Changes in activity after a complete spinal cord injury as measured by the Spinal Cord Independence Measure II (SCIM II)

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Abstract

BACKGROUND: The assessment of rehabilitation efficacy in spinal cord injury (SCI) should be based on a combination of neurological and functional outcome measures. The Spinal Cord Independence Measure II (SCIM II) is an independence scale that was specifically developed for subjects with SCI. However, little is known about the changes in SCIM II scores during and after rehabilitation.

OBJECTIVE: The aims of this study were to evaluate changes in functional recovery during the first year after a complete SCI as measured by the SCIM II compared with neurological recovery (motor scores according to the American Spinal Injury Association [ASIA]).

METHODS: SCIM II data and ASIA motor scores at 1, 3, 6, and 12 months after injury (derived from the database of the European Multicenter Study of Human Spinal Cord Injury) of 64 patients with complete paraplegia and 36 patients with complete quadriplegia were analyzed.

RESULTS: In patients with complete paraplegia, the SCIM II total score improved significantly during the 1-year follow-up, even after discharge from rehabilitation. In contrast, the ASIA motor scores showed little recovery. In patients with quadriplegia, functional and motor recovery developed in parallel during rehabilitation and after discharge.

CONCLUSIONS: The SCIM II is responsive to functional changes in patients with a persistent motor complete SCI. It is clinically useful for monitoring functional improvement during rehabilitation and after discharge. The SCIM II and the clinical examination based on the ASIA protocol are of complementary value and separately describe changes in independence and sensorimotor deficits in SCI patients.
Introduction

Most clinical studies on acute spinal cord injury (SCI) have been focused on the early prediction of outcome (Brown et al., 1991; Burns et al., 2003). A reliable prediction of hand/walking function allows for a prospective management of rehabilitation and of socio-economic sequels (e.g. housing, re-employment) within the initial first weeks after injury (Burns and Ditunno, 2001). The majority of SCI trials were based on neurological measures as primary endpoints (Bracken et al., 1997; Geisler et al., 2001) according to the protocol of the American Spinal Injury Association (ASIA), the International Standards for Neurological and Functional Classification of Spinal Cord Injury (ASIA, 2002). By this ASIA protocol the level of SCI, as well as sensory and motor deficits, can reliably be assessed (Marino et al., 1999). However, for monitoring the efficacy of new therapeutic interventions the combined assessment of not only neurological deficits, but also functional outcome and remaining spinal conductivity might be advantageous (Curt et al., 2004; Ellaway et al., 2004). Functional outcome can be assessed by scoring the activities of daily living, and it reflects the level of self-independence of SCI subjects, which is not adequately reflected in the neurological assessment (Hall et al., 1999). In addition, neurophysiological recordings of spinal conductivity enhance prediction and compensate for an insufficient cooperation of the acute SCI subject.

In the present study the following terms are applied to distinguish between the main mechanisms underlying functional recovery: 1) The mechanism of compensation refers to changes in function that can be achieved without any change in the neurological deficit, e.g. by adapted or new movement strategies. In this study an improvement in the self-independence measure not accompanied by a change in sensory-motor function is attributed to this mechanism. 2) Neural plasticity, a rather broadly used term, addresses mechanisms that involve a reorganization of neuronal circuits. For example, as occurs during motor learning (Moucha and Kilgard, 2006) and after a neurotrauma at both the cortical and spinal
level (cf. Bruehlmeier et al., 1998; Raineteau and Schwab, 2001). In this study it refers to functional improvement beyond the recovery of the neurological deficit (for example, an improvement in walking function without a corresponding increase in muscle strength (Maegele et al., 2002)). It can be exploited by task-specific training of complex functions (e.g. central pattern locomotor generator, CPG), and 3) Repair mechanisms like remyelination/ regeneration and reconnection of damaged spinal tract fibres might be reflected in changes in spinal impulse conductivity, as assessed by neurophysiological recordings. This study aims to roughly separate the effects of compensation, neural plasticity and repair on the recovery of function after SCI. These findings could serve as a basis to evaluate the effectiveness of new therapeutic interventions directed to enhance recovery of function.

Materials and Methods

Subjects
This prospective study included subjects suffering an acute traumatic SCI. The subjects were admitted for post-surgical care and rehabilitation in 16 specialized European SCI Centres. All subjects underwent acute care management and spine surgery (decompression and stabilisation) in specialized trauma centres according to the local standards of treatment. Subjects suffering from an accompanying head trauma and/or other neurological disorders were excluded. Nerve conduction studies of tibial nerves were performed in all patients using a conventional electromyography device to exclude accompanying neuropathy, which might influence the recordings of evoked potentials. Subjects with neuropathy were excluded. Clinicians trained in SCI rehabilitation performed the neurological examinations, while the functional assessments were scored by physical and occupational therapists and / or nurses.
The neurophysiological recordings were performed by independent neurologists. In all SCI subjects the initial exams were performed within the first month after the injury and repeated measures were attempted at 4, 12, 24 and 48 weeks. The subjects were grouped according to their level of lesion (para-tetraplegic) and their neurological deficit (see below) to ASIA A (motor-sensory complete), ASIA B (motor complete, sensory-incomplete), ASIA C and D (motor-sensory incomplete).

The study was approved by the local Ethics Committee of each participating centre and was performed in accordance with the Declaration of Helsinki. All subjects were instructed about the aim of the study and gave their informed consent. Between 2001 and September 2007, a total of 1140 acute traumatic SCI subjects (78% male, mean age 43.2 +/- 18.7 SD) were enrolled by the SCI centres. Of these, 460 subjects had at least a baseline clinical examination performed within 4 weeks and a late assessment at 48 weeks and were included in this study for statistical analysis (ASIA A=47%, B=14%, C=17% and D=22%; tetra 50% and para 50%). The baseline examinations were performed within 14 days in 57% of subjects and within 40 days after injury in the remaining subjects. These subjects were recruited from the following centres: Zurich, Switzerland (48 subjects); Heidelberg, Germany (71); Nijmegen, Netherlands (33); Garche, France (27); Bayreuth, Germany (109); Bad Wildungen, Germany (17); Langensteinbach, Germany (27); Bochum, Germany (14); Murnau, Germany (75); Ulm, Germany (6); Halle, Germany (19); Barcelona, Spain (8); and Prague, Czech Republic (6).

Neurological scoring

The neurological examination was performed according to the standards of ASIA (ASIA, 2002). By this protocol, the level of lesion, the motor and sensory deficit and the completeness of injury is determined. The ASIA Motor Score uses manual testing of 5 key
muscles of each limb (0 = total paralysis, 1 = palpable or visible contraction, 2 = active movement, gravity eliminated, 3 = active movement, against gravity, 4 = active movement, against some resistance, 5 = active movement, against full resistance; maximum total motor score 100). The ASIA Sensory Score determines light touch and pinprick discrimination for each dermatome (0 = absent, 1 = impaired, 2 = normal; maximum total sensory score 112 for each quality).

Functional assessments
For functional outcome the Spinal Cord Independence Measure (SCIM; scoring activities of daily living) and one standardized walking test was applied. The SCIM protocol comprises the level of self-independence (grooming, feeding, self care, bladder management, walking and transfer) with a maximum of 100 points (Catz et al., 1997; Catz et al., 2001). The higher the score the greater is the level of independence. The ambulatory capacity was monitored by the Walking Index Spinal Cord Injury (WISCI II) that describes the need of aids (assistance, crunches, sticks) to cover a distance of 10 metres (Ditunno and Ditunno, 2001; van Hedel et al., 2005). The ordinal scale ranges from 0 (neither standing nor walking function) to 20 (independent walking).

Electrophysiological recordings
Somatosensory evoked potentials (SSEP) of tibial nerves were recorded by electrical stimulation of the posterior tibial nerve (square wave of 0.2 ms duration applied at 3 Hz; cathode placed 2 to 3 cm proximal to the anode). The stimulus intensity was adjusted to produce a visible muscle response, or up to a maximal intensity of 40 mA. Electrodes were attached to the skin over the popliteal fossa to control the transmission of the potentials along the peripheral nerve. Scalp electrodes were positioned at Cz’-Fz according to the international 10/20 electrode system. The electrode impedance was maintained at <5 kΩ.
The peaks of P40 and N50 were used to determine the latency and amplitude of the response. Two sets of 500 responses were averaged and superimposed to ensure consistency.

Motor evoked potentials (MEP) were recorded by applying single pulse transcranial magnetic stimulation (TMS) using a routine circular coil (diameter of 120 mm) magnetic-stimulator. The coil position for stimulation of the anterior tibial muscle (TA) was 4 cm rostral of Cz (vertex). The duration of the biphasic transcranial single-pulse stimuli was set at 200 µs. The sample frequency was 2000 Hz and a band-pass filter was set at 30 Hz to 1 kHz. In incomplete SCI the optimal coil position and TMS threshold to evoke a TA MEP was determined during voluntary muscle pre-activation. The onset of the MEP response was determined for the calculation of the latency.

Statistics
Descriptive statistics were calculated per time point and grouped according to the completeness (ASIA grade A, B, C or D) and level of lesion (tetraplegic and paraplegic subjects). Absolute differences between baseline and end values were calculated for all variables and analyzed using the paired-t-tests or, when not normally distributed, using the Wilcoxon signed rank test for each subgroup of subjects (e.g. tetraplegic ASIA A subjects, paraplegic ASIA D subjects). Bonferroni’s correction was applied to adjust for the 8 comparisons. Differences in changes between the baseline and late assessment were compared between the level of lesion (2 levels: tetraplegic versus paraplegic subjects) and completeness of the lesion (2 levels: sensory-motor complete (ASIA A) versus incomplete (ASIA B, C and D) subjects) using a 2-way analysis of variance (ANOVA). Multiple comparisons were adjusted using Bonferroni’s correction. In addition, a difference between
the treatment centres ("centre effect") on the recovery (i.e. the difference between the baseline and late assessment of the neurological, functional and neurophysiological measures) was investigated using a one-way ANOVA. The p-value was corrected for multiple comparisons using Bonferroni’s correction. Relationships between the changes of the various measures were quantified using Spearman’s correlation coefficient (p). The statistical analysis has been carried out using SAS® procedure PROC MIXED and SPSS Version 14.

Results

Sensory-motor changes

A significant increase of absolute motor scores was monitored over time in all SCI subjects (Table 1). In iSCI (including ASIA B) the gain in motor recovery was higher than in cSCI (F(1,428)=101.5, P < 0.001) and higher in tetraplegic compared to paraplegic subjects (F(1,428)=76.6, P < 0.001). Changes are exemplified for tetraplegic subjects in Figure 1. For this figure, the data from all assessment points were used. For comparison between para- and tetraplegic subjects the relative recovery ((endpoint value-baseline)*100/(100-value at baseline)) was calculated (in paraplegic only lower limbs can recover (max. 50 points), in tetraplegic subjects upper and lower limbs (max. 100 points)). The relative motor recovery was in ASIA A: tetra = 14±19% (mean ± SD), para = 7 ± 18%; in ASIA B: tetra = 24 ± 24%, para = 30 ± 21%; in ASIA C: tetra = 63 ± 27%, para = 58 ± 26% and in ASIA D: tetra = 73 ± 25, para = 67 ± 32. The relative recovery was greater in iSCI compared to cSCI (F(1,426)=306.2, p<0.001) and greater in tetraplegic versus paraplegic subjects (F(1,426)=8.4, p=0.01).
The sensory deficit (pin prick and light touch) showed minor changes over time (Table 1).

The changes differed only between tetraplegic and paraplegic subjects (light touch: F(1,433)=28.5, p<0.001; pin prick: F(1,433)=13.0, p<0.001) but not between the completeness of injury (light touch F(1,433)=1.8, p=0.18; pin prick: F(1,433)=2.1, p=0.15).

The light touch sensation increased significantly in tetraplegic ASIA A and C subjects (Figure 1). In tetraplegic ASIA B subjects, the increase was comparable, but due to the small number of subjects, not significant (p=0.10). Light touch sensation remained unchanged in most paraplegic subjects. Pin prick sensation increased moderately in tetraplegic ASIA C subjects, while again, a comparable but not significant (p=0.07) increase was found in tetraplegic ASIA B subjects.

Functional recovery

All subjects showed a significant improvement (p<0.001) in activities of daily living assessed by the SCIM (shown for tetraplegic subjects in Figure 1). The improvement was greater for paraplegic subjects compared to tetraplegic subjects (F(1,373)=15.8, p<0.001) and greater for iSCI compared to cSCI subjects (F(1,373)=29.3, p<0.001) (Table 1). The mean walking score WISCI increased more in iSCI compared to cSCI subjects (F(1,389)=217.0, p<0.001) and remained unchanged in tetraplegic ASIA A and B subjects. In paraplegic subjects, the minor increase of the mean WISCI values was based on single ASIA A and B subjects, who regained some lower limb motor function. ASIA C and D subjects achieved the highest WISCI scores (Figure 1).

Evoked potentials

In patients with cSCI, SSEP and MEP remained abolished. In iSCI the spinal impulse conductivity, as reflected in SSEP and MEP latencies, were delayed but did not change over
time in paraplegic and tetraplegic subjects (Table 1). Significant changes of amplitudes were found only for the SSEP and MEP of tetraplegic ASIA D subjects (Table 1). The changes in amplitudes were significantly greater for iSCI compared to cSCI subjects (SSEP: $F(1,274)=15.1, p<0.001$; MEP: $F(1,115)=6.6, p=0.012$).

### Relationship between various measures

In subjects with a motor cSCI, the change in SCIM score did not relate with the change in motor score (ASIA A: $\rho = -0.14; p = 0.07$; number of subjects (n) = 177; ASIA B: $\rho = 0.26; p = 0.06, n = 53$). Motor iSCI subjects showed a moderate relationship (ASIA C: $\rho = 0.48; p < 0.001; n = 61$; ASIA D: $\rho = 0.44; p < 0.001; n = 74$).

The change in WISCI score correlated with a change in motor score: ASIA A: $\rho = 0.32; p < 0.001; n = 180$; ASIA B: $\rho = 0.47; p < 0.001, n = 61$; ASIA C: $\rho = 0.41; p = 0.001; n = 65$; ASIA D: $\rho = 0.38; p = 0.001, n = 75$.

No change in MEP latency was observed and no correlation existed with a change in motor score or SCIM. Only in ASIA C subjects was a significant correlation between change in MEP latency and WISCI found: $\rho = -0.78; p = 0.04, n = 7$.

A change in MEP amplitude correlated significantly with various neurological and functional measures (ASIA A: motor score: $\rho = 0.41; p = 0.002; n = 57$; SCIM: $\rho = 0.31; p = 0.03; n = 52$; WISCI: $\rho = 0.87; p < 0.001; n = 52$; ASIA B: motor score: $\rho = 0.65; p = 0.001; n = 21$; WISCI: $\rho = 0.51; p = 0.02; n = 21$; ASIA D: motor score: $\rho = 0.53; p = 0.02; n = 19$; SCIM: $\rho = 0.58; p = 0.01; n = 18$; WISCI: $\rho = 0.58; p = 0.01; n = 19$).

### Centre effect

Among all variables, only the recovery of the SCIM score showed a difference between the treatment centres ($F(12,364)=1.84; P = 0.04$). Pair-wise comparisons showed that the
recovery was significantly higher in centre 3 compared to centres 2 and 4. Between these centres, two differences were noted: the time of baseline assessment (in centre 3, 88% of the subjects were assessed within the first 2 weeks; in centre 2 this was 44% and in centre 3, 15%) and the proportion of ASIA D subjects, who showed initially great functional improvements (in centre 3, 24% were initially ASIA D; centre 2 had 13% and centre 4 had only 4% ASIA D subjects).

Discussion

Mechanisms involved in the recovery from complete and incomplete SCI were analysed by repeated follow-up examinations of neurological, functional and spinal conductivity measures over a one year period. The present study indicates compensation and neural plasticity represent major factors underlying functional recovery in SCI subjects. The neurological examinations showed a minor, although significant, increase of both motor and sensory scores in cSCI. The greater improvement of motor score in iSCI subjects was in the expected range (Waters et al., 1994a, b). The remaining spinal tract conductivity of damaged spinal tracts in general did not change during one year. The relevance of these findings will be discussed with respect to the evaluation of new therapeutic interventions.

Compensation

In several studies, a relationship between ASIA motor score and functional outcome (i.e. walking and hand function) was demonstrated (Curt and Dietz, 1996, 1997). However, as shown here, functional improvement in part occurs independently from neurological recovery.
Motor cSCI subjects regained abilities in SCIM unrelated to changes in motor scores. This improvement is suggested to be due to compensation (learning new movement strategies, including the use of assistive devices). Of course, compensation can be regarded as a form of motor learning associated with some neural plasticity (Moucha and Kilgard, 2006).

Neural plasticity
The neurological deficit, activities of daily living (SCIM) and walking ability improved significantly more in iSCI than cSCI subjects. In line with animal experiments we assume that neural plasticity within the spinal cord represents a major factor for the functional recovery observed in iSCI subjects (Ballermann and Fouad, 2006; Vavrek et al., 2006; Weidner et al., 2001). The reorganization of spinal circuits might occur at several levels of neural networks, involving collateral sprouting of spinal tract fibres as shown in animal models (Raineteau et al., 2002; Raineteau and Schwab, 2001). In addition, reorganization of long propriospinal pathways might be involved in the functional recovery after SCI (Bareyre et al., 2004).

Consequently, locomotor training of iSCI subjects leads to an improvement of walking ability even without changes in motor scores (Dietz, 2002; Maegle et al., 2002; Wirz et al., 2006; Wirz et al., 2005). Such task-specific training approaches are directed at exploiting neuronal plasticity after spinal lesions (Canning et al., 2006; Dietz, 2003; Dietz et al., 1995).

Repair
Evoked potentials objectively monitor spinal tract conductivity and are of predictive value for functional outcome (Li et al., 1990). In line with previous human and animal studies, evoked potentials in iSCI subjects were delayed and reduced in amplitude or abolished relative to the...
severity of spinal cord damage (Alexeeva et al., 1998; Davey et al., 1999; Nashmi et al., 1997). The unchanged latencies of SSEP and MEP in iSCI during the one year follow-up recordings indicate that no obvious repair (i.e. remyelination / regeneration and reconnection of damaged spinal tracts) has occurred. However, the latencies of the evoked potentials mainly reflect fast conducting descending and ascending sensory-motor fibres. Therefore, oligo-synaptic pathways that were shown in rats to arise by collateral sprouting (Bareyre et al., 2004) are not assessed. The increase of SSEP and MEP amplitudes in the iSCI patients could be due to some recovery of spinal tracts (Thomas and Gorassini, 2005).

Centre effect
A difference between centres was only found for the recovery of daily life activities and independence. One centre showed a greater improvement compared to two others. Possible explanations are differences in the time of the baseline assessment and in patient subgroups. No other centre effects were observed.

Conclusion
The present findings indicate that mechanisms of compensation and neural plasticity represent major factors underlying clinical recovery in human SCI. These observations contribute to our clinical understanding of recovery after SCI, and are in line with results from animal studies. However, the differentiation between the mechanisms underlying the recovery of function after SCI can only roughly be performed, as significant overlap exists. Another limitation of this study is that additional mechanisms, which were not assessed, might contribute to functional recovery. For example, the reticulo-spinal (Ballermann and Fouad, 2006) and serotonergic (Oatway et al., 2005) pathways influence recovery of motor function in iSCI rodents. Furthermore, adaptation of the peripheral nervous system
(motoneurones or muscle fibres) that occurs in iSCI (Thomas et al., 1997) and cSCI (Burnham et al., 1997) subjects were not addressed.

New interventional therapies for SCI have various targets of action (Dietz and Curt, 2006). Therefore, protocols combining neurological, functional and spinal conductivity measures are required to distinguish between the effects of compensation, neural plasticity and repair mechanisms of damaged spinal tracts on recovery.

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Table 1. Mean baseline values and mean changes of the neurological measures (ASIA motor score, light touch and pinprick), functional measures (Walking Index for Spinal Cord Injury, WISCI, and Spinal Cord Independence Measure, SCIM) and neurophysiological assessments (amplitudes and latencies of the motor evoked potentials, MEP, and somatosensory evoked potentials, SSEP) for paraplegic and tetraplegic subjects. The mean change was calculated between baseline and the 48th week after SCI (*: p<0.05; **: p<0.01 and ***: p<0.001).
Figure legend

Figure 1. Course of neurological, functional and neurophysiological measures after spinal cord injury.

One year follow-up of neurological sensory-motor scores (ASIA motor and light touch), functional outcome measures (SCIM and WISCI) and neurophysiological assessments of SSEP and MEP latencies in tetraplegic subjects with motor-sensory complete (ASIA A, bold line), sensory incomplete but motor complete (ASIA B, striped bold line), and motor-sensory incomplete (ASIA C, striped and dotted line and ASIA D, dotted line) spinal cord injury. Stars indicate the significance of change from baseline to 48 weeks after SCI (*p<0.05, **p<0.01***p<0.001). Abbreviations: ASIA, American Spinal Injury Association; WISCI, Walking Index for Spinal Cord Injury; SCIM, Spinal Cord Independence Measure; SSEP, somatosensory evoked potential; MEP, motor evoked potential; n.s., not significant. Note the different scales of the y-axis for SSEP and MEP plots. In patients with abolished SSEP and MEP responses latencies could not be calculated. Maximal reference SSEP and MEP latency values (healthy subjects) were derived from (Buchner and Noth, 2005).
References


