Satisfaction with upper extremity surgery in individuals with tetraplegia

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Objective: To supplement the scant information available regarding the satisfaction of patients with tetraplegia following upper extremity reconstructive surgery for such individuals with spinal cord injury (SCI).

Study design: Retrospective study with questionnaire follow-up.

Setting: The Danish Spinal Cord Injury Centers.

Material and methods: In the initial review period, 119 upper extremity surgeries were performed on patients with tetraplegia ($n = 49$). Seven died and the remaining 42 were invited to complete a follow-up questionnaire with a five-level scale ranging from strongly agree to strongly disagree regarding satisfaction. Forty patients completed the questionnaire.

Results: Median time from first surgery was 13 years (2–36). Sixty-five percent of the sample had a C5–C6 SCI, with 64% experiencing complete injury. Initially, 76% of the sample expressed general satisfaction with life, but only 28% of the sample reported that hand appearance improved after surgery. Interestingly, those having surgery from 1991 to 2008 reported significantly greater satisfaction ($P < 0.001$) and were significantly more satisfied with activities of daily living (ADL) ($P < 0.001$) than those having surgery between the years 1973 and 1990. In particular, gain of independence was obtained with pinch/specific hand surgery compared to triceps activation. Accordingly, the pinch/specific hand surgery group was significantly more satisfied than the triceps group on the ADL ($P = 0.027$), and the independence questions ($P < 0.001$).

Conclusion: Overall satisfaction with upper extremity surgery is high. It can have a positive impact on life in general, ability to perform ADL, as well as supplying an increased level of independence.

Keywords: Patient satisfaction, Upper extremity surgery, Tetraplegia, Activities of daily living, Hand function

Introduction

For persons with tetraplegia due to spinal cord injury (SCI) hand function is of extreme importance to gain maximal independence in daily life.^{1–3} Improvement in hand function is comparable to that of bladder and bowel function, which is known to have great impact on the lives of individuals with SCI.^{4,5}

In Denmark, ~3000 people currently live with an SCI. The yearly incidence of traumatic SCI is 50–60, with the main cause being traffic accidents (~50%), while falls account for around 25%.⁶ Each year another 70–80 experience a non-traumatic SCI. Since

survival is the expected outcome, today an increasing number of individuals live with the consequences of paralyzes, where 50% have tetraplegia and thus lacking some upper limb function. This leads to challenges in performing activities of daily living (ADL) and many of the tetraplegic individuals are dependent on personal assistance in their daily routines. Consequently, from the initial rehabilitation, focus is on functional training of the upper extremities, in particular hand function. This includes training of grasping, slipping, trick function, key grip, different kinds of palmar grasps, and various two hand grasps.^{7–9} Functional electrical stimulation of weak muscles is commonly used in daily training, even in-home telerehabilitation is increasing.^{10–15} Recently, robotic rehabilitation of tetraplegic upper

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extremities with an Armeo Spring has shown its possibilities.¹⁶

In addition, persons with tetraplegia are provided with individually adapted aids and splints to make various skills easier. Any improvement of upper extremity function in individuals with tetraplegia is of major advantage.¹⁷

In 1973, upper extremity reconstructive surgery for people with tetraplegia was initiated in Denmark, but mainly for individuals living in East Denmark. In the 1980s, people with tetraplegia in West Denmark were also offered upper extremity surgery. The commonly used surgical procedures include activation of the triceps muscle by posterior part of the deltoid muscle, wrist extension activation by transfer of the brachioradialis muscle to the extensor carpi radialis brevis muscle, and tendon transfers for grasping. In addition, two Freehand operations have been performed in cooperation with the hand surgeon Michael Keith from Cleveland, OH, USA.^{18–21}

An upper extremity surgery has now been performed in Denmark for 40 years. In Denmark, there is a unique possibility to include the complete population of target individuals for this surgery, as everyone may have it performed when the relevant indication is present, irrespective of the individual's socioeconomic situation. With this in mind, the aims of the present study were to describe age, level, and severity of all Danish individuals with SCI who had upper extremity reconstructive surgery performed, the timing of the surgery, and to measure satisfaction, including general impact and changes in ADL experienced after surgery. Another objective was to observe possible differences in satisfaction after triceps and pinch surgeries, corresponding to different levels of function. Similarly, in relation to period of surgery, we wanted to evaluate if increased experience influence the degree of satisfaction.

Material and methods

In Denmark, all individuals with tetraplegia are offered an evaluation of surgical possibilities by a hand surgeon either during their initial inpatient rehabilitation after SCI or as soon as they are found to be neurologically stable.

Inclusion criteria for surgical interventions are: (1) neurological stability, (2) good general health, (3) active muscle function in muscles suitable for transfer, minimum strength 4 (on a 0–5 scale), (4) not too severe spasticity, and (5) none or not too tight contractures.^{22,23}

All participating individuals with tetraplegia were classified according to the International Standards for

Neurological Classification of Spinal Cord Injury, i.e. by neurological level and the American Spinal Injury Association Impairment Scale (AIS).²⁴

Surgery

During the period 1973–2008, 49 individuals with tetraplegia had upper extremity surgery performed. At the time of this survey, 7 had died, and the remaining 42 individuals were all invited to participate in the study. A total of 119 procedures had been performed during 83 surgical interventions in the 49 individuals with tetraplegia (Table 1 and Fig. 1).

Questionnaire

We modified a questionnaire based on a similar survey on rehabilitation outcome after upper extremity surgery in individuals with tetraplegia designed by Woulle *et al.*²⁵ This questionnaire was first translated into Danish by experienced occupational therapists with specific knowledge of upper extremity surgery. Afterwards, the translation was evaluated by a bilingual (English/Danish) person with knowledge in the area of SCI who was given specific information regarding this particular topic, according to recommendations used for the translations of International SCI datasets.²⁶

For specific issues the questionnaire had to be modified to fit Danish circumstances, i.e. questions on costs and occupation were removed.²⁵ One new question about information received before surgery, and a list of tasks that had become easier or more difficult to perform were added, as these previously had been used successfully in a smaller Danish survey.²⁷

In the fall 2008, all tetraplegic individuals living in Denmark and identified to have had upper extremity surgery were invited to answer the questionnaire which is based on a five-level Likert scale ranging from strongly agree to strongly disagree (Fig. 2). This questionnaire is divided into eight areas: (1) general satisfaction (four questions); (2) life impact (four questions); (3) activity of daily living (ADL, five questions); (4) independence (four questions); (5) appearance (one question); (6) reliability (one question); (7) information (one question); and (8) therapy (one question). The questionnaire was sent out and returned by mail with a deadline of 14 days. The four individuals who did not respond were contacted by phone, two responded afterwards and two did not.

In addition to the questionnaire, the individuals were asked to write a list of activities they performed better as well as worse after surgery. They were also asked if they needed fewer aids after surgery. Finally, comments,

Table 1 Number of surgical procedures

Number of surgical procedures	All (N = 49)	In survey (N = 40)	In survey C4–C5 (N = 20)	In survey C6–C8 (N = 20)
Elbow extension				
Posterior deltoid to triceps	25	20	14	6
Wrist extension				
Brachioradialis to extensor carpi radialis longus + brevis	10	7	6	1
Pinch				
Thumb stabilization	54	46	20	26
Hand grasp				
Finger flexion	15	14	6	8
Intrinsic				
Zancolli	7	7	4	3
Miscellaneous (e.g. Biceps rerouting)	5	5	4	1
Freehand (2 Freehand operations, 1 stimulator replaced)	3	3	3	
Total	119	102	57	45

Forty-nine constitute all individuals with tetraplegia who had upper extremity surgery, including seven who have died and two who did not respond to the survey questionnaire. The individuals with tetraplegia are divided by neurological lesion into C4–C5 and C6–C8. Several procedures may be performed in the same individual.

criticism, and suggestions related to the surgery and therapy were requested.

Pre-operative information and post-operative therapy

During the 35 years covered by the study, different procedures for pre- and post-operative information and therapy were in practice.

During the last 10 years of the survey period, the following procedures have been used.

Pre-operative information

After a hand surgeon informed a patient about an intervention and recommended it, the patient was given time

to think about it before making a decision. Generally, surgery was performed 1 year after injury at the earliest.⁸

Post-operative therapy

After surgery, the individual with tetraplegia was sent home during the immobilization period of 4–6 weeks. During this period, more personal assistance and extra aid were often needed, and the municipal authorities provided this extra help.

After the immobilization period, active therapy was initiated in close cooperation with the occupational therapist and the surgeon. Generally, the active training was two times a day in short sessions for a period of 4–12 weeks. The training program was revised each week, allowing the person with tetraplegia to use his

Figure 1 One hundred and nineteen upper extremity surgical procedures were performed in 49 individuals with tetraplegia in Denmark between 1973 and 2008. Several procedures could be performed in the same individual. Seven have died, corresponding to 11 surgical procedures.

Figure 2 Answers from 40 survey participants with tetraplegia responding to the questionnaire. The questions are listed to the left, and were asked (in Danish) in the same order. *The responses regarding negative "life impact" (in question 6) have been inverted in the illustration for consistency with the rest of the answers.

or her hand more and more. Furthermore, the person with tetraplegia was instructed in self-training exercises.

Data analysis

Data were transferred to worksheets in Microsoft Excel (Microsoft Corp., Redmond, WA, USA), for calculation of medians and range and creation of tables. Median and range were used due to the non-parametric characteristics of the data. Fisher's exact and χ^2 were performed to evaluate the possible effect of gender, the neurological level of the spinal cord lesion (C4–C5 vs. C6–C8), the calendar year period for surgery (1973–1990 vs. 1991–2008), and the triceps activation vs. pinch/specific hand surgery on satisfaction. The pre-determined level of significance was set at 0.05. These comparisons were performed by grouping strongly agree with agree, and disagree with strongly disagree. Due to the small number of individuals with tetraplegia included in the study and the variety of surgeries and combinations of these, it is not possible to evaluate which operation improved which specific function. Generally, the evaluation is given for all upper extremity surgeries together.

The internal consistency for the questions within the groups "general satisfaction", "life impact", "ADL", and "independence" was evaluated with the calculation of Cronbach's alpha. Internal consistency is considered excellent when $\alpha \geq 0.9$, good $\alpha = 0.8–0.9$, acceptable $\alpha = 0.7–0.8$, questionable $\alpha = 0.6–0.7$, poor $\alpha = 0.5–0.6$, and unacceptable when $\alpha < 0.5$.²⁸

Results

Participants and demographics

Of the original 49 individuals with tetraplegia who had upper extremity surgery performed, 7 had died prior to this study. None of the deaths were related to their upper extremity surgery. Ninety-five percent (40 out of 42) of the remaining individuals with tetraplegia returned the questionnaire, 21 from West and 19 from East Denmark; seven of these were females – four from West and three from East Denmark. The two individuals who did not answer the questionnaire were contacted. One developed a syringomyelia up to C4 with no practical use of his hand; the other was physically as well as mentally ill and unable to participate.

Age and timing of surgery

At the time of the survey, median age of the participating individuals was 48 years (range 19–73). At the time of injury, median age was 24 years (range 10–63), and median age at first surgery was 36 (range 14–66). Median time from injury to first surgery was 3 years (range 1–24), and median time from first surgery until this survey was 13 years (range 2–36). In East Denmark, the majority of individuals with tetraplegia had their surgery during the mid-1980s, thus on average 21 years prior to this survey, whereas people with tetraplegia in West Denmark underwent surgery mainly during the early 2000s and thus on average 9 years prior to this survey (Fig. 1).

Motor level and AIS

The motor level was C4 in 17.5%, C5 in 35%, C6 in 30%, C7 in 15%, and C8 in 2.5%, and 64% of the respondents with tetraplegia were AIS A, 22% AIS B, 7% AIS C, and 7% AIS D.

Responses to questionnaire

The internal consistency evaluated with Cronbach's alpha (given in brackets) for the groups of questions with "general satisfaction" ($\alpha = 0.93$), "life impact" ($\alpha = 0.94$), "ADL" ($\alpha = 0.95$), and "independence" ($\alpha = 0.91$) were excellent in all instances.

The responses to each question and the average in each category are shown in Fig. 2. The average of positive responses (sum of strongly agree and agree) to the questions on general satisfaction was 76%. For life impact the average positive response was 84%. Ninety percent answered that they had benefited from the surgery and that it had had a positive impact on their life. Improvements in ADL scored 73% positive answers. Eighty-five percent reported that activities had become easier to perform, and 58% reported that they performed activities faster. On average, 53% gave a positive response to having achieved a higher level of independence. Sixty-five percent answered that they were able to function more independently, 58% needed less personal assistance, and 48% used fewer aids. They needed less help to perform activities and with better control of the arms they felt less disabled. Only 28% thought the appearance of their hand(s) had improved after surgery, and 49% were not satisfied with their hand appearance. Sixty-six percent gave a positive answer to the reliability of the surgery and felt that the use of the arm was as good as right after surgery. Seventy-eight percent reported that the information given prior to surgery was good and satisfactory, and 65% that the therapy received after surgery helped gaining better function.

We found no gender differences for any of the satisfaction questions. Likewise, when comparing individuals with tetraplegia with C4–C5 lesions with those with C6–C8 lesions, no significant differences were observed regarding satisfaction.

Satisfaction according to time period of surgery

To evaluate whether there were any differences with satisfaction over the period of 35 years, the individuals were divided into two groups according to the calendar year of surgery, i.e. 1973–1990 and 1991–2008. The latter group answered affirmatively significantly more often regarding general satisfaction ($\chi^2 = 18.54$, $P < 0.001$) and ADL questions ($\chi^2 = 18.89$, $P < 0.001$).

Triceps activation or pinch surgery alone

Comparison of the answers to ADL and the independence questions were carried out for those who had triceps activation or pinch/specific hand surgery as the only procedure (Fig. 3). Those with pinch/specific hand surgery showed a trend towards carrying out more activities, in particular reporting that they were more independent. When comparing the level of satisfaction, those who had pinch/specific hand surgery were significantly more satisfied than the individuals who had triceps activations, i.e. for the ADL questions ($\chi^2 = 7.2$, $P = 0.027$), and the independence questions ($\chi^2 = 17.36$, $P < 0.001$).

Comments from the individuals according to C4–C5 and C6–C8 level of injury

A list of the most common answers to the open question is found in Table 2. These comments were also divided into two groups according to the level of SCI, i.e. C4–C5 and C6–C8, respectively. Individuals with lower cervical lesions seem to have more positive comments related to activities which require a certain hand function.

Some of the survey respondents gave the following additional recommendations:

- Give precise information about surgery and rehabilitation;
- Have realistic expectations;
- Consult other operated tetraplegics before surgery;
- Wait at least 1–2 years before surgery;
- Do not get surgery on both hands;
- Just recommend it!

Discussion

Background and current sample

In a minor study from 1988 including 14 individuals with tetraplegia, 86% were satisfied with the results of their upper extremity surgery.²⁷ This percentage is higher than the general satisfaction of 76% in the present, more comprehensive study, but a different and simpler questionnaire was used in the older study. At least 20 years have passed since the first study giving the individuals with tetraplegia more time to experience less satisfactory results than they might have had than in the early period following surgery. This also concurs with the improvement in satisfaction during the second time period from 1991 to 2008. The current study is unique in the sense that it covers all Danish upper extremity reconstructive surgeries performed on individuals with tetraplegia in the 35-year period. Among those still alive, 95% answered the questionnaire, thus this study is representative for the tetraplegic population in Denmark undergoing this kind of procedure.

Figure 3 Answers to the ADL and the independence questions (Fig. 2) for those who had performed pinch specific hand surgery ($n = 15$) and triceps activation ($n = 10$).

Comparison between studies (Denmark, the USA, and The Netherlands)

The questionnaire from the study by Woulle *et al.*²⁵ on satisfaction with upper extremity surgery in people with tetraplegia was modified as described above. The social security system is different in the USA and Denmark (DK). Many of the Danish individuals with tetraplegia have a personal assistant and can live on the social pension the state provides.²⁹ In addition, medical interventions and care is free of charge in DK. In a similar and more recent study from the Netherlands (NL), the same questionnaire was used.³⁰ The medical and social system in the Netherlands is more comparable to the Danish.

The positive responses in our study, especially regarding general satisfaction and life impact (Fig. 2), but also on ADL and independence, are encouraging and similar to the NL as well as the US studies.^{25,30}

Satisfaction with the appearance of the hand had the lowest score in the DK and US studies and is clearly lowest in the Danish study with only 28% responding that they were satisfied.²⁵ We have no explanation for this difference, in particular when considering that the Danish individuals with tetraplegia found the surgery

met their expectations to a higher degree, but the differences between the studies are small.^{25,30}

The questions related to life impact are high in all three studies.^{25,30} Likewise for the ADL activities, it is particularly encouraging that in all three studies the responses to the questions "I can perform more activities" and "Activities are easier to perform" are around 80% in agreement.^{25,30}

The higher scores in independence, in using less adaptive equipment, and being more comfortable among other people in the US study may be due to the higher degree of self-selection of this kind of surgery in the US study population, while it is an option for all the Danish individuals. These two questions were not included in the results from the Dutch study.²⁵

The reliability of the surgery was judged very similar in the three countries, which means nearly two-third of the individuals think that their surgeries are working well, for some even after many years.^{25,30}

Information given to the individuals with tetraplegia before the surgery has changed in DK over the years, and 78% answered they were satisfied with the received information, while 65% were satisfied with the therapy offered after the surgery. In particular, the latter

Table 2 Answers to an open question regarding the consequences of upper extremity surgery in individuals with tetraplegia

Comments			
Positive comments	N = 34	C4–C5 (N = 19)	C6–C8 (N = 19)
Drink and eat easier	17	6	11
Better hand grasp and coordination	11	7	4
Stretching is easier and better control of the arm	8	7	1
Dress and undress easier	8	5	3
Grasp small things and move heavier too	7	5	2
Using ordinary tools	7	1	6
Write and use PC easier	6	3	3
Drive a car	5	3	2
Grooming easier	4	1	3
Can reach wider and higher	4	3	1
Catheterize	3	1	2
Transferring easier	3	3	
No aids	2		2
No hand splints	2	2	
Driving an electric wheelchair with a joystick	2	2	
Better to drive a manual wheelchair	2	2	
Picking up things from the floor	2	2	
Give a hug	2	1	1
Doing makeup, fastening earrings	2		2
Repairing things and performing fine, accurate activities	2		2
Change wheel on my car	1		1
Better at dancing	1	1	
Cooking	1	1	
Neutral comments	N = 18		
Nothing has become more difficult	16	10	6
No change in number of aids	2	2	
Negative comments	N = 9		
Difficulty in taking and slipping objects again (hooked fingers)	2	1	1
Dressing and button up difficulties	1		
Spasticity in the fingers	1	1	
Difficulty with the Freehand system and lacking of spare parts	2	2	
Difficulty in locking the elbow to do a push-up	1		1
Too long time used for immobilization and training afterwards	1	1	
Operation failed	1		1

Thirty-eight out of 40 individuals gave their comments. Each individual may have given multiple answers.

percentage was much lower than in the US study (86%),²⁵ which again may be due to the option of upper extremity surgery which all Danish individuals with tetraplegia have, which is not the situation in the USA. Therefore, the US individuals may have to use more effort to receive hand surgery and consequently also have a higher gratitude for the therapy afterwards.

The overall positive responses concur with the perception of clinicians caring for individuals with SCI in the USA.³¹ Unfortunately, many individuals with tetraplegia in the USA do not seem to know about the possibility of upper extremity reconstructive surgery, and many had a negative first impression regarding the procedure after consulting a physician.³²

Satisfaction in relation to time period

Improvement in satisfaction during the second time period from 1991 to 2008 could be due to the improved information about surgery available in those years. Individuals thinking of surgery may have had the chance to speak to other people with tetraplegia

who have undergone upper extremity surgery. In addition, surgeons and therapists have gained more experience in evaluating candidates for surgery. Finally, the individuals may have a better memory of the pre-surgical condition due to the shorter time period since surgery.

Comparison of triceps activation and pinch/hand surgical procedures

Although Fig. 3 only includes a small number of individuals, the differences on ADL and particular independence questions are interesting, as pinch/hand surgical procedures were found to give more independence than triceps activation. Likewise, the satisfaction was significantly higher in the group receiving pinch/hand surgical procedures. This also illustrates that the motor level, which partly determine the surgical procedures, may be of importance for the answers given to the questionnaire. Recently, it was confirmed by Wangdell and Friden³³ that triceps activation in itself improves performance and satisfaction.

Consequences of surgery

Answers to the open question (Table 2) showed activities in which individuals with tetraplegia reported improvements after surgery. Again, we observe that the level of the SCI lesion partly determines the consequences reported by the individuals who have undergone upper extremity surgery, as those with the more caudal cervical lesions had greater likelihood to gain function. Furthermore there were few negative comments, although the Freehand system implanted in two individuals got its own comment due to the problem with spare parts when the company producing the system decided to stop the production and the support of the people already implanted.^{14,21,34,35}

Trend of incomplete lesions instead of complete lesions

For some years, the trend seems to be towards more incomplete lesions (AIS B, C, and D) and fewer complete lesions (AIS A).^{36–38} This increases the challenges for surgical interventions in individuals with tetraplegia, as it takes longer time to obtain neurological stability and the decisions about useful surgical interventions are more complex due to different patterns with partly innervated muscles.

Limitations

The number of individuals with tetraplegia having upper extremity surgery is limited in a Danish population of 5.3 million inhabitants. The advantage is that all the individuals are included.

Many of the individuals had different kinds of surgeries on both arm and hand, and therefore it has not been possible to determine which type of surgery improved which particular ADL function to any large degree.

Conclusion

This follow-up survey on the satisfaction of individuals with tetraplegia with upper extremity surgery shows that the participants generally are satisfied with and benefited from the upper extremity reconstructive surgery. The gain in function after surgery has had a positive impact on their lives. People post-surgery generally can more easily perform activities and have a higher degree of independence. There is reasonable satisfaction with the information given before surgery and with the therapy that follows. Improvement in satisfaction during the second time period may be due to the fact that information about surgery has improved, and surgeons and therapists have gained more experience in evaluating candidates for surgery.

All individuals with tetraplegia in Denmark are still offered an evaluation by a hand surgeon prior to discharge as these surgical interventions clearly make a great difference.

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References

- 1 Wangdell J, Fridén J. Satisfaction and performance in patient selected goals after grip reconstruction in tetraplegia. *J Hand Surg Eur* 2010;35(7):563–8.
- 2 Rothwell AG, Sinnott KA, Mohammed KD, Dunn JA, Sinclair SW. Upper limb surgery for tetraplegia: a 10-year re-review of hand function. *J Hand Surg Am* 2003;28(3):489–97.
- 3 Forner-Cordero I, Mudarra-García J, Forner-Valero JV, Vilar-de-la-Peña R. The role of upper limb surgery in tetraplegia. *Spinal Cord* 2003;41(2):90–6.
- 4 Murphy CP, Chuinard RG. Management of the upper extremity in traumatic tetraplegia. *Hand Clin* 1988;4(2):201–9.
- 5 Snoek GJ, Ijzerman MJ, Hermens HJ, Maxwell D, Biering-Sørensen F. Survey of the needs of patients with spinal cord injury: impact and priority for improvement in hand function in tetraplegics. *Spinal Cord* 2004;42:526–32.
- 6 Biering-Sørensen F, Pedersen V, Clausen S. Epidemiology of spinal cord lesions in Denmark. *Paraplegia* 1990;28:105–18.
- 7 Curtin M. Development of a tetraplegic hand assessment and splinting protocol. *Paraplegia* 1994;32:159–60.
- 8 Waters RL, Sie IH, Gellman H, Tognella M. Functional hand surgery following tetraplegia. *Arch Phys Med Rehabil* 1996; 77(1):86–94.
- 9 Harvey LA. Hand function of C6 and C7 tetraplegics 1–16 years following injury. *Spinal Cord* 2001;39(1):37–43.
- 10 Popovic MR, Popovic DB, Keller T. Neuroprostheses for grasping. *Neurol Res* 2002;24(5):443–52.
- 11 Popovic MR, Kapadia N, Zivanovic V, Furlan JC, Craven BC, McGillivray C. Functional electrical stimulation therapy of voluntary grasping versus only conventional rehabilitation for patients with subacute incomplete tetraplegia: a randomized clinical trial. *Neurorehabil Neural Repair* 2011;25(5):433–42.
- 12 Hamid S, Hayek R. Role of electrical stimulation for rehabilitation and regeneration after spinal cord injury: an overview. *Eur Spine J* 2008;17(9):1256–69.

- 13 Taylor P, Esnouf J, Hobby J. Patterns of use and user satisfaction of Neuro Control Freehand system. *Spinal Cord* 2001;39(3): 156–60.
- 14 Taylor P, Esnouf J, Hobby J. The functional impact of the Freehand System on tetraplegic hand function. *Clinical Results. Spinal Cord* 2002;40(11):560–6.
- 15 Kowalczewski J, Chong SL, Galea M, Prochazka A. In-home tele-rehabilitation improves tetraplegic hand function. *Neurorehabil Neural Repair* 2011;25(5):412–22.
- 16 Zariffa J, Kapadia N, Kramer JL, Taylor P, Alizadeh-Meghrai M, Zivanovic V, et al. Feasibility and efficacy of upper limb robotic rehabilitation in a subacute cervical spinal cord injury population. *Spinal Cord* 2012;50(3):220–6.
- 17 Esnouf J, Taylor P, Hobby J. Improvement in activities of daily living using the Freehand: a system designed for people with tetraplegia. *Br J Occup Ther* 2003;66(3):113–7.
- 18 Moberg E. Surgical treatment for absent single-hand grip and elbow extension in quadriplegia. Principles and preliminary experience. *J Bone Joint Surg Am* 1975;57(2):196–206.
- 19 Moberg E. The upper limb in tetraplegia. A new approach to surgical rehabilitation. Stuttgart: Georg Thieme Publishers; 1978.
- 20 Hentz VR, Leclercq C. Surgical rehabilitation of the upper limb in tetraplegia. W.B. Saunders; Elsevier Science Ltd. London, Edinburgh, New York, Philadelphia, St. Louis, Sidney, Toronto; 2002.
- 21 Biering-Sørensen F, Gregersen H, Hagen E, Haugland M, Keith M, Larsen CF, et al. Forbedret håndfunktion hos tetraplegikere ved elektrisk stimulering via implanterede elektroder. [Improved hand function in persons with tetraplegia using electric stimulation via implanted electrodes]. *Ugeskr Læg* 2000;162:2195–8. Danish.
- 22 Medical Research Council. Aids to investigation of peripheral nerve injuries. London: Her Majesty's Stationary Office; 1943.
- 23 Daniels L, Worthingham C. Muscle testing techniques of manual examination. Philadelphia: W.B. Saunders Co.; 1986.
- 24 Kirshblum SC, Burns SP, Biering-Sorensen F, Donovan W, Graves DE, Jha A, et al. International standards for neurological classification of spinal cord injury. *J Spinal Cord Med* 2011; 34(6):535–46.
- 25 Woulle KS, Bryden AM, Peckham PH, Murray PK, Keith M. Satisfaction with upper extremity surgery in individuals with tetraplegia. *Arch Phys Med Rehabil* 2003;84:1145–9.
- 26 Biering-Sørensen F, Alexander MS, Burns S, Charlifue S, Devivo M, Dietz V, et al. Recommendations for translation and reliability testing of international spinal cord injury data sets. *Spinal Cord* 2011;49(3):357–60.
- 27 Biering-Sørensen F, Holst-Nielsen F. Tetraplegi-håndkirurgi. Hvad hjælper håndkirurgi tetraplegikere? [Tetraplegic-hand surgery. What help does hand surgery give tetraplegics?]. *Paraplegia* 1988; 10(1):16–8. Danish.
- 28 George D, Mallery P. SPSS for Windows step by step: a simple guide and reference. 11.0 update. 4th ed. Boston: Allyn & Bacon; 2003, p. 231.
- 29 Biering-Sørensen T, Hansen RB, Biering-Sørensen F. Home aids and personal assistance 10–45 years after spinal cord injury. *Spinal Cord* 2009;47(5):405–12.
- 30 Jaspers Focks-Feenstra JH, Snoek GJ, Bongers-Janssen HM, Nene AV. Long-term patient satisfaction after reconstructive upper extremity surgery to improve arm-hand function in tetraplegia. *Spinal Cord* 2011;49(8):903–8.
- 31 Bryden AM, Wuolle KS, Murray PK, Peckham PH. Perceived outcomes and utilization of upper extremity surgical reconstruction in individuals with tetraplegia at model spinal cord injury systems. *Spinal Cord* 2004;42(3):169–76.
- 32 Wagner JP, Curtin CM, Gater DR, Chung KC. Perceptions of people with tetraplegia regarding surgery to improve upper-extremity function. *J Hand Surg Am* 2007;32(4):483–90.
- 33 Wangdell J, Fridén J. Activity gains after reconstructions of elbow extension in patients with tetraplegia. *J Hand Surg Am* 2012;37(5): 1003–10.
- 34 Gorman PH, Wuolle KS, Peckham PH, Heydrick D. Patient selection for an upper extremity neuroprosthesis in tetraplegic individuals. *Spinal Cord* 1997;35(9):569–73.
- 35 Peckham PH, Keith MW, Kilgore KL, Grill JH, Wuolle KS, Thrope GB, et al.; Implantable Neuroprosthesis Research Group. Efficacy of an implanted neuroprosthesis for restoring hand grasp in tetraplegia: a multicenter study. *Arch Phys Med Rehabil* 2001;82(10):1380–8.
- 36 DeVivo MJ. Epidemiology of traumatic spinal cord injury: trends and future implications. *Spinal Cord* 2012;50(5):365–72.
- 37 Hagen EM, Eide GE, Rekand T, Gilhus NE, Gronning M. A 50-year follow-up of the incidence of traumatic spinal cord injuries in Western Norway. *Spinal Cord* 2010;48(4):313–8.
- 38 Knútsdóttir K, Thónsdóttir H, Sigvaldson K, Jónsson H, Björnsson A, Ingvarsson P. Epidemiology of traumatic spinal cord injuries in Iceland from 1975 to 2009. *Spinal Cord* 2012; 50(2):123–6.