriate.

One limitation to the international study was a lack of agreement on a measure of hand function. As a participating center, we propose to complement the international study with additional tests and measures including the Grasp and Release Test (GRT), The ADL Abilities Test (ADLAT), ADL Habits Survey (ADLHS) and the Spinal Cord Independence Measure – version III (SCIM-III), The Craig Handicap Assessment and Reporting Technique (CHART) as a measure of participation and the SF-12 as a measure of overall health. Finally, a Reconstructive Surgery Satisfaction Survey will be administered to the surgical group one year post-surgery.

The information generated by this extra testing has the potential to provide evidence that will facilitate future agreement in the use of a hand function measure. We invite any other centers with available time and resources to collect this information as a prospective study. This type of collaborative agreement is essential for developing clinically meaningful measures of hand function to critically assess upper limb intervention strategies. We welcome the inclusion of any other centers that would want to collect this information in addition to the International Study.
Poster 1

SURGICAL IMPROVEMENT OF UPPER EXTREMITY FUNCTION IN HIGH-LEVEL SPINAL CORD INJURIES DUE TO DIVING ACCIDENTS

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Introduction: Diving accidents are catastrophic events frequently causing high level spinal cord injury (SCI), mostly in active adolescents or young adults. Many papers have been dedicated to the epidemiology, trauma mechanism, morbidity and prevention of these events, yet the effect of upper extremity surgery in this specific population has not been adequately studied.

Objective: To investigate the objective clinical improvement and subjective patient satisfaction after reconstructive upper extremity surgery in high-level tetraplegia after diving accidents.

Patients and Methods: Between 1978 and 2010, a total of 47 patients (2 female, 45 male) with a mean age of 24 years (range: 14 to 54 years, 43% under 20 years) underwent surgery to restore arm and hand function lost due to cervical SCI caused by a diving accident. The 65 operated upper extremities (18 bilateral) were categorized from O0 to OCU6, yet more than 50% of the patients had no or only one motor (Brachioradialis) available for tendon transfer below the elbow (IC 0-1). Functional parameters, such as key pinch, grasp strength and active thumb-index opening were measured prospectively.

Results: Overall, 166 reconstructive procedures were performed in 65 upper extremities with a mean of 2.6 operations per extremity in a mean of 2.6 (max: 5) stages. These included 5 biceps and 26 posterior deltoid transfers for elbow extension, 6 operations to restore wrist extension (BR-ECRB), 35 procedures for key pinch (10 passive, 8 active BR-FPL and 17 combined BR-FPL and ECRL-FDP for grasp). In 11 hands restoration of thumb extension or abduction was performed, thumb stabilization was done by CMC arthrodesis in 12 and FPL split tenodesis in 22 cases and intrinsic reconstructions in 16 hands (6 Zancolli lasso, 5 EDM-APB and 5 House procedures). In 4 cases an Advanced Balancing Combined Digital Extension Flexion Grip (AB-CDEFG) reconstruction including 7 procedures was possible. Despite the high level of tetraplegia in many patients, overall results compared favourably to reconstructions after other causes of tetraplegia (such as traffic accidents, falls) regarding objective parameters as well as subjective outcome tools as the Canadian Occupational Performance Measure (COPM).

Conclusions: Muscle-tendon transpositions and joint stabilizations have a great potential to improve arm and hand function and thus independence and mobility in tetraplegic patients, even when suffering from high-level SCI due to diving accidents.

Poster 2

STEPS IN THE DEVELOPMENT OF RECONSTRUCTIVE TETRAPLEGIA SURGERY IN HUNGARY FROM 1958 TO 2010

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Introduction: The first paper on tendon transfer for tetraplegia came from the Mayo Clinic in 1958. In the same year a 17 year old tetraplegic girl classified as OCU5 was treated with Bunnell’s procedure by Jenő Manninger and Jörg Böhler in Hungary. This procedure was rarely performed in Hungary but during 1980s a few cases have been carried out such as tenodeses, fusions and muscle tendon transfers. There was a break about 30 years ago.

Methods: In attempt to improve tetraplegia upper limb surgery service in Hungary we initiated a project to provide this service the year of 2002. Between 2002 and 2010, 57 tetrapleg patients (11 females, 46 males, mean age 34 years) were treated with surgical reconstruction of upper limbs. Interval between injury and examination ranged from 1 to 27 years. They had all sustained traumatic spinal cord injuries from level
C4 to C7 and were classified as OCu 1-8 and with (n=12) and without (n=45) functioning triceps according to the international classification.

**Results:** 140 individuals with tetraplegia were examined initially. 125 reconstructions were performed on the 57 patients. Surgical treatments included restoration of elbow extension (n=45), active key pinch and grasp (n=80) and active thumb abduction (n=5). An average active elbow extension strengths of 4 MRC and average key pinch of 3.9 kg and grasp of 6.2 kg could be restored. Active opening of the first web space increased by an average of 9 cm (8-13cm). A website was created to promote contact between patients who have undergone surgery and those who are potential candidates.

**Conclusion:** Reconstructive surgery on upper limbs in patients with tetraplegia play an important role in the rehabilitation. This review of the history shows that slow but positive progress is being made in tetraplegia surgery service in Hungary.

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**Poster 3**

**INTERMUSCULAR MYOFASCIAL CONNECTIONS OF FLEXOR CARPI ULNARIS CONTRIBUTE TO WRIST FLEXION TORQUE IN THE SPASTIC ARM OF CEREBRAL PALSY PATIENTS**

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**Background:** The flexor carpi ulnaris muscle (FCU) is thought to be the strongest forearm muscle and is held responsible for the flexion and ulnar deviation deformity of the wrist in cerebral palsy. Recent studies revealed an important role of fascia in muscle performance [1, 2]. It is thought that myofascial connections play a substantial role in the functioning of the spastic arm in cerebral palsy [2]. The hypothesis was that both tenotomy of the FCU and subsequent dissection of the fascia affect the flexion torque at the wrist.

**Methods:** Eleven patients having a transposition of the tendon of the FCU were included. Under general anesthesia without administration of muscle relaxants, the FCU was percutaneously stimulated with supramaximal electrical pulses through two skin electrodes that were placed on the cubital tunnel of the elbow. The surgeon fixated the forearm in neutral position and assured that the hand was not blocked dorsally. A force transducer was placed on the volar side of the distal tubercle of os metacarpale III. The palmar crest of the hand was assumed to be the volar projection of the wrist flexion axis. The moment arm was the distance of the impact point of the force transducer to this palmar crest. Isometric wrist torque was measured under three conditions: before tenotomy, after tenotomy of the distal tendon, and after subsequent dissection of the fascia around the FCU up until approximately halfway the muscle belly. Each session consisted of three trials that were averaged. Change of torque was expressed as a percentage relative to the torque before tenotomy.

**Results:** After tenotomy, the wrist flexion torque decreased on average to 85%. After dissection of the FCU from surrounding structures, the torque decreased to 71%. The 14% difference between the after tenotomy and after dissection conditions was significant (p < 0.05).

**Conclusions:** In these patients, dissection of the FCU resulted in 14% decrease of wrist torque and thus affected the FCU muscle function. The myofascial connections of spastic muscles may play a role in the development of deformities in the spastic arm of cerebral palsy patients and should not be overlooked in planning surgical intervention.

**REFERENCES**


**Poster 4**

**EFFECT OF GRAVITY COMPENSATION ON KINEMATICS, MUSCLE ACTIVATION AND TRAINING OF THE SHOULDER AND ARM IN CERVICAL SPINAL CORD INJURY**

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**Introduction**: Many applications in upper extremity rehabilitation after cervical spinal cord injury (CSCI) include arm support during treatment, for example robotics and suspension arms. However, the specific effect of arm support (gravity compensation) in subjects with CSCI is largely unknown.

**Aim**: To assess the effect of gravity compensation on joint excursions, movement parameters, and electromyographic (EMG) characteristics of the upper extremity in subjects with CSCI.

**Methods**: Nine subjects with a CSCI (at least one year time since injury) participated in a cross-sectional study (Part 1). Maximal reaching task and a reach and retrieval task, were both performed with and without gravity compensation. Angles at elbow and shoulder joints, EMG, and movement times were measured and compared for both conditions.

Four of the subjects also participated in a pilot intervention study (Part 2). The subjects followed a training program which comprised of one and a half hour training session three times a week. The subjects trained for 4 weeks with and for 4 weeks without the use of gravity compensation. Subjects were assessed before and after each training period and four weeks after the end of the second training period. Study parameters were kinematics, EMG and functional tests.

**Results**: Cross-sectional part: During the maximal reaching task with gravity compensation seven subjects showed less elbow extension. In the reach and retrieval task with gravity compensation movement execution was performed closer to the midline, movement times increased in four and decreased in two subjects. The amplitude of muscle activation decreased, especially, in anti-gravity muscles while timing was not influenced by gravity compensation.

Results after training (measured without gravity compensation): Number of repetitions during a reach and retrieval task increased after both training conditions and was still seen at follow up. Further analysis of kinematic, EMG and functional tests data showed no specific effects of training with gravity compensation on performance without gravity compensation after the training period.

**Discussion and conclusion**: Gravity compensation results in reduction of activity in the anti-gravity muscles and a more direct line of action. Potentially the use of gravity compensation might intensify training possibilities. However, the present small pilot study showed no specific effects on kinematics, EMG, and functional outcome tests. Further research with a larger population is needed to demonstrate possible benefits of training with gravity compensation. The study demonstrates that training of the upper extremity can be effective in tetraplegics even in the chronic phase.

**Keywords**: electromyography; goal directed movements; kinematics; rehabilitation; robotic assisted therapy; spinal cord injury; tetraplegia; upper extremity.

**Poster 5**

**DEPENDENCE OF ELBOW FLEXION STRENGTH ON SHOULDER JOINT RIGIDITY**

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Severe brachial plexus injuries may require surgical functional restoration by extraplexal donor nerve transfer. Restoration of elbow flexion (EF) and shoulder postural control is the highest priority [1]. The ability to maintain posture depends on the strength and role of restored muscles. If the shoulder is too weak to maintain glenohumeral joint stability and shoulder posture, arthrodesis may be performed. Our objective is to investigate how shoulder rigidity affects the behavior of muscles crossing the elbow and shoulder during EF. We used an upper extremity model [2] to perform EF simulations. We used computed muscle control [3] to calculate muscle activations during EF. For four clinical cases -1) normal, 2) arthrodesis, 3) axillary nerve transfer and 4) suprascapular nerve transfer - we simulated an EF motion from 0 to 90 degrees flexion with the arm in arthrodesis posture [1], the forearm and wrist in neutral rotation, and a 5 lb weight at the hand.
For case 1, all muscles had normal function. For cases 2, 3, and 4, supraspinatus, infraspinatus, deltoid, subscapular, teres major/minor, lat. dorsi, and coracobrachialis were initially paralyzed [4]. We estimated that recipient axillary muscle (deltoid, teres minor) and suprascupper muscle (supraspinatus, infraspinatus) activation capacity after nerve transfer was 30% of normal, and all muscles distal to the shoulder, including biceps and triceps, were normal. Future studies will investigate the effect of variations in activation capacity after nerve transfer on shoulder rigidity.

Case 1 accomplished the EF task using 11.7% of the maximum isometric elbow flexion moment (IEFM) that the model can generate. Case 2 required only 9.0% of IEFM, since activity of muscles crossing the shoulder, including biceps, is not required to hold shoulder posture. Of the nerve transfer cases, case 4 was not capable of maintaining arm posture and required 39.5% of IEFM to flex the elbow. Conversely, case 3 was able to maintain arm posture while using only 21.4% of IEFM. Calculated muscle activations indicate higher biceps and triceps activity as shoulder rigidity decreases. These results suggest that axillary nerve transfer may be more suitable for restoring shoulder function to maintain arm posture during EF. More importantly, the results demonstrate how muscle function at one joint can affect the perceived strength at another joint. Low EF strength may be intuitively perceived as the result of weak muscles crossing the elbow. However, if weak shoulder muscles cause the biceps to divert a high proportion of force to maintain arm posture, then simply strengthening shoulder muscles would more effectively increase EF strength.


Poster 6

BUILDING A PROGRAM FOR TENDON TRANSFER IN TETRAPLEGIA: THE MONTREAL EXPERIENCE.

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Objectives : The aim of this paper is to review in detail the process through which we went to develop a tendon transfer program for tetraplegia.

Introduction : Tendon transfer in tetraplegia is a well known and standard procedure in several spinal cord injury centers in the world. It is however still an unknown technique for most of the medical community and an accessory problem for health politics facing large scale health debate. We developed a program and thought it would be interesting to present our experience to help professionals setting-up their own program. We present a retrospective study of tetraplegia tendon transfer program set up in Montreal Canada, two years after our first case.

Methods : We performed a qualitative analysis on the entire process from the first idea to build a tendon transfer program to the effective establishment of the program and its implementation. All correspondence about the program was reviewed retrospectively. The thematic analysis was guided by complexity theory, a contemporary form of systems theory, which selected attributes to be measured and clustered them into themes. Different steps were identified, named and then classified.

Results : Six decisive step were identified from our qualitative analysis Following the initial idea, first step was selection of members for a local multidisciplinary team. Second step was an exhaustive literature review Third step was contact with a mentor team Fourth step, participation to the international meeting. Fifth step, establishment of administrative procedures in the organization Sixth step, first surgery to restore pinch and grasp in a 22 years old lady.

Conclusion : Tendon transfer surgery and rehabilitation need a dedicated team and administrative support. Building this team is a long and organized process from which distinct steps can be identified.
Poster 7

EVALUATING THE NEEDS OF UPPER LIMB SURGERY IN A TETRAPLEGIC POPULATION: PRESENTATION OF THE CRITERIA FOR REJECTION OF SURGERY.

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Study design: Retrospective study
Objectives: The aim of this study was to gather data on the reasons for candidate rejection for tendon transfer surgery.

Methods: Looking at all charts of tetraplegic patients hospitalized in the last 2 years in our center, we reviewed the medical conditions, level of injury and quality of rehabilitation process and other factors to identify the reasons for rejecting surgery. Analyzing those reasons, we classified them in categories and subcategories.

Results: We divided the reasons for rejections into 2 categories: patient’s clinical factors and patient’s personal choices: we further subdivided them into several subcategories. For the patient’s clinical factors: level of injury too high, incomplete lesion with insufficient hand function, age, poor compliance to rehabilitation, medical issues preventing surgery and the like. For the patient’s personal choices category, we subdivided it into: not wanting to have the arm operated, wanting to wait for other cure, not wanting to be dependant again, other reasons (family, work issues).

Conclusion: Decision for proceeding to tendon transfer surgery involves many factors. A clear comprehension of the factors leading to surgery rejections will help targeting the interventions dedicated at minimizing the rejections.

Poster 8

A REHABILITATIVE PROTOCOL AFTER POSTERIOR DELTOID PRO TRICEPS FOR ELBOW EXTENSION RESTORATION IN QUADRIPLEGIC PATIENTS.

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Between the year 2007 and 2009, in our Rehabilitation Division, 5 patients who had undergone Posterior Deltoid Pro Triceps Surgery were rehabilitated to regain extension of the elbow.

All 5 patients were SCI patients with post traumatic quadriplegia (ASIA A) and level of lesion in C5. They all had undergone anterior and posterior surgical stabilisation.

The average age was 32 years old, Giensa classification in group 2, with Biceps and BR muscle strength =5 and Triceps =0; Posterior Deltoid =3/4 in 4 patients and = 3 in one patient.

All these patients underwent an intensive pre surgical rehabilitative programme for two months, with active muscular reinforcement and electrical therapy for the Posterior Deltoid and the muscles of the entire arm and of the trunk. At the end of this pre surgical programme, 5 patients had a Posterior Deltoid muscle strength = 5 and one patient = 4.

All functional surgery procedures were performed in Dr. A. Landi’s Hand Surgery Unit of the nearby Modena Hospital between 2007 and 2009 (for one patient the surgery was bilateral), one year after the spinal cord lesion.

All patients followed an intensive rehabilitative post-surgical protocol that starts 3 weeks after the surgery and includes scar management and trophic muscular massage; during these 3 weeks patients wear a supportive cast on the operated arm.

Simultaneously, passive mobilization is initiated (flexion/extension of the elbow), carefully avoiding arm abduction and acting on the distal insertion of the triceps and including careful control of the muscular tension. Starting from the third week we introduce electrical stimulation on the triceps territory as well.
Patients have to wear the open cast on the arm night and day for one more week, and after the fourth week only at night.

30 days after surgery, we start to introduce the patient to active elbow flexion/extension movements and from this moment on there is a progressive improvement of the movement, trying among others reaching and place and hold exercises. 40 days after the surgery, the cast is discontinued also at night.

Within 60 days from upper limb functional surgery, all patients had a complete restoration of active elbow extension against resistance (muscle strength =5) and they managed their arms in functional activities (e.g. wheelchair pushing, body transfer, daily life activities).

In 2 patients we obtained a complete restoration of some simple personal tasks. The patient is able to wash himself, dress the upper body and insert catheter.

**Poster 9**

**PREOPERATIVE EVALUATION AND REHABILITATION TREATMENT IN PATIENTS OF GROUP 4 AND 5 (GIENS INTERNATIONAL CLASSIFICATION) OPERATED WITH TENODESIS OF THE EXTENSOR MUSCLES, ARTHRODESIS OF TM AND PALLIATIVE OF BR TO FPL, ECRL TO FDP AND PR TO FDS**


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Authors consider the clinical setting with the preoperative evaluation and re-education treatment in patients group 4 and 5 submitted to functional surgery according to a new technique (extensor time: EDC and EPL tenodesis to the extensor retinaculum and arthrodesis of the TM with 2 shape-retaining grafts and the PR to FDS; flexor time: BR to FPL, ECRL to FDP and Zancolli’s lasso procedure).

The rehabilitation program schedules an immobilization by a plaster cast for 10 days in the extensor time. After this a re-education takes place with TM protection by thermoplastic brace for 35 days. After the flexor time, the hand immobilization for 10 days is followed by a re-education period according to an outline, which includes protection of MF in 65° flexion for 35 days.

Particular attention has been dedicated to the evaluation approach, which, in the several years of experience, has allowed us to select some tests for their functional meaningfulness (Jamar, Pinch and Jebsen) and for their attention to the satisfaction of the patient (GAS scale and some activities among ADL previously settled and significant for his/her autonomy and self-government); these tests have shown a greater sensitivity to functional variations occurred after the surgical treatment, in comparison to others more general or peculiar for the grasp activities.

The evaluation tests are performed before and after the surgical intervention; then they are repeated afterwards for the outcome assessments.

According to this outline 9 patients have been evaluated and treated; some functional results will be presented.
**Poster 10**

**TETRAPLEGIA GROUP 4 AND 5: LONG TERM SURGICAL TREATMENT FOLLOW UP AND NEW TREATMENT PROPOSAL**

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The authors present their 20 years experience in tetraplegia surgical treatment. Group 4 and 5 patients have been reviewed comparing results of two different two-stage reconstruction procedures. 9 out of 13 patients belonging to the first group treated by CMC fusion, EDC-EPL tenodesis followed by PT to FPL and ERCL to FDP could be assessed at follow up (mean: 17 yrs, 14-19). 21 out of 39 patients alternatively treated by CMC fusion, BR to EDC-EPL followed by PT to FPL and ERCL to FDP could be assessed at follow up (mean: 7 yrs, 2-13).

All patients declared to be satisfied and obtained a better hand function, despite of a certain MP hyperextension and finger hook appearance.

To avoid this deformity authors propose a new surgical approach: CMC fusion, EDC-EPL tenodesis, PT to FDS followed by BR to FPL and ERCL to FDP and Zancolli Lasso.

All of the 9 patients treated by new approach referred to be satisfied at a short follow up, without MP and fingers deformities. Longer follow up is necessary to establish the best approach.

**Poster 11**

**SATISFACTION WITH UPPER LIMB SURGERY IN INDIVIDUALS WITH TETRAPLEGIA**

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**Purpose**: To evaluate the satisfaction with the upper-limb reconstructive surgery in individuals with tetraplegia.

**Method**: A survey with 21 questions was sent to 42 Danish tetraplegics, who have had reconstructive surgery from 1973 to 2008. They underwent 71 operations, including 96 procedures. The surgical interventions were: 19 triceps activations, 7 wristextensions, 42 stabilizations of the thumb - both active and passive, 13 fingerflexors, 7 Zancolli, 8 miscellaneous, among these 2 FreeHand operations.

In the whole period 49 tetraplegics had surgery, but 7 have died.

In addition to the questionnaire the individuals were asked to write the activities they could perform better as well as worse.

**Results**: 40 surveys (95 %) were returned. The positive responses were: 76 % were generally satisfied with the results of the surgery, 84 % felt that the surgery had a positive impact on their lives and 73 % reported improvement in ADL activities. 59 % that the needed less personal assistance. 78 % were satisfied with the information prior to surgery and 69 % for postoperative therapy. However only 28 % reported that they were satisfied with the appearance of their hand.

**Conclusion**: The results show that the overall satisfaction with upper-limb surgery is high. It has a positive impact on life in general, the ability to perform ADL as well as an increase in the level of independence.

**Comment**: In Denmark all tetraplegics are offered an evaluation for potential hand surgery before final discharge from both SCI units.
PREVENTION OF SHOULDER SUBLUXATION FOLLOWING AN INCOMPLETE CERVICAL SPINAL CORD INJURY

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A rising incidence of incomplete cervical cord injuries in the last decade has resulted in an increased number of upper limb clinical problems. This includes varying degrees of shoulder subluxation with potentially devastating consequences for function and long term independence. Prevention and moderation of shoulder subluxation is therefore indicated to prevent long term soft tissue damage, loss of function and pain.

A retrospective study of thirty consecutive incomplete cervical cord injuries (C3 – C6) presenting to the Queen Elizabeth National Spinal Injuries Unit for Scotland over a two year period was carried out. The average age was forty-eight and the mean length of stay was thirty-nine weeks. Two patients died during follow-up. The majority complained of early onset shoulder pain at initial mobilisation and the clinical evidence of varying degrees of shoulder subluxation became apparent.

In the majority of cases, one shoulder was involved but occasionally the condition was bilateral. The dominant shoulder was most commonly affected predominantly directly related to the level of neurological pattern of loss.

A combination of functional electrical stimulation (FES) and the use of sling suspension systems (OB Help Arms) was used routinely during regular hand therapy sessions. This was augmented with external elasticated shoulder supports and, in the latter stages, customised taping to support the shoulder in its correct position. Commercially available active shoulder supports were investigated but found to be limited and bilateral ones were not available. Taping of the shoulder(s) was carried out where using a technique to mimic the origins, layout and insertion points of the deltoid muscle. This technique was routinely used for eight weeks after the initiation of rehabilitation.

The increasing incidence of incomplete cervical cord injuries has resulted in the increasing awareness of the problem of shoulder subluxation and the importance of early intervention to promote early rehabilitation with minimal loss of function and pain.
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GENERAL INFORMATION

**CONGRESS VENUE**

Conference (21-22 September) :
Musée National des Invalides
129 rue de Grenelle
75007 Paris, France
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Worshop (20 September) :
- W1 : Surgical techniques
  Faculté de Médecine des Saints Pères
  45 rue des Saints Pères, 75007 - Paris

- W2+ W3 Shoulder + Botulinum toxin workshops
  Neurologic Rehabilitation Centre - Coubert 77 (bus transportation from Paris)

**OFFICIAL LANGUAGE**

English is the official language of the Congress

**USEFUL TELEPHONE NUMBERS**

International code for France : 33
Emergency number : dial 112

**WEATHER CONDITIONS**

The weather is usually fair, and the temperature between 15-25° Celsius. It may occasionally rain

**LODGING**

There are many hotels within walking distance of the Congress site. This is a touristic area, and we recommend that you book as early as possible. We will send you a representative list of nearby hotels upon request. (v.lothon@gsante.fr)