Physical Capacity and Complications During and After Inpatient Rehabilitation for Spinal Cord Injury

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Physical Capacity and Complications During and After Inpatient Rehabilitation for Spinal Cord Injury

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The following manuscripts are part of this thesis and have been published or submitted for publication:

Haisma JA, van der Woude LH, Stam HJ, Bergen MP, Sluis TA, Bussmann JB. Physical capacity in wheelchair-dependent persons with a spinal cord injury: a critical review of the literature. *Spinal Cord* 2006; 44: 642-652.

Haisma JA, Bussmann JB, Stam HJ, Sluis TA, Bergen MP, Dallmeijer AJ, de Groot S, van der Woude LH. Changes in Physical Capacity During and After Inpatient Rehabilitation in Subjects With a Spinal Cord Injury. *Arch Phys Med Rehabil* 2006; 87: 741-748.

Haisma JA, van der Woude LH, Stam HJ, Bergen MP, Sluis TA, Groot de S, Dallmeijer AJ, Bussmann JB. Prognostic models for physical capacity at discharge and 1 year after discharge from rehabilitation in persons with a spinal cord injury. *Arch Phys Med Rehabil* 2007; 88:1694-1703.

Haisma JA, van der Woude LH, Stam HJ, Bergen MP, Sluis TA, Post MW, Bussmann JB. Complications following spinal cord injury: occurrence and risk factors in a longitudinal study during and after inpatient rehabilitation. *J Rehabil Med 2007*; 39: 393-398.

Haisma JA, Bussmann JB, Stam HJ, Sluis TA, Bergen MP, Post MW, Dallmeijer AJ, van der Woude LH. Physical fitness in persons with a spinal cord injury: the association with complications and duration of rehabilitation. *Clin Rehabil* 2007; 41: 932-940.

Haisma JA, Bussmann JB, Stam HJ, Bergen MP, Sluis TA, van den Berg-Emons HJ, Post MW, van der Woude LH. Physical independence and health-related functional status following a spinal cord injury: a prospective study on the association with physical capacity and complications. Submitted to *J Rehabil Med.*

1

Introduction

Spinal cord injury

A spinal cord injury (SCI) is an interruption of the neural pathways in the spinal canal and is characterized by muscle weakness, loss of sensation and autonomic dysfunction below the level of the lesion. The extent of these neurological deficits is determined by both the level and completeness of the lesion. A complete lesion results in loss of motor function and sensation in the lowest sacral segment whereas, following an incomplete lesion function in this segment is maintained.[1] The SCI can either have a traumatic or a non-traumatic cause. In traumatic cases, injury is typically the result of a traffic or sporting accident, but an increasing number of injuries result from a low impact fall, for example, in those with osteoporosis.[2,3] A non-traumatic SCI may be caused by metastasis, infection and spinal haemorrhage or infarction.[3,4] An estimated 183 new traumatic SCI occur in The Netherlands per year, of whom 154 survive hospitalization, which corresponds to an incidence of over 10 per 1,000,000 per year.[2] The incidence of non-traumatic SCI is easily underestimated because many are not registered as SCI, but this incidence largely exceeds the incidence of traumatic injuries.[2,4-6] As compared to the able-bodied population, the life expectancy of those with SCI is reduced. For example, a 20-year-old man with a traumatic paraplegia has an estimated life expectancy of 46 years, whereas an able-bodied man the same age, will have another 58 years to live.[3,7] However, because the treatment of complications has improved over the past decades, the life expectancy following SCI has increased.[2] Although the life expectancy may have improved, many patients report a low level of functioning and well-being.[8-10] Functioning following SCI may be threatened because most patients have complications, have a low physical capacity, and depend on others for daily activities.[6,9,11,12] Therefore, it is important to investigate opportunities to optimize functioning following SCI.

If injury or disease to the spinal cord leads to neurological deficit, patients are admitted to a hospital at least until circulatory and respiratory functions have stabilized, after which most of the traumatic cases are discharged to specialized rehabilitation centres.[2,3,5] Clinicians at these centres aim to provide care according to guidelines supported by the Dutch Flemish Spinal cord Society, and they teach and train patients to function as independently as possible, as soon as possible.[3] After inpatient rehabilitation, over 90% of the patients are discharged home and others are discharged to guided living facilities or nursing homes.[5] In The Netherlands the mean duration of hospitalization is 49 days and the mean inpatient rehabilitation is 240 days.[13] Length of stay not only depends on severity of the injury and complications, but also on the availability of services and post-discharge care.[5,13] After discharge, patients will be seen at rehabilitation centres for outpatient training or routine follow-up visits. The occurrence of complications could necessitate readmission to the hospital or rehabilitation centre.[14] Of secondary importance, but worth considering, are the expenses involved in the life-time care of those with SCI.[7] Based on findings of the Models Systems in the United States, the costs directly attributable to SCI are approximately € 190,000 in the first year, and € 19,000 for each subsequent year for a person with a complete paraplegia; the costs for those with tetraplegia may be more than double.

Spinal cord injury and functioning

A spinal cord injury is a condition that suddenly changes a patient's functioning. The International Classification of Functioning, Disability and Health (ICF) helps visualize how a condition, like SCI, influences functioning, and how the aspects of functioning interact with one another (Figure 1).[15,16]

Both the separate aspects of functioning, and the interactions between them may be influenced by environmental factors and by personal factors. The SCI directly leads to impairments in voluntary control, sensation and autonomic function. One

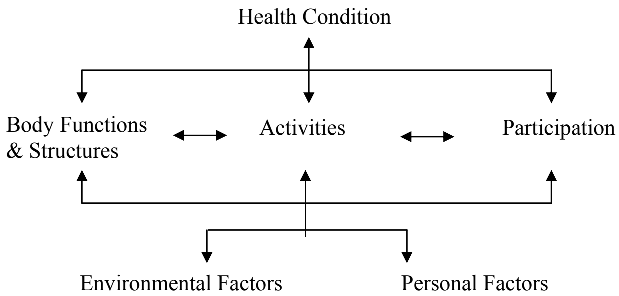

Figure 1 Interactions as described in the International Classification of Functioning, Disability and Health (ICF) model.[15]

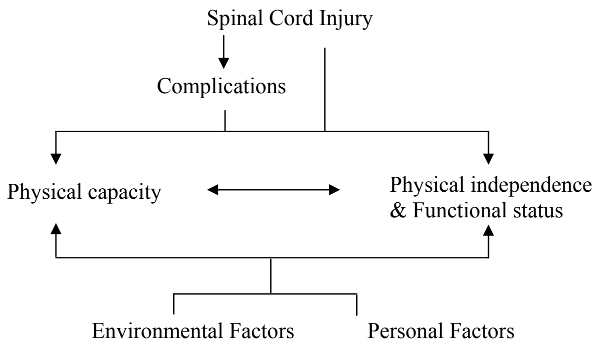

Figure 2 Interactions between aspects of functioning, complications, environmental and personal factors evaluated in this thesis; adapted from the International Classification of Functioning, Disability and Health (ICF) model.[15]

of the functions that is also impaired is the physical capacity, which is the combined ability of muscles and respiratory and cardiovascular systems to attain a certain level of activity.[12,17,18] Physical capacity is sometimes referred to as physical fitness or fitness. The SCI not only results in neurological impairments, but patients with SCI are also at risk of complications, which cause secondary impairments. Both the SCI and the complications will influence activities and participation.[19,20] It is important to get insight into changes in functioning following SCI, and how these changes interact with complications and environmental or personal factors (Figure 2).

Physical capacity

We can evaluate physical capacity by determining muscle strength and respiratory or cardiovascular function separately, or by determining their combined function (Figure 3). To determine muscle strength, manual muscle testing is used in clinical practice, and isokinetic or handheld dynamometry are used in research.[12,21] Dysfunction of respiratory muscles and respiratory complications affect respiratory function which can be assessed, for example, with spirometry.[22] Cardiovascular changes occur especially in those with a cervical or high thoracic lesion,[23,24] but it is difficult to quantify their cardiovascular function because the stroke volume is not easily measured in rehabilitation practice, and heart rate is difficult to interpret.[17,25] However, the combined function of cardiovascular, neuromuscular and respiratory systems can be measured with the aerobic capacity (i.e. the endurance capacity), the anaerobic capacity or the sprint power.[26] The endurance capacity comprises both the peak oxygen uptake and peak aerobic power output during a peak exercise test with hand rim wheelchair propulsion or arm crank exercise. The peak oxygen uptake is reflected by oxygen consumption; the peak power output is the product of the velocity of the wheelchair and the drag force of wheelchair and patient.[27]

Previous studies have used these different methods when they established a component of physical capacity, but comparative values for the level of different components of physical capacity in a general population with SCI is still lacking, and the different methods used need to be critically evaluated (Chapter 2).[17]

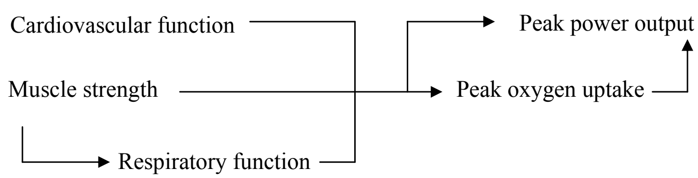

Figure 3 Interactions between components of physical capacity.

Importance of evaluating physical capacity

Following SCI, physical capacity is an important aspect of functioning, which is supported by previous studies that have shown that physical capacity interacts with other aspects of functioning and with well-being.[12,28-30] Its interaction with complications suggests that a low physical capacity predisposes to complications and that, conversely, complications influence physical capacity.[31,32] Furthermore, the interaction between physical capacity and activities suggests that a basic physical capacity is a prerequisite to being active, and that daily activities could influence physical capacity (Figure 2).[33-36] Because most patients are wheelchair bound and have a limited physical capacity, the performance of daily activities is strenuous and, as a consequence, they may be discouraged from being active and involved.[20,37-39] These interactions could indicate an unfortunate sequence of events: a low physical capacity makes activities strenuous, and consequently limits daily activities and reduces social involvement, and the consequent inactive lifestyle further reduces physical capacity and daily activities, and so on.[40]

However, because most of the aforementioned studies focused mainly on male subjects, those with a traumatic paraplegia or relatively active subjects,[12] their results cannot be translated to a general population with SCI. Additionally, the reported interactions were mostly cross-sectional, which cannot help establish the hypothesized sequence of events.[41] Until now prospective data on changes in physical capacity, and the interactions with other aspects of functioning or complications have not been described in a general SCI population.

Complications

Previous studies demonstrated that complications are a common problem following SCI,[11,42] that they may necessitate readmission to a rehabilitation centre or hospital,[14,43] and that they are associated with functioning (Figure 2). Complications interact with body functions. With a sacral pressure sore, for example, patients cannot sit. If a pressure sore requires a patient to take bed rest, he or she may be at risk of other complications, such as venous thrombosis.[9] Furthermore, complications interfere with activities. If a patient cannot sit in, or ride, his wheelchair he will not be able to perform activites.[12,44] Conversely, on the long term a low level of activity may be associated with complications like glucose intolerance or cardiovascular disease.[45,46] Complications are associated with participation; for example, patients with complications are less likely to be employed.[47] On the other hand, participation in training programs may reduce the risk of complications.[48] Unfortunately, these interactions could aggravate the previously suggested sequence of events, because complications could further reduce functioning, and the consequent reduced level of functioning could increase the risk of additional complications. Although the studies that focussed on complications may be more representative of a general population with SCI than those determining physical capacity, most are cross-sectional. This means that the hypothesized sequence of events can, again, only be established with new prospective data.

Changes in physical capacity and complications over time

Positive changes in physical capacity are expected to be not only the result of natural recovery, but also the effect of training programs during rehabilitation.[3,49] Alternatively, a decline in physical capacity may be caused by the cumulative effect of relative inactivity, as compared to the situation before injury. To establish the net effect of these proposed interactions prospective data were required (Chapter 3).[41] Modifiable lifestyle characteristics do influence physical capacity in the able-bodied population, but their effect in those with SCI is largely unkown.[50,51] Furthermore, prognostic models for their level of physical capacity have not been evaluated. Therefore, insight into the prognostic value of person, lifestyle and lesion-related characteristics following SCI are required (Chapter 4). Similarly, in order to evaluate the recovery of complications and to effectively target prevention or screening programs, changes in the occurrence of complications over time and their risk factors need to be investigated (Chapter 5). During rehabilitation, effort is put into both the improvement of physical capacity and into the prevention or treatment of complications;[3] however, the effectiveness of this effort has not been evaluated, and prospective data on the complex interactions between changes in physical capacity, the duration of rehabilitation and the occurrence of complications are lacking (Chapter 6).

Activities and participation

A low physical capacity and the occurrence of complications become especially noticeable when they interfere with the performance of daily activities (Figure 2). However, in comparison with the able-bodied population, a decline in physical capacity and complications invariably have a greater impact on functioning in those with SCI.[52] Physical independence interacts with social involvement, sense of control and well-being, which makes it especially important to investigate.[37,53] Cross-sectional studies showed that physical capacity and complications are associated with physical independence following SCI.[13,20,33,34,54] However, prospective studies on these associations may provide more insight into the directions of the interactions (Chapter 7).

The Umbrella project

The present study is an extension of a Dutch multi-centre study, the Umbrella project. This project investigates the restoration of mobility during SCI rehabilitation. Eight Dutch rehabilitation centres with a specialized spinal cord unit participated. Between 1999 and 2005 they collected findings in 225 subjects with SCI who were wheelchair bound at the start of active rehabilitation. Several outcome measures, which reflect different aspects of functioning, were monitored on 4 separate occasions: at the start of rehabilitation, 3 months into active rehabilitation, at discharge, and 1 year after discharge. The Umbrella project forms the epidemiological backbone of the larger research program ‘Physical strain, work capacity and mechanisms of restoration of mobility in the rehabilitation of persons with a spinal cord injury’, which is part of the first Rehabilitation Program of the Netherlands Organization of Research and Development (Zon-Mw).[55] The ultimate aim of the Zon-Mw Program is to improve the research infrastructure of rehabilitation practice. Besides the Umbrella project, the Zon-Mw SCI-rehabilitation program includes other research projects which are often more experimental in set-up.[56]

Outline of this thesis

Chapter 2 of this thesis presents a review of the reported level of physical capacity, and discusses the consequences of methodological differences between studies. Subsequently, Chapters 3 to 7 discuss findings based on prospective data of the Umbrella project. Chapter 3 describes changes in the level of physical capacity over time, the associations with age, gender, the level and completeness of the lesion, and the interactions between components of physical capacity (Figure 3). Chapter 4 establishes prognostic models for physical capacity at discharge from inpatient rehabilitation, and for physical capacity 1 year after discharge. The prognostic value of person, lifestyle and lesion-related characteristics are discussed. The occurrence and risk factors of complications are established in Chapter 5. Chapter 6 reports on the interaction between changes in physical capacity over time on the one hand, and the occurrence of complications and the duration of phases of rehabilitation on the other. Chapter 7 describes changes in physical independence over time, and determines whether physical independence and functional status are associated with physical capacity and complications. Finally, Chapter 8 discusses the main findings, methodological strengths and weaknesses, implications for clinical practice and suggestions for future research.

2

Physical capacity in wheelchair-dependent persons with a spinal cord injury: a critical review of the literature

JA Haisma, LH van der Woude, HJ Stam, MP Bergen, TA Sluis, JB Bussmann

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Abstract

Objective: To assess the level of physical capacity (peak oxygen uptake, peak power output, muscle strength of the upper extremity and respiratory function) in wheelchair dependent persons with a spinal cord injury (SCI).
Methods: Pubmed (Medline) search of publications from 1980 onwards. Studies were systematically assessed. Weighted means were calculated for baseline values.
Results: In tetraplegia the weighted mean for peak oxygen uptake was 0.89 l/min for the wheelchair exercise test (WCE) and 0.87 l/min for armcranking or hand-cycling (ACE). The peak power output was 26 W (WCE) and 40 W (ACE). In paraplegia the peak oxygen uptake was 2.10 l/min (WCE) and 1.51 l/min (ACE), whereas the peak power output was 74 W (ACE) and 85 W (WCE). In paraplegia muscle strength of the upper extremity and respiratory function were comparable to that in the able-bodied population. In tetraplegia muscle strength varied greatly, and respiratory function was reduced to 55-59% of the predicted values for an age, gender and height matched able-bodied population.
Conclusions: Physical capacity is reduced and varies in SCI. The variation between results is caused by population and methodological differences. Standardized measurement of physical capacity is needed to further develop comparative values for clinical practice and rehabilitation research.

Introduction

Physical capacity can be described as the capacity of the cardiovascular system, muscle groups and the respiratory system to provide a level of physical activity.[17] It is reduced in persons with a spinal cord injury (SCI) by the direct loss of motor control and sympathetic influence below the level of lesion. Additionally, the majority of persons with a SCI will be wheelchair users and dependent on arm work for mobility and activities of daily living. Subsequently, an inactive lifestyle may further reduce physical capacity.[12,36] A low level of physical capacity is associated with a decrease in activity,[12,57] functional status[33,58] and participation.[36,59] This may result in the vicious circle of decreased physical capacity leading to decreased activity and participation, which further reduces physical capacity, and so on. Furthermore, a low level of physical capacity is associated with a high risk of medical (cardiovascular) complications.[31,32] The association of a low level of the physical capacity with a relapse in different aspects of health, may contribute to a reduction in quality of life.[9,39,58] Hence, the evaluation of physical capacity can give an indication of the potential level of activity, participation and quality of life.[36,58,59]

Clinicians and rehabilitation researchers need comparative values for different components of physical capacity (i.e. peak oxygen uptake, peak power output, muscle strength of the upper extremity and respiratory function).[12] This will help them set targets in SCI rehabilitation.[49] Additionally, monitoring changes in physical capacity may give an indication of the effectiveness of training and rehabilitation programs.[60] Persons with SCI may become motivated to participate in exercise programs, when they learn about their health status and how it evolves.

Although much research has focused on physical capacity in SCI, the reported level of physical capacity varies greatly. This could be attributed to the disparity in population, methodology and presentation of results, which hamper comparisons and generalization.[9,12,17] Furthermore, few studies have addressed more than one component of physical capacity simultaneously.[12,17,49]

Therefore, the purpose of this study was to integrate evidence on different components of physical capacity in SCI, by critically analyzing absolute values and (in) consistencies in the literature. This way a set of comparative values for components of physical capacity in this population may be obtained. We formulated the following research question: What is the reported level of peak oxygen uptake, peak power output, muscle strength of the upper extremity and respiratory function in persons with SCI who are wheelchair-dependent?

Methods

Data search

To gain insight into the level of physical capacity in SCI, we searched Pubmed (Medline), and included publications from 1980 onwards. SCI-related studies were explored with the Medical Subject Headings (MeSH) 'spinal cord disease' and the terms tetraplegia, quadriplegia or paraplegia. This search was combined with the following MeSH headings: 'physical fitness', 'oxygen consumption', 'exercise test' or 'spirometry'. Then the search was combined with one of the following terms: wheelchair ergometry, endurance, physical capacity, manual muscle testing, handheld dynamometry or myometry. Additionally, we scanned the references in studies, and experts checked the resultant list of studies for completeness. Figure 1 shows the flowchart for the search and selection of studies.

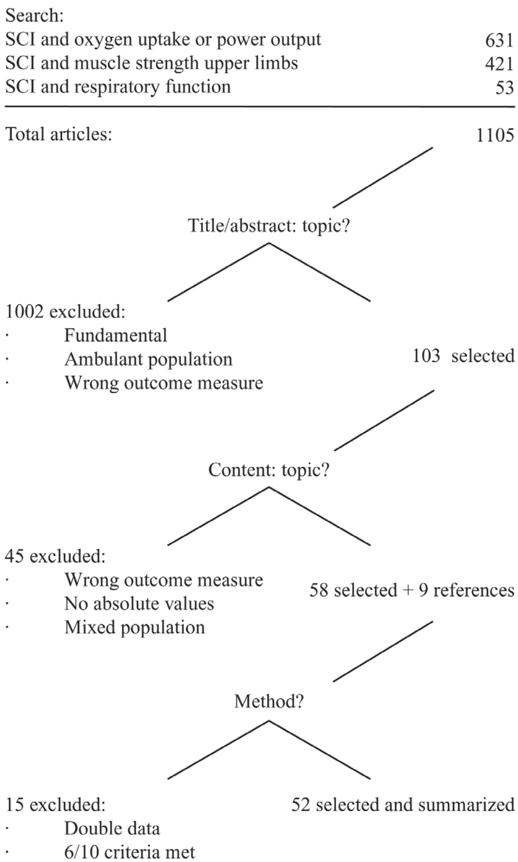

Figure 1 Flowchart for search and selection of studies on physical capacity

Data selection

Topic-related criteria

To be eligible for inclusion, a study had to specify the following items: (1) Results for subjects with SCI who were wheelchair-dependent. (2) Whether results concerned subjects with a tetraplegia or a paraplegia. (3) One of the following outcome parameters: (i) peak oxygen uptake (VO_{2peak}; l/min or ml/min) or peak power output (PO_{peak}; W or kpm/min) measured by a wheelchair exercise test (WCE), arm-cranking or handcycling (ACE); (ii) manual muscle testing grade (MMT) or handheld dynamometry score (HHD; Newton or kg) for the upper extremity; (iii) forced expiratory flow per second (FEV1) or forced vital capacity (FVC) as absolute values in litres, or as a % of the predicted values for an age, gender and height-matched able-bodied population. (4) The method used.

Methodological criteria

The resultant 67 studies were assessed on their methodological quality. Because we were interested in baseline values of physical capacity, we abbreviated an established checklist for the evaluation of effect studies.[61,62] If studies specified 7 of the following items they were assumed methodologically fit for inclusion. (1) Inclusion and exclusion criteria. (2) Source of selected population. (3) Description of subjects. (4) Inclusion of ≥ 10 subjects with a tetraplegia or ≥ 10 subjects with paraplegia. (5) Outcome measure. (6) Details on the measuring protocol. (7) Statistical method. (8) Means and standard deviations. (9) Number of dropouts. (10) Reasons for not completing tests.

Two studies were excluded because they fulfilled only 6 of these criteria. Thirteen studies were excluded, because they concerned doubly reported data.

Data extraction

A data extraction form was used to collect information on population characteristics, methods and results. We calculated the weighted means of the combined results.

Results

Tables 1-3 summarize the data of the selected studies. Figures 2 and 3 show mean results for the studies and their combined weighted means.

Peak oxygen uptake and peak power output

Most selected studies assessed subjects with paraplegia. Most subjects were men, who participated in sports, were on average 30 years old, and were assessed > 6 years post-injury. There was variability among the profile used, the starting power output or velocity, and the subsequent increments. For paraplegia the mean VO_{2peak} during the WCE (Table 1A) ranged from 1.10 to 2.51 l/min (weighted mean 2.10 l/min; Figure 2a) and the mean PO_{peak} ranged from 46 to 102 W (weighted mean 74 W; Figure 2b). During ACE (Table 1B) the mean VO_{2peak} ranged from 1.03 to 2.34 l/min (weighted mean 1.51 l/min; Figure 2a) and the mean PO_{peak} ranged from 66 to 117 W (weighted mean 85 W; Figure 2b). In subjects with a tetraplegia the mean VO_{2peak} during WCE (Table 1C) ranged from 0.76 to 1.03 l/min (weighted mean 0.89 l/min; Figure 2a) and the mean PO_{peak} ranged from 21 to 33 W (weighted mean 26 W; Figure 2b). During ACE (Table 1D) the mean VO_{2peak} ranged from 0.78 to 0.95 l/min (weighted mean 0.87 l/min; Figure 2a) and the PO_{peak} ranged from 35 to 43 W (weighted mean 40 W; Figure 2b).

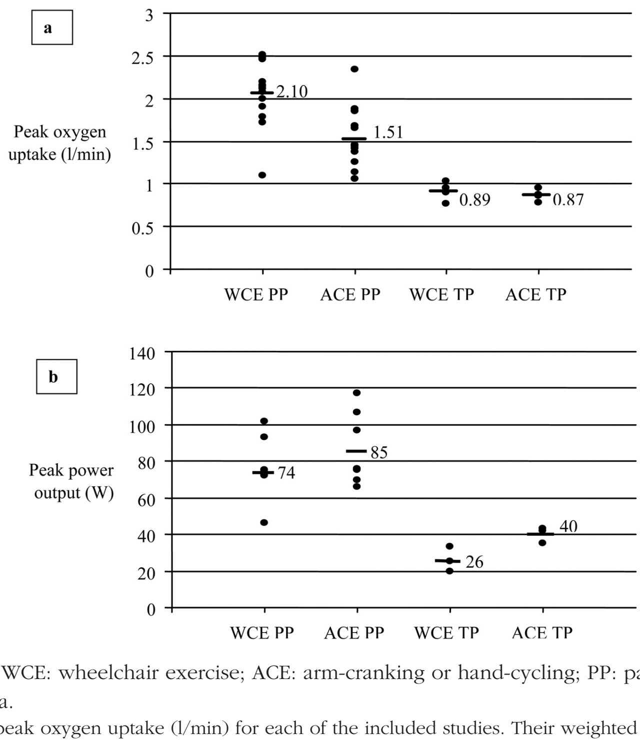

Figure 2 WCE: wheelchair exercise; ACE: arm-cranking or hand-cycling; PP: paraplegia; TP: tetraplegia.
(a) Mean peak oxygen uptake (l/min) for each of the included studies. Their weighted mean is specified.
(b) Mean peak power output (W) for each of the included studies. Their weighted mean is specified.

Table 1A Paraplegia: peak endurance capacity during wheelchair exercise

author	*year*	*n*	*age*	*M/F*	*C/I*	*TSI*	*activity*	*C/D*	*E/T*	*start; increments*	*HR*	*VO_2*	*PO*	*Comment*
Bernard[71]	2000	12	30	?	?	?	athletes	C	T	3 mins 4 km/h; incr 1 km/h/min	176	2.07		
Bougenot[72]	2003	7	35	7/0	7/0	12	no training	C	E	15 W; incr 10 W/2min		1.99	74	
Cooper[73]	1992	10	32	10/0	?	9	athletes; 8h/week	C	E	2.23 m/s; incr 0.446 m/s or 2.68 m/s; incr 10W/90sec	183	2.46		
Coutts[74]	1995	18	?	27/0	?	?	athletes	C	E	40 rpm; incr 20 rpm, until 80, then 10 W/90s		2.47		
Dallmeijer[75]	2004	9	36	9/0	?	13	4 h/week	C	T	10 W/min	182	1.79	93	PP = able bodied ACE = WCE
Gass[76]	1995	9	31	9/0	9/0	9	no training	C	T	3.5 km/h; incr 0.5 km/h or 0.5% gradient, until 4%, then speed only	177	1.72		ACE = WCE
Janssen[12]	2002	107	35	96/11	?	10	6 h/week	C/D	E/T	incr %PO, fixed W, speed or gradient		2.12	75	Related to activity
Kerk[77]	1995	6	22	2/4	6/0	4	athletes	C	E	3.1 m/s; incr 0.5 m/s/min		2.51		
Knechtle[78]	2001	9	28	?	5/4	?	athletes	C	T	8 km/h 1%; incr 0.5%/2min		2.13		
Martel[79]	1991	20	27	20/0	?	10	5 h/week	C	E	5 W, incr 10 W/min	190	1.9	74	PO: ACE>WCE VO_2:ACE=WCE
Rasche[80]	1993	6	26	6/0	6/0	7	athletes	C/D	T	D: 3 mins, incr 10-15 W; C: 50%max; incr 10-15 W	198 187	D: 2.13 C: 2.18	100 104	VO_2, PO: D=C.
Schmid[81]	1998	30	35	30/0	30/0	11	?	C	E	20 W; incr 10 W/3min	177	2.08	73	
Schmid[82]	1998	10	30	0/10	10/0	12	sedentary	C	E	20 W; incr 10 W/3min	180	1.09	46	
Veeger[83]	1991	45	34	40/8	?	?	athletes	C	T	2 km/h or 1%/min	178	2.19	72	$VO_{2:}$ F<M
Vinet[84]	1996	7	29	7/0	4/3	>2	6 h/week	C	T	4 km/hr; incr 1 km/h/min	176	2.46		

M/F: ratio male/female; C/I: complete/incomplete; TSI: time since injury (years); C/D: continuous or discontinuous protocol; E/T: ergometry or treadmill; HR: peak heart rate (bpm); VO_2: peak oxygen uptake (l/min); PO: peak power output (Watt); ACE: arm-cranking exercise; WCE: wheelchair exercise; PP: paraplegia.

Table 1B Paraplegia: peak endurance capacity during arm-cranking or handcycling

author	*year*	*n*	*age*	*M/F*	*C/I*	*TSI*	*activity*	*C/D*	*start; increments*	*HR*	*VO_2*	*PO*	*Comment*
Dallmeijer[75]	2004	9	36	9/0	?	13	4 h/week	C	incr 10 W/min	188	1.88	117	PP = able bodied ACE = WCE
Ellenberg[85]	1989	10	30	7/3	7/3	0,1	no training	C	25 W; incr 25 W/3mins	170	1.06	66	
Gass[76]	1995	9	31	9/0	?	9	ADL only	C	20 W; incr 5 W/30s	177	1.65		ACE = WCE
Hooker[18]	1993	27	25	27/0	27/0	2	sedentary	C	1min; incr 8.2 or 16.3 W	171	1.26	76	PP < able bodied
Hooker[86]	1993	9	33	9/0	4/5	10	no training	C	3 mins; incr 8.2 W/min	150	1.14	70	
Hopman[87]	2004	6	33	6/0	5/1	?	4 h/week	C	incr 3, 5 or 10 W/min	179	1.68		
Hopman[88]	1998	4	28	4/0	3/1	7		D	2-10 W/min	185	1.85	97	
Jacobs[89]	2001	10	39	10/0	10/0	7		D	65 W; incr 16 W/min		1.45	107	
Knechtle[90]	2003	7	42	?	7/0	?	athletes	C	60 W; incr 20 W/2mins		2.34		
Martel[79]	1991	20	27	20/0	?	10	5 h/week	C	5 W, incr 10 W/min	190	1.88	97	PO: ACE>WCE VO_2:ACE=WCE
Mossberg[91]	1999	11	35	10/1	?	9	?	D	20 W; incr 10 W/2min	178	1.38		Asynchronous = synchronous.
Steinberg[92]	2000	26	30	26/0	26/0	6	athletes and sedentary	C	25 W; incr 12.5 W/min	177	1.44	75	
Yamasaki[93]	1998	22	38	22/0	22/0	13	athletes and sedentary	C	0 W; incr 5 W/min	160	1.41		Related to activity

M/F: ratio male/female; C/I: complete/incomplete; TSI: time since injury (years); C/D: continuous or discontinuous protocol; HR: peak heart rate (bpm); VO_2: peak oxygen uptake (l/min); PO: peak power output (Watt); ACE: arm-cranking exercise; WCE: wheelchair exercise; PP: paraplegia.

Table 1C Tetraplegia: peak endurance capacity during wheelchair exercise

author	*year*	*n*	*age*	*M/F*	*C/I*	*TSI*	*activity*	*C/D*	*E/T*	*start; increments*	*HR*	*VO_2*	*PO*	*Comment*
Coutts[74]	1995	9	?	9/0	?	?	athletes	C	E	20 rpm; incr 10/min		0.95		
Dallmeijer[94]	1997	20	33	?	14/6	7	athletes and sedentary	C	E	Incr 10% PO_{peak}/min		0.85	21	
Gass[95]	1980	9	34	9/0	8/1	12	no training	C	T	2% gradient or 0.5 km/h/min	125	0.76		
Janssen[12]	2002	59	35	50/9	?	7	4 h/week	C/D	E/T	incr %PO, fixed W, speed or gradient		0.90	25	Related to activity
Schmid[81]	1998	20	34	20/0	20/0	11	?	C	E	10 W; incr 5 W/3mins	110	1.03	33	PO: TP<PP

Table 1D Tetraplegia: peak endurance capacity during arm-cranking or hand cycling

author	*year*	*n*	*age*	*M/F*	*C/I*	*TSI*	*activity*	*C/D*	*increments*	*HR*	*VO_2*	*PO*	*Comment*
Hopman[87]	2004	6	26	6/0	5/1	?	3-5 h/week	C	3-5 W/min		0.86		
Hopman[88]	1998	5	34	5/0	5/0	11		C	2-10 W/min	118	0.87	42	
Hopman[96]	1996	21	32	18/3	16/5	8	athletes and sedentary	C	20% PO_{peak}		0.78	35	Related to activity
Lasko[97]	1991	24	29	24/0	?	9	?	C	4 W/min	123	0.95	43	Related to increments

M/F: ratio male/female; C/I: complete/incomplete; TSI: time since injury (years); C/D: continuous or discontinuous protocol; E/T: ergometry or treadmill; HR: peak heart rate (bpm); VO_2: peak oxygen uptake (l/min); PO: peak power output (Watt).

Table 2 Muscle strength of the upper extremity in subjects with a tetraplegia

author	*year*	*n*	*age*	*M/F*	*C/I*	*TSI*	*M/H*	*Strength upper extremity*	*Comment*
Beninato[54]	2004	20	37	16/4	13/7	?	M	Shoulder flex grade 3.7/ext 3.6; Elbow flex 4.4/ext 2.1; wrist flex 1.5/ext 3.3	MMT 20-point scale
Bryden[68]	2004	43	32	36/7	43/0	6	M	Elbow ext: 60/74 grade 0; 14/74 grade 1-2 Elbow flex: median 4+; range 3-5	MMT 20-point scale.
Burns[64]	2005	19	54	19/0	9/10	?	M/H	Elbow flex 2/7 grade 3; 5/7 grade 4 ext 6/12 grade 3; 6/12 grade 4 Make-test flex 7.3 kg; ext 8.0 kg Break-test flex 9.0 kg; ext 11.1 kg	Break test >make test
Fujiwara[67]	1999	14	31	12/2	14/0	1.3	M	ASIA motor score: 20/50 Shoulder score: 25/30	
Herbison[65]	1996	88	34	78/10	?	?	M/H	Elbow flexors: 26/176 grade 3.5 (↔ 4 kg); 47/176 grade 4.0 (↔ 5.1 kg); 50/176 grade 4.5 (↔ 6.7 kg); 53/176 grade 5 (↔ 9.0 kg).	MMT 10-point scale. HHD more sensitive to change
Hjeltnes[69]	1998	10	25	10/0	10/0	0.3	M	ASIA motor score: 19/50	MMT 5-point scale. Related to training.
Marino[70]	1995	50	?	47/3	50/0	1	M	ASIA: mean 19/50; median 16/50	MMT 5-point scale.
May[63]	1997	12	27	10/2	10/2	5	H	Internal rotation shoulder 14.8 kg External rotation 11.7 kg	
May[63]*	1997	11	28	10/1	8/3	8	H	Internal rotation shoulder 30.6 kg; external rotation 22.0 kg	Paraplegia
Schwartz[66]	1992	122	?	122/0	?	0.2	M/H	MMT grade elbow flex 5; wrist extensor grade 4. HHD: elbow flex left 8.0 kg, right 9.2 kg; Wrist ext left 6.3, right 6.6 kg	MMT 10-point scale; HHD more sensitive to change

*May[63] specifies results of those with a paraplegia and those with a tetraplegia. M/F: ratio male/female; TSI: time since injury (years); C/I: complete/incomplete; M/H: manual muscle testing or hand-held dynamometry; ↔: corresponds to; ASIA= summation of MMT grade elbow flexion, wrist extension, elbow extension, finger flexion, finger spread (max = 50); Shoulder score: summation MMT of scapula abductors, shoulder adductors and extensors (max = 30).

Table 3 Respiratory function following SCI

author	*year*	*n*	*age*	*M/F*	*C/I*	*smoking*	*TSI*	*FEV1*	*FEV1%*	*FVC*	*FVC%*	*Comment*
Data on subjects with Paraplegia												
Alemenoff[98]	1995	81	54	?	27/54	53N; 28C	23	3.18	90	4.20	86	Related to smoking.
Bernard[71]	2000	12	30	?	?	?	?	4.09	98			
Kerk[77]	1995	6	22	2/4	6/0	?	4			3.0		
Linn[99]	2000	41	40	19/22	41/0	N	14		89		85	Related to smoking
Schilero[100]	2005	15	49	15/0	?	6N; 7F; 2C	16	3.17	86	4.18	84	TP<PP; related to bronchodilatator use.
Schilero[101]	2004	5	40	?	2/3	1N; 3F; 1C	19	3.50		4.26		
Silva[102]	1998	12	31	12/0	12/0	N	?	3.62	84	4.05	81	PP<able bodied; related to ACE training
Data on subjects with Tetraplegia												
Almenoff[98]	1995	84	46	?	12/72	55N; 29C	16	2.40	64	2.94	59	
Almenoff[103]	1995	25	43	25/0	6/19	10C; 15N	11	2.07	55	2.46	50	
Gass[95]	1980	9	34	?	8/1	3C	12	2.57	80	2.38		
Grimm[104]	2000	32	42	?	12/20	14N; 11F; 7C	14	2.47	62	3.07	58	
Liaw[105]	2000	20	34	16/4	20/0	2C	0.2	1.20	40	1.4	37	Related to training
Linn[99]	2000	35	40	16/19	35/0	N	14		57		52	
Lougheed[106]	2001	6	32	5/1	6/0	2N; 2F; 2C	7	2.27	57	2.67	53	
Rutchik[28]	1998	10	36	10/0	4/6	4N; 5F; 1C	9	2.25	54	2.81	51	Related to training
Schilero[100]	2005	15	42	15/0	?	6N; 7F; 2C	13	2.29	56	2.91	55	TP<PP; TP < able bodied
Schilero[101]	2004	5	45	?	2/3	3F; 2C	17	2.28		2.97		Related to bronchodilatator use
Spungen[107]	1999	10	41	10/0	4/6	9N; 1C	16	2.23	56	2.79	53	Related to steroid use
Spungen[108]	1993	34	45	34/0	34/0	12N; 14F; 8C	12	2.97		2.12		
Walker[109]	1989	15	28	11/4	0/15	N	>2			2.60	61	Related to training
Wang[110]	2002	15	41	?	15/0	?	4	1.83	61	2.16	59	Related to training

M/F: ratio male/female; TSI: time since injury (years); C/I: complete/incomplete; smoking history N: never; F: former; C: current; FEV1: absolute forced expiratory flow in one second (liters); FEV1%: forced expiratory flow in one second as % of predicted; FVC: forced vital capacity (liters); FVC% forced vital capacity as % of predicted; TP: tetraplegia; PP: paraplegia.

Muscle strength upper extremity

Most selected studies assessed subjects with a tetraplegia. Most subjects were men, who were on average 30 years old. Time since injury ranged from 1 month to 6 years. In paraplegia the mean strength of the shoulder internal rotators was 30.6 kg and of the external rotators 22.0 kg.[63] For subjects with tetraplegia these values were 14.8 and 11.7 kg, respectively.[63] The elbow flexion in subjects with tetraplegia ranged from 4.0 to 9.2 kg.[64-66] The mean strength for wrist extension was 6.5 kg.[64] Elbow extension scored between 8.0 and 11.1 kg.[64]

MMT grades were used varyingly. One study reported a mean shoulder flexion of grade 3.7 and a mean shoulder extension of 3.6.[54] Summation of the score of three muscles in both shoulders resulted in a score of 25 out of 30.[67] Elbow flexion ranged from a grade 2 to 5.[54,64-66,68] Wrist extension ranged from 3.3 to 4.[54,66] Elbow extension ranged from 0 to 2.[64,68] The mean wrist flexion was 1.5.[54] The mean motor score of the 5 key muscles of both upper extremities was 19 or 20 out of 50.[67,69,70]

Respiratory function

Most selected studies assessed subjects with a tetraplegia. Time since injury usually exceeded 10 years. In paraplegia mean FEV1 ranged from 86-98% of the predicted value for an age, gender and height matched able-bodied population (weighted mean 90%; Figure 3). The mean FVC ranged from 81-86% of the predicted value (weighted mean 85%). In tetraplegia mean FEV1 ranged from 40-80% of the predicted value (weighted mean 59%). The mean FVC ranged from 37-61% of the predicted value (weighted mean 55%).

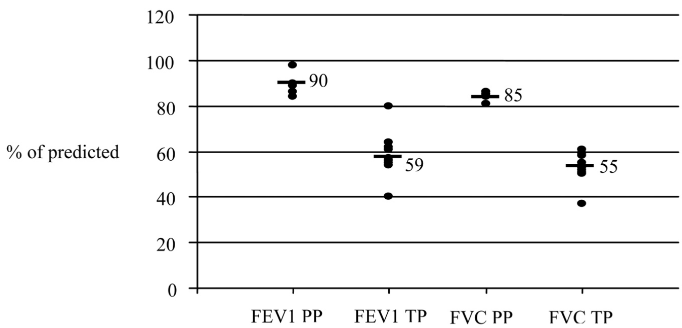

Figure 3 Mean respiratory function (as % of predicted values for an age, gender and height matched able-bodied population) for included studies; PP: paraplegia; TP: tetraplegia; FEV1: forced expiratory flow in one second; FVC: forced vital capacity. Weighted mean FEV1 or FVC for included studies is specified.

Discussion

Level of peak oxygen uptake and peak power output

Relatively low values for VO_{2peak} and PO_{peak} were a common finding and can be attributed to the dependency on arm exercise, the extent of paralysis, the reduced sympathetic control and the relative inactivity, which compromise physical capacity in SCI.[18,73,90,111] ACE in sedentary able-bodied persons is suggested to induce an oxygen uptake of 70% of the oxygen uptake that can be reached during a treadmill running test.[112] Assuming the 70% ratio applies to persons with a paraplegia, the mean of 1.51 l/min corresponds to 2.16 l/min. This is comparatively low, especially because daily use of a wheelchair may induce a training effect in persons with a paraplegia, and therefore, they may even be compared to an able-bodied population practised in arm-exercise.[73,75 113] It indicates that factors like paralysis of lower limbs, altered autonomic control and inactivity, do compromise physical capacity in paraplegia.

In paraplegia, the weighted mean VO_{2peak} in WCE was higher than during ACE. This is in agreement with another study, which suggested that during WCE a larger muscle mass is activated, because muscles involved in stabilisation of the trunk, and in the (un)coupling of the hand to the rim will be used.[114 79] However, this is inconsistent with studies that assessed the same population alternately with both methods (Figure 4). These studies showed no significant differences in VO_{2peak},[76,79,115,116] or an even higher VO_{2peak} during ACE than during WCE.[75,115] The inconsistency could be attributed to the fact that the present review compared results from different populations. The subjects studied during ACE were generally less active, and tested sooner after injury than subjects studied during WCE. Persons with longstanding SCI generally have a higher VO_{2peak} than persons with a recent SCI.[49,117] Protocol

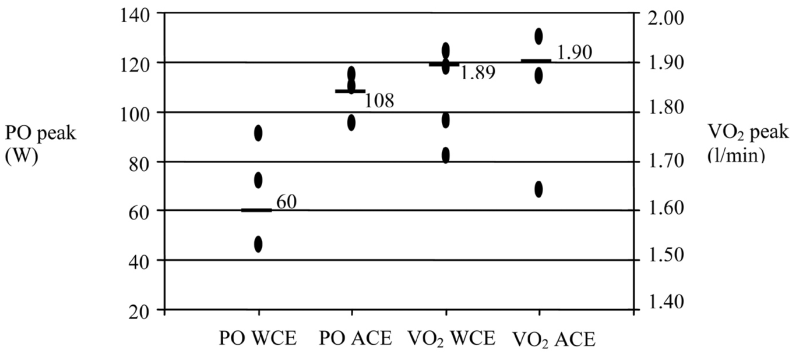

Figure 4 Results of four studies, which compared outcome during WCE (wheelchair exercise) to outcome of ACE (arm-cranking or hand-cycling). Mean peak power output (PO_{peak}) and peak oxygen uptake (VO_{2peak}) for these four studies are indicated. Their weighted mean is specified.

differences could also explain the differences found;[75,78,97,118] overall, the ACE started at a higher power output, and had greater subsequent increments. It is suggested that greater increments may underestimate peak values.[97]

The weighted mean PO_{peak} was lower in WCE than during ACE. This is consistent with other studies that assessed the same population alternately with both methods (Figure 4),[75,79,115,116] and suggests that the discontinuous and more complex movement pattern of wheelchair propulsion (as opposed to the continuous movement in arm-cranking), may limit its efficiency and lead to a lower PO_{peak}. The combination of the relatively high VO_{2peak} with the low PO_{peak}, supports the finding that wheelchair propulsion is mechanically less efficient than armcranking.[79]

Measuring peak power output and peak oxygen uptake

VO_{2peak} and PO_{peak} have proven valid and sensitive outcome measures for the assessment of physical capacity,[17] and should be included in the follow-up of persons with a SCI. The outcome of the maximal exercise tests were expressed as peak levels of oxygen uptake and power output (instead of maximal levels), because some subjects may have been able to activate a larger muscle mass, either through activation of the lower limbs (e.g. in those with incomplete lesion), or without the restraints from overuse and fatigue of the upper extremities.[25,76,88] The large variability in results found in paraplegia may be attributed to differences in measurement protocol[75,78,118] and study population.[12] Because of lack of homogeneity, no consistent conclusions on the influence of a particular protocol can be drawn.

Muscle strength of the upper extremity

The HHD score for shoulder strength in subjects with a paraplegia compared favourably to an age and gender matched able-bodied population.[119] This seems plausible, as in paraplegia muscle strength may be enhanced by daily use of the upper extremity.[73] However, in tetraplegia, muscle strength additionally depends on the level and completeness of injury, neurological recovery and spasticity. In subjects with high cervical lesions shoulder strength was reduced to 50% of values found in subjects with a paraplegia, or in the able-bodied population.[63,119] The strength of elbow flexion and wrist extension was reduced to 15-30% of that in the able-bodied population.[64,66,119] However, elbow extension showed relatively greater strength (30-50% of that in the able-bodied population).[64,119] The range of reported strength within the same muscle group, may be attributed to subjects with incomplete lesions, who have a haphazard innervation pattern. Additionally, daily wheelchair use may have had a training effect in some subjects, and may cause overuse in others.

Measuring muscle strength of the upper extremity

Most studies incorporated the widely recognized and practical MMT and this was the motivation for choosing the MMT score as an outcome measure. However, the different scales and summations used hamper comparison between studies. The MMT score has other limitations, when compared to the HHD. Firstly, it is an ordinal scale, and therefore summations are not very meaningful. Secondly, it is a subjective score, probably sensitive to observer-bias.[21] Thirdly, it is limited in the ability to identify change for grades 4-5, and the registration of recovery is restricted by a ceiling-effect.[21,65,66 120,121] Fourthly, it seems less valid, because it has a limited correlation with isokinetic dynamometry, which is often regarded the gold standard for the assessment of muscle strength, but is not manageable in use.[21,63,122] The HHD score has shown to be valid, and has a good reliability in SCI, both with experienced and inexperienced examiners.[63-65]

Muscle strength is an important component of physical capacity, and is related to functioning.[123] Because outcome measures need to be valid, sensitive to change and reliable, consensus needs to be reached on how to assess strength. HHD seems a valuable tool for the evaluation of muscle strength in some patients with SCI.

Level of respiratory function

In subjects with a tetraplegia the respiratory function was greatly reduced as compared to an age, gender and height matched able-bodied population, whereas in paraplegia the scores were relatively normal. This is consistent with other reports, which suggest that the level of lesion is inversely correlated with respiratory function.[9,22] When the thoracic and lumbar segments are injured, muscles of expiration are affected, whilst injury to the upper cervical cord additionally affects muscles of inspiration.[9,22] Furthermore, increased inactivity in tetraplegia may add to the reduced respiratory function.[95] Both FEV1 and FVC were reduced, hence the ratio FEV1/FVC remained stable, which suggests the respiratory problems are mostly restrictive in nature.[98] However, it is suggested that with loss of the sympathetic influence from the upper six thoracic segments, the parasympathetic bronchoconstriction remains unopposed.[100,103,104] This, together with airway obstruction following possible mucus collection, may result in additional obstructive problems.[108]

The variability found in outcome in tetraplegia may be attributed to population differences. Studies that included subjects with incomplete lesions,[98,99,124] or those who were able to perform a maximal exercise test,[95] were expected to have higher scores. Smoking was related to a reduced respiratory function in subjects with a paraplegia; surprisingly, however, these studies reported no significant relation between smoking and respiratory function in tetraplegia.[98,99,124] Therefore, on the basis of these studies, smoking cannot be held responsible for population-related differences in outcome in tetraplegia.

Measuring respiratory function
The respiratory function was expressed as a % of predicted values from an age, gender and height-matched able-bodied suitable reference population. However, because level of lesion is an important determinant of respiratory function, one would ideally want to correct for this, but it would require a large comparative database to make a valid correction. All selected studies used the American Thoracic Society (ATS) criteria for accepting individual spirometry results. This may lead to biased results, because the most impaired subjects are not able to meet these criteria. It has been suggested that when the criteria are modified, reproducibility can be guaranteed without loss of results from these subjects.[125] Respiratory complications are responsible for about 25% of deaths following a SCI,[126] and 68% of persons with a SCI experience respiratory complaints.[127] Improved respiratory function may contribute to the prevention of complications; therefore, evaluation of this function is important in SCI rehabilitation.

Limitations

We aimed at integrating evidence on different aspects of physical capacity. However, the cardiovascular function was not investigated for two reasons. Firstly, stroke volume is not easily measured in rehabilitation practice. Secondly, peak heart-rate is not a valid measure of physical capacity in SCI, and is not sensitive to change during training.[17,25,88] Reasons for this may be that upper body exercise is limited by local fatigue and overuse (rather than cardiovascular strain), and that peak heart-rate varies too much in persons with a tetraplegia.[75,76,79,115]

Overall a positive selection is shown which will bias the results. Firstly, most studies focused on male athletes.[12,69,102] Secondly, only those able to perform the tests were included, possibly excluding subjects with high cervical lesions. Thirdly, only those willing to participate were included. Hence, motivation and state of mood could influence both the selected population and performance during the tests. Due to lack of homogeneity among the included studies, the integration of findings did not provide consistent and comparative values.

Conclusions

The level of physical capacity is reduced and varies in persons with a SCI. The variation between results is caused by population and methodological differences. To allow interpretation and comparison of results, researchers should meticulously describe the population and the methods used. Standardized assessment of physical capacity in clinical practice and rehabilitation research is needed for the effective prediction and evaluation of progress in future. The present study provides suggestions for the parameters to be determined and methods to be used. Additionally, it provides a descriptive database for physical capacity in persons with a SCI and, with caution, these data may be used as reference material in rehabilitation and training.

3

Changes in physical capacity during and after inpatient rehabilitation in subjects with a spinal cord injury

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Abstract

Objective: To assess changes in components of physical capacity and its determinants during and after inpatient rehabilitation in persons with a spinal cord injury (SCI). To investigate the association among components of physical capacity.

Methods: Prospective multicenter cohort study. At the start of active rehabilitation (n= 186), 3 months later, at discharge, and 1 year after discharge (n= 123), we measured the peak aerobic power output (POpeak), peak oxygen uptake (VO_2peak), muscle strength of the upper extremity (manual muscle test, handheld dynamometry) and respiratory function (forced expiratory flow per second, forced vital capacity).

Results: Random coefficient analysis demonstrated that the POpeak, VO_2peak, strength, and respiratory function improved during inpatient rehabilitation, and that VO_2peak, strength, and respiratory function continued to improve after discharge. Age, sex, and level and completeness of lesion were determinants of the (change in) components of physical capacity.

Conclusions: Physical capacity improves during inpatient rehabilitation, and some components continue to improve after discharge. Subpopulations have a different level of (change in) physical capacity. The components of physical capacity are related; intervention studies are needed to confirm whether training 1 component could improve another component.

Introduction

Physical capacity is the combined ability of the cardiovascular, the respiratory and the musculoskeletal systems to attain a certain level of activity.[17] The different components of physical capacity (eg, power output, oxygen uptake, muscle strength, respiratory function) are related.[102,128,129] Additionally, the components are influenced by personal and lesion related factors and by training.[9,12,89,102 29]

Physical capacity is reduced in persons with a spinal cord injury (SCI) through muscle weakness, loss of autonomic control below the level of injury,[88,111,130] reduced activity, and subsequent changes in metabolic and vascular function.[12,24,31,130] A reduced physical capacity is an important determinant of the health status of persons with an SCI, because it exposes them to an increased risk of complications,[9,31] and is related to a reduced level of functioning and quality of life.[9,31,33,59] Therefore, an important goal in rehabilitation practice is to reverse the debilitative cycle of: a reduced physical capacity leading to reduced activity and functioning, which in turn further reduces physical capacity, and so on.[31,33] This reversal may be achieved by improving the physical capacity through rehabilitation training programs.

Knowledge on the change in physical capacity during inpatient rehabilitation is a prerequisite for the development of optimal rehabilitation programs, and for setting realistic individual rehabilitation goals. After discharge there are less training opportunities and more activities of daily life (ADLs) to perform. Because physical capacity is related to the performance of ADLs, it is especially important to determine whether persons with an SCI can maintain their level of physical capacity after discharge.[35,57,58]

Although much research has focused on physical capacity in SCI this was often limited by the particular study population or the design. Most research has focused on one component of physical capacity (eg, either peak oxygen uptake [VO_2peak], or muscle strength, or respiratory function). However, more than one component of physical capacity should be studied simultaneously to analyze the relation between the different components.[17] Follow-up studies have found significant differences between admission and discharge scores,[17,49] but because it was suggested that most changes occur during the first phase of rehabilitation,[131] it is important to investigate the change over shorter periods of time. Because there is some debate as to whether the level of activity during daily life is adequate enough to maintain physical capacity after discharge,[40] a longitudinal study is needed to gain more insight into the changes after inpatient rehabilitation. Age, sex, and level and completeness of the lesion were found to be factors related to the physical capacity in cross-sectional studies,[9,12] and longitudinal data will give insight into the influence of these factors on the change in physical capacity.

The main purpose of this study was to determine changes in the components of physical capacity (ie, the peak aerobic power output [POpeak], VO_2peak, muscle strength of the upper extremity and respiratory function) during inpatient rehabilitation and the year after discharge in persons with an SCI, who were wheelchair-dependent. Furthermore, we assessed the association between personal and lesion characteristics, and the (change in) physical capacity over time. Finally, the relations between the different components of physical capacity were studied.

Methods

Participants

The present study was part of the Dutch research program "Physical strain, work capacity and mechanisms of restoration of mobility in the rehabilitation of persons with a spinal cord injury." Subjects with a SCI who were in their initial inpatient rehabilitation were recruited from 8 participating specialized rehabilitation centres. Subjects were eligible for inclusion if they were between 18 and 65 years of age, were wheelchair-dependent, had sufficient comprehension of the Dutch language to understand the purpose of the study and testing methods, and did not have a progressive disease or a psychiatric condition interfering with constructive participation. Subjects were excluded from the study if they had cardiovascular contraindications for exercise, a resting diastolic blood pressure greater than 90mmHg, or a systolic blood pressure greater than 180mmHg.[132] Additionally, the maximal exercise test was contraindicated in the presence of compromising complaints of the musculoskeletal system. Within two weeks of admission, eligible subjects were informed about the study by a physician and invited to participate. Subjects had one week to consider participating, after which a physician or a nurse not involved in the research program requested consent. The Medical Ethics Committee approved the experimental protocol, and all subjects gave a written informed consent before participating.

Design

Subjects admitted to rehabilitation from 1999 to 2004 were included if they met eligibility criteria. They were assessed at 4 points in time (called measurement times): at the start of active inpatient rehabilitation when the subject was able to sit in a wheelchair for at least 3 hours (t1), 3 months later (t2), at discharge (t3), and 1 year after discharge (t4). If the subject was discharged within 1 month after t2, the performed assessment at t2 was considered a "discharge" assessment and, hence, was included in the analysis of physical capacity at t3. If a subject no longer relied on a wheelchair for mobility the previously collected data were analyzed, but no new data were collected.

Subject characteristics and level and completeness of the lesion and physical capacity scores were determined according to a standardized procedure. Tetraplegia was defined as a lesion at or above the T1 segment, and paraplegia as a lesion below the T1 segment. A complete lesion was defined as motor complete, that is, American Spinal Injury Association (ASIA) grade A or B.[1] An incomplete lesion was defined as ASIA grade C or D.[1] In each of the 8 rehabilitation centers a trained research assistant was responsible for the data collection. At each measurement the same testing equipment (ie, research wheelchair, treadmill,[a] dynamometer,[b] Oxycon Delta[c]) was used after standardized calibration.

Procedure

POpeak and Vo2peak. To determine POpeak and VO_2peak subjects performed a graded maximal wheelchair exercise test on a motor-driven treadmill.[a] Prior to testing subjects were asked to consume a light meal only, refrain from smoking, drinking coffee or alcohol two hours before testing, and to void their bladder The testing protocol and equipment has been described previously by Kilkens et al.[133] For each subject, and at every measurement time, a drag test was used to allow the calculation of the power output for the wheelchair-user system on the treadmill at increasing inclinations.[27]

Subjects performed 2 blocks of submaximal exercise of 3 minutes each, separated by a 2-minutes rest. The inclination of the treadmill was set horizontal during the first block and at .36° during the second block. The velocity of the treadmill was set at 2km/h for subjects with tetraplegia and at 4km/h for subjects with paraplegia. Sometimes (eg, in subjects with a low cervical lesion) a protocol with a velocity of 3km/h was chosen. After 2 minutes of rest, the maximal exercise test followed at the same constant velocity, and the inclination was increased .36° every minute. The test was terminated when the subject was exhausted or could no longer maintain the speed of the treadmill. The VO_2peak (in L/min) was defined as the highest value of oxygen consumption recorded during 30 seconds. The POpeak (in watts) was defined as the power output at the highest inclination that could be maintained for at least 30 seconds.

Strength of the upper extremity. To determine the strength of the upper extremity, the shoulder abductors, internal and external rotators, elbow flexors and extensors, and wrist extensors were tested with the manual muscle test (MMT) in both arms. This test was performed in standardized positions, in which subjects performed a movement either with or without gravity, or against resistance.[134] The strength was rated on a scale ranging from 0 to 5.[134] Summing the scores of the 12 muscle groups gave an MMT sum score (maximum, 60).

The muscle groups (with exception of the wrist extensors) that scored 3 or greater on the MMT were tested with handheld dynamometry[b] (HHD) according to a standardized protocol.[135] The break test was used: the subject exerted a maximal force against a dynamometer and the examiner applied sufficient resistance to just overcome the force exerted by the subject.[119] The maximum force (in newtons) of the 10 muscle groups was summated. Only when an MMT or HHD score was available for all muscle groups (ie, 12 or 10, respectively) was a sum score calculated, and included in the estimation of the muscle strength at that measurement time.

Respiratory function. Flow-volume curves were made with the Oxycon Delta[c] to assess respiratory function. Three repeated curves were made, and if the resultant curve did not have its characteristic shape an extra measurement was done.[136] The forced vital capacity (FVC) (in liters) and forced expiratory flow per second (FEV_1) (in liters) for each subject were additionally expressed as a percentage of what this subject was expected to score in comparison with an age, sex, and height-matched able-bodied population.[137]

Analyses

We used random coefficient analysis[d] to analyze the change in physical capacity over time and its determinants.[138,139] An important advantage is that the method takes into account the dependency of repeated assessments within 1 subject and within 1 rehabilitation center. Additionally, the analyses can be carried out with missing values.[138,139] This offers the advantage (compared, eg, with repeated-measurements analysis of variance) that more subjects can be included, which gives a more realistic representation of the group performance at each measurement time. Thus, we included subjects in the analyses when 1 or more components of physical capacity at 1 or more measurement times could be determined, and we could adequately assess the change in physical capacity over time with varying group composition.[138,139]

Change in the physical capacity during and after inpatient rehabilitation. A basic regression model was made for the change in each component of physical capacity. Time was not included in the model as a single continuous variable, but as a set of dummy variables with the physical capacity at discharge chosen as the reference variable. In this analysis, the physical capacity at discharge was estimated by the intercept. The differences between the physical capacity at discharge and the physical capacity at the other measurement times were estimated by the coefficients for these measurement times. Estimates of the physical capacity at the other measurement times were obtained by adding these coefficients to the intercept. To model had to include all three dummy variables to permit a valid assessment of the physical capacity.

Relation between the (change in) physical capacity and personal and lesion characteristics. To determine whether the variables age, sex, and level and completeness of the lesion were related to the (change in) physical capacity over time, these independent variables and their interaction terms with the dummy variables were alternately added to the basic model. Then, the variables and interaction terms with a *P* value of .10 or less were selected and simultaneously added to the basic model. Through backward elimination the nonsignificant variables (P>.05) were removed. To allow a valid analysis of the relation between an independent variable and the change in physical capacity over time, we had to include all its interaction terms even if the relation proved significant over only 1 time interval.

Relation between the different components of physical capacity. To investigate whether the components of physical capacity were related, the association between the $\dot{V}O_2$peak, muscle strength and respiratory function, and the (change in) POpeak was first analyzed, and then the association between muscle strength and respiratory function, and the (change in) $\dot{V}O_2$peak was analyzed separately. In both instances, we controlled for those independent variables that significantly contributed to the POpeak and $\dot{V}O_2$peak in the respective preceding model, by including these variables in the model. We made models for both the POpeak and $\dot{V}O_2$peak according to the procedure described in the above paragraph. This resulted in two models with independent variables and the components of physical capacity that were significantly related to the POpeak or $\dot{V}O_2$peak.

Results

Participants

At the start of active rehabilitation the group consisted of 186 subjects, and a year after discharge there were 123 subjects. During the course of the study 58 subjects dropped out at some point: 16 subjects became wheelchair-independent, 25 refused further participation, 9 subjects were irretraceable, and 8 subjects died. There were several reasons for not collecting data at 1 particular measurement time: 44 subjects were discharged within 3 months after admission, hence they did not perform a t2 measurement; in 20 instances the neurologic deficit was too large to be able to perform the test; on 14 occasions subjects had cardiovascular or musculoskeletal contraindications; in 9 instances subjects had a halo traction or other fixation; in 6 instances other pathology (eg, infection, pressure ulcer) prevented assessment, and technical problems prevented assessment on 8 occasions. Table 1 gives the group sizes, means and standard deviations (SDs) for the subject characteristics, lesion characteristics and

Table 1 Subject and lesion characteristics and physical capacity scores at the four measurement times

Characteristic and score		Start		Three Months		Discharge		Year After Discharge	
		n	*Mean ± SD*	*n*	*Mean ± SD*	*n*	*Mean ± SD*	*n*	*Mean ± SD*
Age (y)	TP	75	39±13	66	39±13	66	40±13	42	39±13
	PP	110	41±15	72	41±15	102	41±15	81	42±14
Sex (% men)	TP	76	74	66	73	66	76	42	74
	PP	110	75	72	78	101	74	81	74
Height (m)	TP	75	1.78±0.09	66	1.77±0.10	65	1.77±0.09	42	1.76±0.09
	PP	108	1.78±0.10	70	1.79±0.08	100	1.79±0.10	80	1.78±0.09
Body mass (kg)	TP	75	70±14	65	72±14	64	74±15	42	77±17
	PP	110	73±14	71	74±14	101	75±14	81	77±17
Time since injury (d)	TP	75	108±67	65	212±76	65	388±176	42	787±206
	PP	110	102±62	71	190±75	101	269±117	81	657±138
Complete (% complete)	TP	76	66	63	60	64	52	41	54
	PP	109	69	71	73	102	72	80	73
Peak heart rate (bpm)	TP	22	112±19	22	111±18	35	117±22	16	122±28
	PP	80	147±21	62	153±26	87	152±25	61	154±27
Vo_2peak (L/min)	TP	22	0.85±0.25	22	0.85±0.36	35	0.99±0.37	17	1.17±0.43
	PP	80	1.07±0.37	63	1.22±0.37	87	1.32±0.43	62	1.31±0.47
POpeak (W)	TP	23	17±9	23	16±7	35	25±16	16	30 ±21
	PP	76	35±18	63	44±18	90	48±22	61	51±23
MMT sum score (/60)	TP	70	39±15	62	41±15	65	45±15	38	47±13
	PP	105	58±5	71	59±3	99	59±3	79	59±2
HHD sum score (N)	TP	29	1076±495	30	1273±442	35	1473±523	23	1485±647
	PP	81	1668±482	57	1810±488	71	1934±523	57	1992±508
FEV_1 (L)	TP	71	2.42±1.00	64	2.52±0.94	64	2.94±0.98	41	3.09±1.09
	PP	104	2.95±1.00	71	3.11±0.83	100	3.37±0.99	73	3.41±0.98
FEV_1 (% predicted)	TP	71	64±25	64	66±20	64	77±22	41	81±24
	PP	104	77±22	71	80±18	100	86±20	73	88±21
FVC (L)	TP	71	2.89±1.30	64	2.96±1.05	64	3.55±1.23	41	3.75±1.34
	PP	104	3.59±1.25	71	3.81±1.03	100	4.15±1.21	73	4.21±1.18
FVC (% predicted)	TP	71	63±26	64	65±19	64	77±22	41	82±24
	PP	104	78±25	71	81±19	100	88±21	73	90±20

Subjects were included when at least 1 component of physical capacity was determined at that particular measurement time.
Abbreviations: PP, subjects with paraplegia; TP, subjects with tetraplegia.

physical capacity scores at the different measurement times for those subjects in whom at least 1 component of physical capacity could be obtained at that particular measurement time.

Change in the Physical Capacity During and After Inpatient Rehabilitation

The POpeak, VO_2peak, muscle strength, and respiratory function improved during inpatient rehabilitation, and the VO_2peak, muscle strength, and respiratory function continued to improve after discharge. Figures 1 through 3 show the change in physical capacity over time as estimated with the basic regression model.

Relation Between the (Change in) Physical Capacity and Personal and Lesion Characteristics

Table 2 presents data on the association between the (change in) physical capacity and the independent variables. The respective regression coefficients represent the change in outcome score associated with an increase in the independent variable of 1 unit. Because table 2 presents data after backward elimination, the dummy variables, and significantly contributing variables and interaction terms are given.

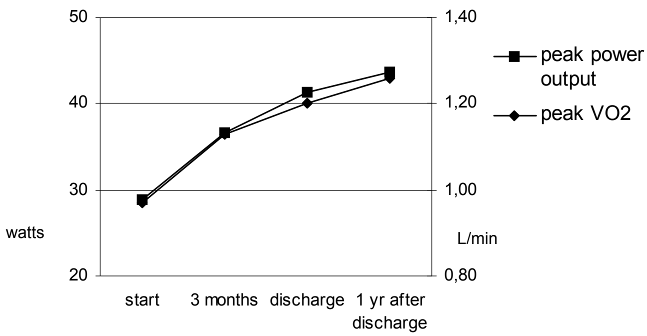

Figure 1 Change in POpeak (in watts) and VO_2peak (in L/min) as calculated from the basic model

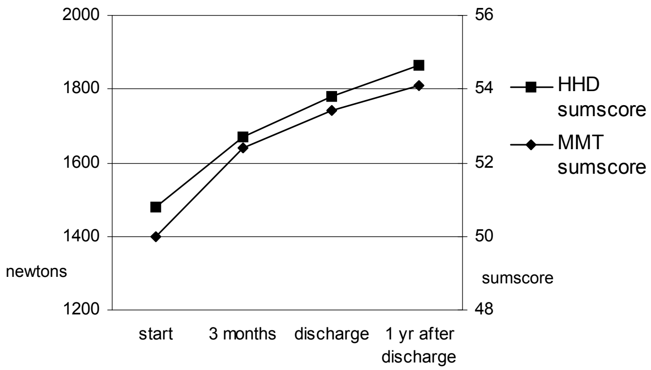

Figure 2 Change in HHD score (newtons) and MMT sum score (maximum, 60) as calculated from the basic model

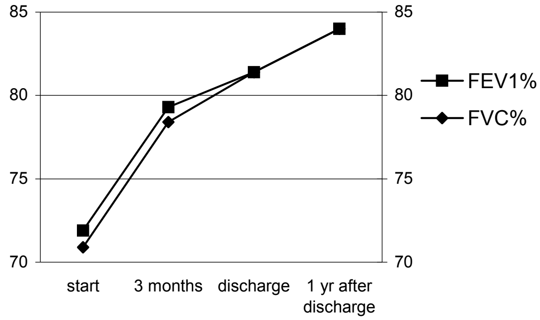

Figure 3 Change in FEV_1 and FVC as a percentage of the predicted value (compared with an age, sex, and height-matched able-bodied population) as calculated from the basic model.

Age. Age was significantly related to the POpeak and HHD score: an increase in age of 1 year was associated with a decrease of 0.3W or 7N, respectively. During inpatient rehabilitation the improvement in POpeak and HHD was significantly less in older subjects. After discharge the MMT score improved significantly more in older subjects, whereas the percentage of FVC improved significantly less in older subjects.

Sex. Men had a significantly greater POpeak, VO_2peak, and HHD score than women (14W, .35L/min, 575N greater, respectively). During inpatient rehabilitation the improvement in POpeak and HHD score was significantly greater in men than in women.

Level of the lesion. In subjects with a tetraplegia the POpeak, VO_2peak, muscle strength, and percentage of FVC were significantly lower than in those with paraplegia. During inpatient rehabilitation, the improvement in muscle strength and percentage of FEV_1 was greater in subjects with a tetraplegia. After discharge the VO_2peak and MMT improved more in this group.

Completeness of the lesion. Subjects with a complete lesion had a significantly greater HHD score, and a significantly lower percentage of FVC than subjects with an incomplete lesion. In subjects with a complete lesion the improvement in percentage of FEV_1 during inpatient rehabilitation was significantly greater than in subjects with an incomplete lesion.

Relation Between the Different Components of Physical Capacity

Table 3 presents data on the association between the VO_2peak, muscle strength, and respiratory function, and the POpeak in 1 column, and for the association between muscle strength and respiratory function, and the VO_2peak in the other column. The respective regression coefficients represent the change in POpeak or VO_2peak associated with an increase in VO_2peak, strength or respiratory function of 1 unit. The level of lesion, the VO_2peak, the HHD score, and the percentage of FVC were significantly

Table 2 Data on the longitudinal relation between subject and lesion characteristics and the (change in) physical capacity

Independent Variable	*POpeak (W)*	*Vo_2peak (L/min)*	*MMT Sum Score*	*HHD (N)*	*FVC (%)*	*FEV_1 (%)*
Discharge	49 (38 to 59)	1.13 (1.03 to 1.24)	51 (47 to 54)	1935 (1684 to 2186)	76 (66 to 86)	81 (76 to 86)
Δt1–t3*	−22 (−28 to −15)	−0.18 (−0.29 to −0.07)	−6 (−9 to −4)	−642 (−850 to −434)	−14 (−22 to −7)	−10 (−15 to −5)
Δt2–t3†	−10 (−15 to −5)	−0.08 (−0.19 to 0.02)	−3 (−5 to −1)	−379 (− 559 to −199)	−7 (−14 to 0)	−7 (−11 to −2)
Δt3–t4‡	6 (−2 to 14)	0.22 (0.08 to 0.37)	0.1 (−1.1 to 1.4)	135 (−53 to 323)	12 (5 to 18)	2 (−1 to 6)
Sex§	−14 (−20 to −7)	−0.35 (−0.48 to −0.23)	n.s.**	−575 (−742 to −408)	n.s.	n.s.
Age	− 0.3 (−0.5 to −0.1)	n.s.	0.01 (−0.06 to 0.09)	−7 (−13 to −1)	0.16 (−0.05 to 0.37)	n.s.
Level ‖	11 (7 to 15)	0.23 (0.11 to 0.35)	4 (2 to 5)	348 (215 to 481)	6 (1 to 10)	2 (−3 to 8)
Complete¶	n.s.	n.s.	n.s.	99 (25 to 173)	−5 (−8 to −2)	−1 (−5 to 3)
Sex * t1–t3 #	6 (1 to 12)	n.s.	n.s.	154 (34 to 274)	n.s.	n.s.
Sex * t2–t3 #	4 (0 to 9)	n.s.	n.s.	132 (20 to 244)	n.s.	n.s.
Sex * t3–t4 #	−1 (−7 to 5)	n.s.	n.s.	−51 (−167 to 65)	n.s.	n.s.
Age * t1–t3	0.2 (0.02 to 0.3)	n.s.	−0.01 (−0.06 to 0.04)	4 (0.1 to 8)	0.09 (−0.09 to 0.27)	n.s.
Age * t2–t3	0.1 (−0.03 to 2.4)	n.s.	0.01 (−0.02 to 0.05)	3 (−1 to 7)	0.09 (−0.08 to 0.26)	n.s.
Age * t3–t4	−0.1 (−0.3 to 0.1)	n.s.	0.04 (0.01 to 0.06)	−1 (−5 to 3)	−0.23 (−0.39 to −0.08)	n.s.
Level * t1–t3	n.s.	−007 (−0.19 to 0.05)	6 (4 to 7)	138 (11 to 265)	n.s.	5 (0.3 to 10)
Level * t2–t3	n.s.	0.01 (−0.11 to 0.13)	2 (1 to 4)	107 (−7 to 221)	n.s.	4 (−0.5 to 8)
Level * t3–t4	n.s.	−0.20 (−0.36 to −0.04)	−1 (−2 to −0.5)	−6 (−129 to 117)	n.s.	−2 (−5 to 2)
Complete * t1–t3	n.s.	n.s.	n.s.	n.s.	n.s.	−6 (−11 to −1)
Complete * t2–t3	n.s.	n.s.	n.s.	n.s.	n.s.	1 (−4 to 6)
Complete * t3–t4	n.s.	n.s.	n.s.	n.s.	n.s.	1 (−3 to 5)

All results are regression coefficients (β) and 95% confidence intervals (CIs) for the model after backward elimination. The regression coefficients represent the change in outcome associated with an increase in the independent variable of 1 unit. *The difference in physical capacity between the start of active rehabilitation and discharge; †The difference between t2 and discharge; ‡The difference between discharge and 1 year after discharge. §0 = men; 1 = women; ‖0 = tetraplegia; 1 = paraplegia; ¶0 = incomplete; 1= complete. # Interaction terms are represented by the 2 terms joined by asterisks. That is, sex by t1–t3 represents the relation between sex and the change in outcome during inpatient rehabilitation; sex by t2–t3 represents this relation between t2 and discharge; and sex by t3–t4 represents this relation between discharge and 1 year after discharge. **Association not significant (n.s.) and not included in the model.

Table 3 Data on the longitudinal relation between the components of physical capacity

Independent Variable	*POpeak (W)*	*Vo_2peak (L/min)*
Discharge	−3.5 (−30 to −17.1)	0.12 (−0.09 to 0.32)
Δt1−t3*	−3.8 (−5.9 to −1.7)	−0.07 (−0.13 to −0.01)
Δt2−t3†	−0.5 (−2.5 to 1.4)	−0.01 (−0.07 to 0.05)
Δt3−t4‡	0.7 (−2.3 to 3.6)	0.04 (−0.04 to 0.12)
Sex§	n.s.¶	−0.13 (−0.24 to −0.02)
Level‖	7.8 (4.9 to 10.6)	n.s.
Vo_2peak (L/min)	29.3 (25.8 to 32.7)	n.e.¶
HHD (N)	0.0087 (0.0057 to 0.0117)	0.0004 (0.0003 to 0.0005)
FVC (%)	0.09 (0.04 to 0.14)	n.s.
FEV_1 (%)	n.s.	0.0039 (0.0021 to 0.0058)

All results are regression coefficients (β) and 95% CIs for the model after backward elimination. *The difference in physical capacity between the start of active rehabilitation and discharge. †The difference between t2 and discharge. ‡The difference between discharge and 1 year after discharge. §0 = men; 1 = women; ‖0 = tetraplegia; 1 = paraplegia. ¶Association not significant (n.s.); independent variable not entered (n.e.).

associated with the POpeak. For example, an increase in strength of 100N was associated with an increase in POpeak of .87W (regression coefficient, .0087, multiplied by 100N) (see table 3). Sex, the HHD score, and percentage of FEV_1 were significantly associated with the Vo_2peak.

Discussion

Change in the Physical Capacity During and After Inpatient Rehabilitation

In accordance with Hjeltnes,[131] the increase in physical capacity is suggested to be greater during the early phase of inpatient rehabilitation than at a later stage (see figs 1−3). The fast recovery at the beginning of rehabilitation could be attributed to the start of the learning and training process, but also to natural recovery and the recuperation from trauma and complications.

In contrast to previous suggestions,[29,40] the improvement found in Vo_2peak, muscle strength, and respiratory function after discharge from inpatient rehabilitation suggests that the physical activity level during everyday life and during possible outpatient rehabilitation or (sporting) activities was sufficient to improve these components of physical capacity in the present study population. Future analysis of the association between outpatient rehabilitation or physical activity, and the level of physical capacity is required.

Vo2peak and POpeak. During inpatient rehabilitation the POpeak and Vo2peak improved 41% and 24% (increase in score as a percentage of score at t1, as calculated with basic model), respectively, which is within the range reported by others.[49,69]

The relatively greater improvement in POpeak as compared with the increase in Vo2peak could be attributed to an improved wheelchair propulsion efficiency, which may contribute to an increase in POpeak.[25,133,140] In contrast to other studies,[57,141] the POpeak did not change significantly after inpatient rehabilitation. A reason for this could be that the wheelchair configuration has an influence on the POpeak.[141] One year after discharge, subjects are expected to be trained in the use of their own wheelchair, and the compulsory use of a research wheelchair (instead of a private well-adapted wheelchair) at all measurement times may have underestimated the change in POpeak in our study.

Strength of the Upper Extremity. In our study population the MMT improved 7% and the HHD score 20% (increase in score as a percentage of the score at t1) during inpatient rehabilitation. Hjeltnes and Wallberg-Henriksson[69] reported a larger relative change in the MMT score, however, they reported only on subjects with tetraplegia. In our study population the subjects with tetraplegia improved more than those with paraplegia, therefore the results for our subjects with tetraplegia are comparable to previous findings.[69] The MMT score in our subjects changed less than the HHD score, probably because the MMT is limited in its ability to show a continued increase once a muscle group has reached a grade 4 or 5.[21,65,66]

Respiratory Function. The improvement we found during inpatient rehabilitation, was similar to findings by Liaw et al,[105] and may be attributed to natural recovery, but also to a rehabilitation program that includes endurance training which may positively influence respiratory function.[102,109,128] To date there are no known longitudinal data, which support the significant improvement in respiratory function found after discharge. Other studies reported a decrease in respiratory function with an increase in time postinjury,[99] or found no change in respiratory functioning 1 year after injury.[142] However, differences in design hamper a valid comparison with these studies.

Relation Between the (Change in) Physical Capacity and Personal And Lesion Characteristics

Age. The decrease in POpeak and HHD with an increase in age, was in agreement with cross-sectional studies.[12,99,143] However, to date no prospective study has reported the finding that older subjects showed less improvement in these components than younger subjects.

Sex. The relation found between gender and the (change in) HHD score, could be attributed to the relatively small functional muscle mass in women, and may have contributed to the reduced improvement in POpeak in women during inpatient rehabilitation.[144]

Level of the lesion. The influence of the level of the lesion on the components of physical capacity was in agreement with previous studies which have more specifically shown a reduction in physical capacity with an increase in affected segments.[12,92,98,99] The relatively large improvement in $\dot{V}O_2$peak, muscle strength and percentage of FEV_1 in our subjects with a tetraplegia was possibly the result of both training and the recovery of partially denervated segments, whereas the improvement in paraplegia was more the result of training. Dallmeijer et al[57] did not find this difference in recovery, which may partly be explained by the fact that the subjects with a tetraplegia in their study had relatively more musculoskeletal complaints than their subjects with a paraplegia.

Completeness of the lesion. The lower HHD score found in our subjects with an incomplete lesion (compared with those with a complete lesion) does not seem logical, and does not coincide with findings by Dallmeijer et al,[38] but could be attributed to our study population. Because we focused on wheelchair-dependent subjects, the relatively well-performing subjects with an incomplete lesion were excluded. Additionally, the inclusion of only those subjects able to perform the tests would have excluded poorly performing subjects with a complete lesion. This selection may have given a distorted picture of the difference in performance between the two groups.

Relation Between the Different Components of Physical Capacity

To date no other study has assessed the relations between the components of physical capacity on a longitudinal basis. In agreement with the present findings, correlation studies showed that both the $\dot{V}O_2$peak and muscle strength were related to the POpeak, and that muscle strength was related to the $\dot{V}O_2$peak.[12,25,129,144] Although the relation was significant in the present study, a relatively large (compared with the initial score) increase in respiratory function was associated with a relevant change in POpeak or $\dot{V}O_2$peak. Janssen et al[144] suggested that the different components of physical capacity are limited by the actual active muscle mass and that strength training programs may improve POpeak and $\dot{V}O_2$peak. Our findings seem to support this suggestion, but have to be interpreted with caution as complete causality cannot be established with our study's design.

Limitations

The methodology of the study had some limitations. First, the reported level of physical capacity may have been overestimated because the tested subjects represented a positive selection of all persons with SCI: they had survived the critical period after injury and were not limited by (cardiovascular or musculoskeletal) complaints. Second, there was an increase in the proportion of subjects able to perform the maximal aerobic exercise test and muscle strength assessments over time, which probably reflected an improvement in functional status of these additional subjects. This was not necessarily revealed by an improvement in the results and, therefore, the improvement in these components may have been underestimated. Third, because the subjects able to perform the tests varied for each component of physical capacity, the results of each component could reflect the performance of different subgroups.

The results on muscle strength of the upper extremity have to be interpreted with caution. By summing the scores, information about the change in strength of specific muscle groups could be lost. The MMT score was chosen because it is widely used in the clinical setting; however, it is an ordinal, subjective scale with each increase in grade representing a different increase in strength.[21] To facilitate the collection of reliable data, a standardized protocol was used to describe the procedure, and experienced research assistants received training both prior to and during the study period. The HHD score is presented by a valid and reliable continuous scale, but it has some restrictions: in the assessment of the wrist extensors its reliability is limited, and it does not cover the lower ranges of strength.[63,66,145,146] The development of new manageable equipment to measure muscle strength through all ranges and for all muscle groups seems important.

Conclusions

We found positive changes in the in the different components of physical capacity both during and after inpatient rehabilitation. The continued improvement after discharge was contrary to our expectations and illustrates that it is worthwhile to regularly assess the physical capacity of persons with SCI after discharge. It is also important to create optimal conditions (eg, educational programs and training facilities) to facilitate further improvement. The results demonstrate that subpopulations show different changes in physical capacity. Specific training and follow-up programs should explore these differences in order to help each patient develop his or her maximal potential physical capacity. The relationships found between the different components of physical capacity suggest that training one component could contribute to the improvement of other components, but this must be confirmed by intervention studies.

Suppliers (a) Angio Lode Ergometer; Lode BV, Zernikepark 16, 9747 AN Groningen, The Netherlands; (b) MicroFET; Biometrics Europe BV, Kabelstraat 11, 1322 AD Almere; (c) Jaeger Toennies, Nikkelstraat 2, 4823 AB Breda, The Netherlands, (d) MlwiN version 1.1; Centre for Multilevel Modelling, Graduate School of Education, University of Bristol, 35 Berkeley Sq, Bristol, BS8 1JA, UK.

4

Prognostic models for physical capacity at discharge and 1 year postdischarge from rehabilitation in persons with spinal cord injury

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Abstract

Objective: To develop prognostic models for the physical capacity at discharge and 1 year after discharge from inpatient rehabilitation in persons with spinal cord injury (SCI).
Methods: Inception cohort at 8 Dutch rehabilitation centers. The data collected at start of rehabilitation (n=104), at discharge (n=81), and 1 year later (n=74) were used to make prognostic models. Physical capacity was determined on these occasions by the endurance capacity (peak oxygen uptake – VO_2peak; in L/min – and peak power output – POpeak; in watts) during a maximal exercise test, by arm muscle strength, and by respiratory function. Multiple regression models either with, or without prior outcome, evaluated subject, lifestyle, and lesion-related predictors.
Results: Only start VO_2peak contributed to the prediction of discharge VO_2peak (R^2=.51). Discharge VO_2peak alone contributed to its prediction 1 year later (R^2=.75). Start POpeak, sex, age, and level of lesion contributed to discharge POpeak (R^2=.73). Discharge POpeak, hours of employment before injury, and level of lesion contributed to POpeak 1 year later (R^2=.81). Models without prior outcome explained less variance. Education, employment, body mass index, not smoking, and stabilization of spine positively contributed to endurance capacity. Muscle strength was well predicted (R^2 range, .68−.84). Without prior outcome, respiratory function was poorly predicted.
Conclusions: Because prior outcome contributed to an accurate prediction, the early assessment of physical capacity is important when establishing prognoses. Although their accuracy warrants caution, models could complement clinical expertise when informing patients of expected physical outcome, and identifying those at risk of a low physical capacity.

Introduction

After spinal cord injury (SCI), there are several reasons why the prediction of physical capacity, defined as the ability of muscles and the cardiorespiratory system to maintain a certain level of activity,[17] is important. First, the prediction of physical capacity allows clinicians to estimate prognoses. With this knowledge they can inform patients, family, and caregivers about the possible consequences of the lesion.[121,147] Second, the prediction of physical capacity at discharge may provide rehabilitation goals.[148] Third, prognoses of outcome 1 year after discharge may indicate the necessity of outpatient training, assistive devices and other postdischarge care.[149,150] Finally, prognoses of physical capacity partly indicate functional consequences, the expected level of well-being, and those at risk of complications.[9,46,59] In summary, during and after spinal cord rehabilitation insight into the expected physical and functional capacity could help set realistic goals, target screening and interventions, plan postdischarge care, and justify follow-up visits.

Previous studies have assessed predictors of physical capacity, but had methodologic limitations. Most were cross-sectional or combinations of cross-sectional and longitudinal associations and were, therefore, not strictly predictive.[36,60,147,151] Furthermore, the prognostic models that were made had different shortcomings.[152,153] First, the outcome measure may have been limited by a ceiling effect, which hampered the prediction of outcome at a later phase of recovery.[121,148,153] Second, often one component of physical capacity was investigated, whereas the simultaneous assessment of different aspects (eg, endurance capacity, muscle strength, respiratory function) may more specifically indicate the required treatment strategy.[17,153] Furthermore, because most persons with SCI are wheelchair users, the endurance capacity (ie, the peak oxygen uptake (VO_2peak) and peak power output (POpeak) during a wheelchair exercise test) is related to functioning. Therefore, the endurance capacity may give a more valid indication of functional prognoses than would muscle strength alone.[33,133] Third, earlier studies did not always report the prediction accuracy of models.[34] The accuracy of the model, that is, whether the predicted outcome corresponds with the observed outcome, partly determines its clinical relevance.[41,154]

The rehabilitation of patients with SCI would not only benefit from an accurate prediction of outcome, but also from the identification of modifiable predictors. Unfortunately, most known determinants of physical capacity, like age, sex and level of the lesion, can be taken into consideration, but are not changeable.[60,151] Some modifiable aspects of lifestyle (eg, smoking or alcohol use) and management (eg, stabilization of the spine) were found to be associated with physical capacity.[36,46,124,141,155,156] However, causality cannot be established from the available cross-sectional data for those with SCI. If we could demonstrate that giving up smoking, increasing participation in employment, increasing sport activity, moderating alcohol or dietary intake, and stabilizing the spine (by surgical fixation, or wearing a halo or corset) predict a favorable outcome, we might have means to enhance physical capacity during an early phase of recovery.

The aim of this study was to develop prognostic models for 4 aspects of physical capacity (ie, VO_2peak, POpeak, arm muscle strength, respiratory function) in wheelchair-dependent subjects with SCI. We aimed to assess the contribution of both modifiable (smoking, alcohol consumption, body mass index [BMI], stabilization of spine) and not modifiable characteristics (age, sex, education, employment, level of the lesion) at the start of rehabilitation in predicting physical capacity at discharge, and the contribution of these characteristics at discharge in predicting outcome 1 year after discharge from inpatient rehabilitation.

Methods

Participants

This study was part of the Dutch research program "Physical Strain, Work Capacity and Mechanism of Restoration of Mobility in the Rehabilitation of Persons with an SCI." Between 2000 and 2005, the 8 participating rehabilitation centers admitted a total of 387 patients with SCI. Patients were eligible for inclusion if they were wheelchair dependent, were between 18 and 65 years of age, had enough comprehension of the Dutch language to understand the purpose of the study and had no progressive disease or psychiatric condition.[151]

All subjects followed a regular inpatient rehabilitation program at specialized spinal cord units. Clinicians at these units largely provide their care according to guidelines supported by the Dutch Flemish Spinal cord Society.[3] Although, this society recommends patients to visit these specialized centers for outpatient follow-up or training,[3] some subjects visited these centers, whereas others visited an outpatient clinic closer to their homes. The medical ethics committee approved the experimental protocol, and prior to participation all subjects gave a written informed consent.

Procedure

Data were obtained at the start of active rehabilitation, when the subject began functional, endurance, and strength training in the wheelchair. The start of active rehabilitation was marked by the moment when the subject could to sit in a wheelchair for at least 3 hours at a time. Subsequently, data were obtained at discharge and 1 year after discharge from inpatient rehabilitation.[151] Prior outcome was used to predict physical capacity at follow-up. Therefore, subjects were included if their physical capacity could be assessed on at least 2 occasions; either both at the start of rehabilitation and at discharge (when predicting discharge outcome), or both at discharge and 1 year later (when predicting outcome 1 year after discharge). To optimize the quality of the data, a standardized protocol was followed, whereby 1 research assistant was responsible for the data collection at each rehabilitation center. Furthermore, all 8 research assistants were experienced rehabilitation professionals, who received training and instructions both before and during the study program. Additionally, the equipment (treadmill,[a] Oxycon Delta,[b] handheld dynamometer[c]) was calibrated before use, and the same equipment was used at subsequent assessments.

Physical Capacity

The endurance capacity was determined by the VO_2peak and the POpeak during a graded maximal wheelchair exercise test on a motor driven treadmill. We asked subjects not to smoke or drink coffee or alcohol 2 hours before the test. Additionally, subjects were asked to void their bladder prior to the exercise test. Subjects started with 2 blocks of submaximal exercise, during which a suitable treadmill velocity was chosen for the graded maximal exercise test. After 2 minutes of rest, the maximal exercise test started. Subjects were encouraged to keep up the speed of the treadmill while its inclination was increased .36° every minute. Finally, the test stopped when the subject was completely exhausted, or could no longer keep up the speed of the treadmill.[133,151] The VO_2peak (in L/min) was defined as the highest value of oxygen consumption recorded during 30 seconds. The POpeak (in watts) was determined from the velocity of the treadmill belt and the result of a separate wheelchair drag test.[27] It was defined as the power output at the highest inclination that the subject could maintain for at least 30 seconds.

The strength of 10 muscle groups (shoulder abductors, internal and external rotators, elbow flexors and extensors) was determined with the handheld dynamometer for those muscles with a strength of at least grade 3 during manual muscle testing.[119,151] Subsequently, the maximum force (in newtons) of the muscle groups was summed.[151] Sum scores were only calculated if strength could be determined in these 10 muscle groups. Respiratory function was determined from a standardized lung function test.[137] The forced expiratory volume per second (FEV_1) was expressed as a percentage of the volume expected for an age, sex, and height-matched able-bodied person.[137]

Predictors

Because at discharge or at follow-up 1 year after discharge, prior physical capacity may not be known, we made models with prior physical capacity, and models without prior physical capacity. For the models including prior outcome, physical capacity at the start was included when predicting discharge outcome, and physical capacity at discharge was included when predicting outcome 1 year after discharge. Additionally we determined the contribution of both modifiable and not modifiable characteristics.

Subject and Lifestyle Characteristics. At the start of rehabilitation, self-report information on date and place of birth, education, smoking, alcohol use, and hours of sport participation and employment prior to the injury were collected. The educational level was defined as follows: "low" for primary or prevocational practical education (score, 1); "middle" for lower secondary or vocational practical education (score, 2); and "high" for higher secondary or higher education (score, 3). If subjects (or 1 or both parents) were born outside The Netherlands, they were defined analogous to criteria used by the Central Bureau of Statistics, as not being of Dutch origin (not Dutch, 1; Dutch, 0). Although some subjects refrained from smoking during rehabilitation, most had started smoking again 1 year after discharge. Therefore, we defined a smoker based on cigarette use prior to the lesion (smoker, 1; nonsmoker, 0). Similarly, to determine alcohol use, subjects were asked whether they used beer, wine, or liquor prior to the lesion (alcohol use, 1; no alcohol use, 0). Subjects were asked how many hours a week on average they had participated in sports (team or individual), and how many hours a week they had been employed before the lesion. At each assessment, age and BMI (calculated as kg/m^2) were calculated.

Lesion Characteristics. At each assessment, the physician determined level and completeness of the lesion. Tetraplegia (score, 0) was defined as a lesion at or above the T1 segment, and paraplegia (score, 1) as a lesion below the T1 segment. A complete lesion (score, 1) was defined as motor complete, that is, American Spinal Injury Association (ASIA) grade A or B, and an incomplete lesion (score, 0) as motor incomplete, that is, ASIA grade C or D.[1] A physician consulted medical charts and self-report information to establish whether and how the spine had been stabilized (surgical stabilization, 1; no surgical stabilization, 0; and stabilization by means of halo or corset, 1; no halo or corset, 0).

Data Analysis

Subject, lifestyle, and lesion characteristics were summarized with descriptive statistics. Based on these characteristics, we compared the physical capacity between different subject groups with independent t tests. Potential predictors were cross-tabulated and if there was substantial correlation between characteristics (R>.80), only the characteristic with the highest correlation with physical capacity was included in a multivariate model.[157] Multiple linear regression analyses revealed several models predicting four aspects of physical capacity. Characteristics known at the start were included as independent variables when predicting physical capacity at discharge. Characteristics known at discharge were included as independent variables when predicting physical capacity 1 year after discharge.

For the first model, physical capacity at the start was included as an independent variable by forced entry (ie, it was included in the model first, regardless of its significance). Subsequently other characteristics (determined at the start of active rehabilitation) were included following the stepwise forward procedure. Therefore, the characteristic that explained most of the remaining part of the variance (ie, the variance not already explained by prior outcome) was included next. The analysis was repeated, and the characteristic remained included if it made a significant (P≤.05) contribution to the predictive power of the model. This procedure, of selecting a characteristic, determining its contribution and analyzing the power of the model, was repeated for all characteristics until a model with the highest predictive power for these characteristics remained. Subsequently, a separate model was made without physical capacity at the start, which, therefore, included the other independent variables following the aforementioned stepwise-forward procedure.

Similarly, we made prognostic models for the physical capacity one year after discharge. The physical capacity at discharge was included by forced entry, and other discharge characteristics were included following the stepwise-forward procedure. A separate model was made without physical capacity at discharge. For each model, the explained variance and the standard deviation (SD) of the residuals was given. Residuals are the differences between the observed and the predicted outcome. The residual SD portrays how accurately the model predicts outcome in this population and, therefore, partly determines how meaningful a model is in the general population.[41] All data were analyzed with SPSS.[d]

Results

Of the 387 patients with SCI admitted for rehabilitation during the study period, 225 were considered eligible for the research program. Because we made prognostic models, only those patients whose physical capacity was determined on 2 occasions were included in our study population. This meant that of the 104 subjects for whom we determined the POpeak at the start, 81 were included when predicting the POpeak at discharge. They had started their active rehabilitation 104±66 days postinjury. Seventy-

Table 1 Characteristics at the start and at discharge from rehabilitation as predictors of endurance capacity at discharge and 1 year after discharge, respectively

Subject or Lifestyle Characteristic	*Start (n=81)*	*Discharge (n=74)*
Age at start or discharge (y)	40±14	37±13
Men (%)	74	73
Not of Dutch origin (%)*	17	26
Employment before lesion (h/wk)†	34±22	32±21
Education (%): Low‡	38	35
Middle	36	28
High	26	37
Smoker before lesion (%)	46	47
Consumed alcohol before lesion (%)	79	73
BMI start or discharge (kg/m2)	23±4	23±4
Sports before lesion (h/wk)§	3±4	4±5
Lesion characteristic		
Paraplegia at start or discharge (%)	79	80
Complete lesion at start or discharge (%)	64	64
Surgical stabilisation of spine (%)	54	57
Halo or corset (%)	28	37

Values are mean ± SD or percentage. *Subject or at least 1 of parents born outside The Netherlands. †Mean hours per week employed before lesion. ‡"Low" is primary or prevocational practical education; "middle" is lower secondary or vocational practical education; "high" is higher secondary or higher education. §Mean hours per week participating in sports before lesion.

four subjects were included when predicting the POpeak 1 year after discharge. Their discharge took place 258±115 days postinjury. Table 1 presents their descriptive subject, lifestyle, and lesion characteristics.

The population included in the research program showed a similar distribution of these characteristics.[151,158] Of all patients admitted with SCI during the study period, however, relatively few (48%) had a complete lesion.[158] The number of subjects included when predicting different aspects of physical capacity at the 2 occasions did not coincide for several reasons. First, hindered by cardiovascular contraindications, limited wheelchair skills or complications, not all subjects completed a maximal exercise test on all 3 testing occasions.[151] Second, fewer subjects were included when predicting strength, because only those with reasonable strength in 10 arm muscle groups were included. Table 2 presents the mean physical capacity at each assessment both as a predictor and as an outcome. Table 3 gives the mean physical capacity found in several subject groups. The significance levels indicated in table 3 were based solely on one-to-one associations determined with independent t tests.

Tables 4 and 5 present results of the multiple linear regression analyses for physical capacity at discharge and 1 year later, respectively. To facilitate interpretation of these results, examples are given in the footnotes. For each aspect of physical capacity results of the model with, and the model without prior outcome are given.

Table 2 Physical capacity as Predictor or as Outcome

	Predicting physical capacity at discharge			Predicting physical capacity 1 year after discharge		
Variable Predictor	*n*	*Predictor (start)*	*Outcome (discharge)*	*n*	*Predictor (discharge)*	*Outcome (1 yr later)*
Vo2peak (L/min)	75	1.05±0.29	1.31±0.41	73	1.27±0.46	1.33±0.54
POpeak (W)	81	31±16	45±19	74	46±24	48±26
Arm muscle strength (N)	63	1534±503	1807±501	55	1756±481	1860±551
FEV_1 (%)*	113	77±23	87±20	93	87±20	90±20

Values are n or mean ± SD. *Expressed as percentage of the flow expected for an age, sex, and height-matched able-bodied person.

Table 4 tells us, for example, that the regression equation predicting discharge VO_2peak reads: 0.25±1.01* start VO_2peak. This means that only VO_2peak at the start contributed to the VO_2peak at discharge. Table 5 tells us that, again, only the discharge VO_2peak contributed to its prediction 1 year later. The POpeak at the start, sex, age, and level of the lesion predicted POpeak at discharge (Table 4). The discharge POpeak, hours of employment before injury, and level of the lesion contributed to the prediction of POpeak 1 year later (Table 5). Several not modifiable characteristics were identified as predictors of discharge outcome: age, sex, employment, education, and level of the lesion. These characteristics, together with ethnicity, also contributed to the prediction of outcome 1 year after discharge. Some modifiable predictors of discharge outcome were identified: BMI, smoking, and stabilization of the spine. Only BMI made a modifiable contribution to the prediction of outcome 1 year after discharge. Tables 4 and 5 also present the variance explained by each predictor in these multivariate models. They indicate that the variance in discharge outcome is explained mostly by prior physical capacity (variance explained, 51%-70%) (see table 4). The variance in physical capacity 1 year after discharge is even more so explained by outcome at discharge (variance explained, 74%-82%) (see table 5). Furthermore, level of the lesion, sex, and employment make relatively large contributions to the explained variance. To indicate the prognostic value of the models, the total explained variance (adjusted R^2) and the residual standard deviations are given.

Table 3 Physical capacity at discharge and 1 year after discharge as found in subject groups defined at the start and at discharge, respectively

	Vo_2peak (L/min)		*POpeak (W)*		*Arm Muscle Strength (N)*		*FEV_1 (%)*	
	discharge	year after discharge	discharge	year after discharge	discharge	year after discharge	discharge	year after discharge
Age at prior assessment								
<40 (y)	1.36±0.40	1.35±0.56	47±19	49±26	1981±531†	1961±556	85±18	88±18
≥40 (y)	1.21±0.42	1.25±0.47	40±20	46±26	1685±505†	1712±520	88±21	90±22
Sex								
Men	1.39±0.37†	1.39±0.52*	49±19†	52±26†	2049±474†	2096±497†	80±21	87±21
Women	1.04±0.41†	1.09±0.48*	29±12†	34±19†	1303±340†	1398±338†	83±23	83±22
Ethnicity								
Not Dutch	1.20±0.36	1.09±0.47	43±19	44±20	1821±374	1758±385	79±18	81±23
Dutch	1.31±0.42	1.37±0.54	44±20	49±27	1806±594	1842±601	83±23	87±21
Education‡								
Low	1.14±0.36†	1.19±0.39	38±20*	39±22*	1639±459	1746±545	80±21	82±22
Middle/high	1.39±0.42†	1.40±0.59	48±18*	53±26*	1845±557	1928±566	84±23	88±21
Employment before lesion (h/wk)								
≤16	1.10±0.32†	1.13±0.28*	35±15†	35±16†	1505±488†	1591±536*	80±25	82±24
>16	1.37±0.42†	1.38±0.57*	47±20†	52±26†	1935±544†	1941±544*	83±20	88±21
Level of lesion								
Paraplegia	1.34±0.428	1.37±0.54*	48±19†	52±25†	1985±517†	1910±566	89±19*	89±20
Tetraplegia	1.11±0.34*	1.10±0.42*	27±14†	27±17†	1468±392†	1608±470	81±19*	89±21
Surgically stabilized spine								
Yes	1.31±0.40	1.36±0.53	46±21	51±27	1885±533	1815±543	82±22	85±21
No	1.27±0.43	1.24±0.51	41±18	43±22	1705±580	1814±582	82±21	87±20

Halo or corset								
Yes	1.37±0.38	1.42±0.56	50±19	56±26*	1885±519	1886±553	85±22	86±20
No	1.26±0.43	1.24±0.50	42±19	42±24*	1770±579	1787±591	81±22	85±23
Smoking								
Smoker	1.19±0.39	1.22±0.52	38±19†	42±24	1803±560	1802±518	79±18	83±17
Nonsmoker	1.36±0.42	1.39±0.39	49±20†	52±26	1809±574	1843±603	84±24	88±25
Alcohol								
Some	1.31±0.42	1.33±0.55	44±20	49±26	1902±537†	1923±547*	82±22	85±22
None	1.22±0.41	1.23±0.46	41±20	42±21	1459±511†	1541±501*	82±21	89±20
BMI prior assessment								
Overweight§	1.29±0.46	1.31±0.46	45±21	43±26	1889±605	1791±525	86±25	87±25
Not overweight	1.29±0.40	1.32±0.56	44±19	49±25	1761±544	1821±592	80±20	85±20
Sports before lesion								
<3 (h/wk)	1.27±0.41	1.31±0.50	41±20	45±25	1756±522	1792±518	80±23	84±24
≥3 (h/wk)	1.33±0.41	1.32±0.56	47±19	51±26	1879±596	1889±651	84±20	88±18

Values are mean ± SD. Comparisons between subject groups made with independent *t* tests. *$P\leq.05$; †$P\leq.01$. ‡"Low" is primary or prevocational practical education; "middle" is lower secondary or vocational practical education; "high" is higher secondary or higher education. §BMI ≥25kg/m^2.

Table 4 Prognostic models for physical capacity at discharge: stepwise forward multiple linear regression analyses with predictors defined at start

	VO_2peak (L/min) (n=75)				*POpeak (W) (n=81)*				*Arm Muscle Strength (N) (n=63)*				*FEV_1 (%) (n=113)*			
	With Start VO_2peak		Without Start VO_2peak		With Start POpeak		Without Start POpeak		With Strength at Start		Without Strength at Start		With Start FEV_1		Without Start FEV_1	
Independent Variable	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%
Constant	0.25±0.13		0.56±0.16		15±5		−2±11		882±124		667±254		24±5		91±3	
Start PC	1.01±0.12††	51	n.e.		0.80±0.08 ††	65	n.e.		0.57±0.07††	70	n.e.		0.72±0.05††	59	n.e.	
Sex*			0.40±0.10††	13	10±3††	5	20±3††	23	401±63††	9	674±73††	39				
Age (y)					−0.23±0.08**	2	−0.29±0.12	3	−8.08±1.90††	4	−12±3††	9				
Education†			0.13±0.05	5							100±44	3				
Employment‡													0.12±0.06	2		
Smoking§							−8±3	3							−10±4	5
BMI (kg/m^2)							1.20±0.43**	2			30±9**	4				
Lesion level‖			0.26±0.11	6	8±3	2	21±4††	20	177±69	2	456±83††	15				
Surgical stabilization													6±2	2		
Halo or corset#							8±3	4								
Accuracy	R^2=.51 RSD=.29		R^2=.24 RSD=.36		R^2=.73 RSD=10		R^2=.54 RSD=13		R^2=.84 RSD=203		R^2=.70 RSD=277		R^2=.63 RSD=12		R^2=.05 RSD=20	

$P \leq .05$ unless as indicated below. Abbreviations: n.e.: not entered; PC, physical capacity; RSD, residual standard deviation. *men=1; women=0. †1=low, 2=middle; 3=high. ‡Mean hours per week before lesion. §Smoker=1; nonsmoker=0. ‖Paraplegia=1; tetraplegia=0. ¶Stabilization of spine=1; no surgical stabilization=0. #Halo or corset stabilizing spine=1; no halo or corset=0. $^{**}P \leq .01$; $^{\dagger\dagger}P \leq .001$.

Table 5 Prognostic models for physical capacity 1 year after discharge: stepwise forward multiple linear regression analyses with predictors defined at discharge

	Vo2peak (L/min) (n=73)*				*POpeak† (W) (n=74)*				*Arm Muscle Strength (N) (n=55)*				*FEV_1 (%) (n=93)*	
	With Discharge VO_2peak		Without Discharge VO_2peak		With Discharge POpeak		Without Discharge POpeak		With Discharge Strength		Without Discharge Strength		With Discharge FEV_1	
Independent Variable	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%	β ± SE	%
Constant	0.04±0.09		0.78±0.16		−4±4		12±10		39±117		447±300		16±5	
PC at discharge	1.02±0.07 ¶	75	n.e.		0.86±0.06 ¶	79	n.e.		1.04±0.06 ¶	82	n.e.		0.86±0.05 ¶	74
Sex*							13±5	4			732±91 ¶	33		
Age (y)							−0.35±0.17	3			−17±4 ¶	7		
Ethnicity									−190±75	2	−383±112‖	5		
Education†											127±50	4		
Employment‡			0.01±0.00‖	9	0.20±0.07‖	1	0.48±0.11 ¶	15						
Lesion level§			0.32±0.14	5	8±4	1	30±6 ¶	20			568±102 ¶	12		
BMI (kg/m²)											46±12‖	7		
Accuracy	R^2=.75 RSD=.27		R^2=.14 RSD=.50		R^2=.81 RSD=11		R^2=.42 RSD=20		R^2=.84 RSD=223		R^2=.68 RSD=313		R^2=.74 RSD=10	

$P≤.05$ unless as indicated below. *men=1; women=0. †1=low, 2=middle; 3=high. ‡Mean hours per week before lesion. §Paraplegia=1; tetraplegia=0. ‖$P≤.01$; ¶$P≤.001$.

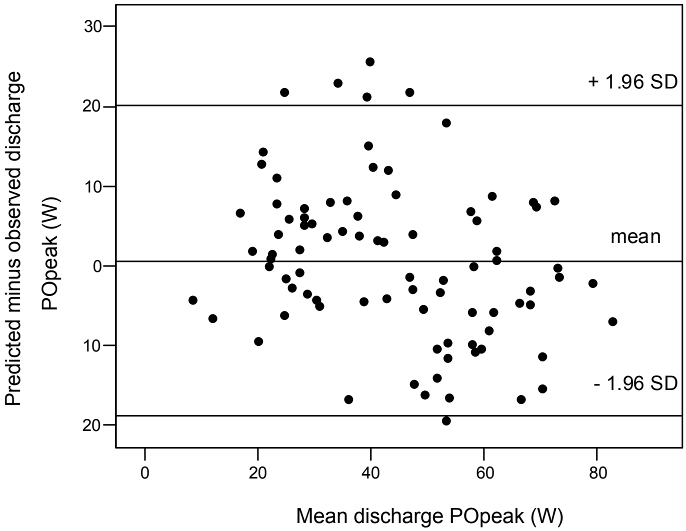

Figure 1 Bland-Altman plot illustrates the distribution of the differences between the observed and the predicted discharge POpeak.

Overall, POpeak and muscle strength were relatively well predicted, with explained variances ranging between 42% and 84%. Without prior outcome, VO_2peak and respiratory function were poorly predicted. The residual SD, which is a measure of the prediction accuracy of a model, described the association between the predicted and the observed outcome.[157] As an example, Figure 1 illustrates the association between the predicted and the observed discharge POpeak. This Bland-Altman plot depicts the distribution of the differences between the predicted and the observed discharge POpeak and shows that in this population the predicted POpeak may be 20W higher or lower than the observed outcome.

Discussion

Prognostic models revealed that prior physical capacity made an important contribution to the prediction of outcome, and identified both modifiable and not modifiable predictors. Considering the proportion of variance explained by our models, they compared favorably to those predicting physical capacity in different populations,[119,159] and to those predicting other health measures after SCI.[20,30,160,161] Our models are unique, because they were based on longitudinal data, reflected different aspects of physical capacity and included subject, lifestyle, and lesion related predictors. However, this hampers a constructive comparison with models predicting other outcome measures, in different populations with other predictors for several reasons. First, inherent differences in the predictability between outcome measures complicate a comparison of the accuracy of the models. Physical capacity is an objective measure of health following SCI, therefore, it may be more predictable than subjective measures such as life satisfaction.[17,30] At the same time, physical capacity may be influenced by natural recovery, training, motivation and concurrent disease,[17,149] which could make it less predictable than the ability to walk or quality of life, which are both stable during different phases of recovery.[150,10] Second, unique predictors (like level of lesion or stabilization of the spine) apply to those with SCI but are not generalizable.[9,119] Third, because a prognosis indicates that a predictor precedes the predicted in time, models based on cross-sectional data were not prognostic, further complicating comparisons.[36,141,154] Knowledge on the predicted physical capacity may provide objective information of a patient's expected functional status, which helps to evaluate symptoms, the effect of interventions and the necessity to refer the patient to postdischarge facilities.[121,154]

One must remember, however, that because the accuracy of prognostic models is limited,[41,154] they may only complement clinical expertise, and caution is needed when using them as decision tools in rehabilitation practice. Below we discuss the possible value of these prognostic models as informative guidelines, and in identifying those at risk of a low physical capacity.

Prior Physical Capacity as a Predictor of Outcome at Follow-Up

In agreement with others, prior outcome was the strongest predictor in our study,[30,34] which alone explained 51% to 82% of the variance. The finding that characteristics like level of lesion and sex were of little prognostic value (in addition to prior physical capacity), suggests that prior outcome may encapsulate the variance caused by these characteristics. Because knowledge of prior physical capacity seems essential in making an accurate prediction, and because it may summarize the influence of several subject, lifestyle, and lesion characteristics, we recommend that physical capacity be monitored regularly starting at an early phase of rehabilitation. Despite the strong association with prior physical capacity, a previous study fortunately showed that physical capacity did change during active rehabilitation and that some aspects continued to change after discharge.[151] In agreement with this study,[151] the current models suggested that changes in physical capacity partly depended on characteristics that were of prognostic value besides prior physical capacity, such as age, level of the lesion, and also employment, for example. Additionally, factors like rehabilitation or follow-up programs could have influenced changes in physical capacity. Our subjects followed a regular rehabilitation program, but unfortunately we did not have valid information on its contents. However, it would not have been rational to include rehabilitation characteristics, unknown at the start of active rehabilitation, in these prognostic models.

Without knowledge of prior physical capacity, its prediction proved challenging and models were less accurate. This difference was especially noticeable for the models predicting outcome 1 year after discharge. The predictive value of the investigated characteristics was less strong 1 year after discharge. It could be that after discharge other factors, not currently investigated (eg, housing, community care, social support) were associated with physical capacity. Therefore, future investigation of the influence of these factors seems necessary. In the meantime, we recommend that their possible influence receives attention at follow-up visits.[162]

Prognostic Models for Different Aspects of Physical Capacity

This study revealed relatively good prognostic models for the POpeak and arm muscle strength, which explained more variance as compared with those predicting VO_2peak and respiratory function. The POpeak may be influenced by a person's skills and efficiency. Therefore, it is more closely related to functioning than VO_2peak.[25] VO_2peak is related to organ function and, therefore, more influenced by complications.[163] Respiratory function was less predictable for several possible reasons. First, respiratory function was expressed as a percentage of the expected flow in an age, sex, and height-matched able-bodied person. Therefore, these characteristics were corrected for and could not contribute to the explained variance. Second, other not currently investigated predictors, such as comorbidity, may have contributed specifically to the variance in respiratory function. Third, relatively large differences in respiratory function between subjects may overshadow the associations with predictors within subjects.[41] Because a small proportion in variance of respiratory function was explained, the clinical relevance of these models is limited. However, the prediction of POpeak and muscle strength could complement clinical professional knowledge when informing patients on the outcome and when planning training and follow-up programs.

Prognostic Factors

Table 3 illustrated different levels of physical capacity in several subject groups, but these differences need to be interpreted with care, and multivariate models were needed to establish associations. The one-to-one associations found may have been caused by chance alone, because many differences were tested. Furthermore, these associations did not correct for possible confounders. As expected, the multivariate models showed that level of lesion and sex were important predictors of physical capacity.[12,119,124,153] However, these models also identified other predictors, which made small, but significant, contributions to the explained variance, some of which are modifiable.

Not surprisingly, smoking predicted a poor respiratory function, but the negative association found with the peak power output suggests that giving up smoking may lead to a more favorable physical capacity.[45,124] In the able-bodied population, moderate alcohol consumption is suggested to be cardioprotective, whereas the consumption of large quantities will have adverse health effects. A predictive effect of alcohol was not established in our multivariate models, and the influence of alcohol intake remains undecided.[45] Another study showed that alcohol use following SCI was similar to that of the able-bodied population, but revealed an increased incidence in alcohol abuse, which may negatively affect health.[164] Therefore, future research needs to focus on a more detailed investigation of the effect of alcohol use and abuse after SCI.

Unexpectedly, BMI was a positive predictor of physical capacity. However, as with other indicators of body composition, like skinfolds and abdominal circumference, it is difficult to interpret the BMI after SCI.[165] In an early phase of recovery, a low body mass may be attributed to a catabolic state following injury, concurrent pathology, or complications. Therefore, a low BMI may be negatively associated with physical capacity. In contrast, during a later phase of recovery, relative inactivity and altered metabolism and fat distribution may cause an increase in BMI to be negatively associated with physical capacity.[46,159] These mechanisms did not influence the association between BMI and physical capacity 1 year after discharge, but may become apparent at a longer follow-up period. Surprisingly, hours of sports did not contribute to the prediction of physical capacity.[9,12] It may be that sport participation changed after the lesion. Prospective data on sport participation, its barriers and its association with physical capacity are needed.[166] Contrary to others, our models revealed a positive predictive effect of both conservative and surgical stabilization of the spine.[34,155] Perhaps the immobilization period is shorter after surgical stabilization, resulting in an early start of rehabilitation and insignificant deconditioning.[3] Because stabilization seemed to have no prognostic value after discharge, its influence may be restricted to an early phase of recovery.

Not modifiable predictors are valuable because they may identify those at risk of a low physical capacity. In the present study, more hours of paid employment before injury positively predicted physical capacity especially after discharge, which may correspond with findings that those previously employed had a shorter inpatient stay and that physical capacity was associated with employment after injury.[59,147,160] Perhaps those previously employed have greater physical or mental learning skills, which may enable them to adapt to wheelchair skills more easily, or may provide them with opportunities for re-education. Therefore, those previously employed may return to a more active lifestyle through being employed after discharge. Further prospective data are needed to establish these proposed explanations.[167] Although no significant colinearity existed between sex and hours of employment, and although both predictors contributed to the explained variance simultaneously, it is difficult to rule out that the predictive effect of employment was mediated through a covariate like sex.[147,157] However, the promising outcome for those in the habit of working indicates the importance of vocational rehabilitation, and clinicians need to create and evaluate opportunities to return to employment after discharge from rehabilitation.[167]

Foreign subjects tended to have a lower level of different aspects of physical capacity. Not being Dutch negatively predicted strength and its recovery during the year after discharge. Studies of the Model Spinal Cord Injury Systems showed similar associations with ethnicity, and their authors attributed the differences to ethnic minorities being at an economic disadvantageous position and having less access to resources.[160,168] In this study, foreign subjects originated from different countries, had diverse cultural backgrounds and their comprehension of the Dutch language differed. Therefore, our results cannot be generalized, and are difficult to compare with the abovementioned American studies.

The positive predictive value of education has been reported previously.[34,47] However, this seems contradictory to the finding that the less educated had a shorter inpatient rehabilitation, as reported by Eastwood.[160] Hypothesizing, it might be that those with lower level of education did physically more demanding work before injury, which may have made it easier to learn (wheelchair) skills. As a result, they may have been discharged sooner than those previously holding, for example, desk jobs. In contrast, those with a higher level of education may have had more knowledge of how (and means) to lead a healthy lifestyle, which may have positively contributed to their physical capacity. Education is important in the prevention of complications and in the maintenance or improvement of physical and functional capacity. Therefore, we recommend that clinicians give complete information to all patients, not just to those who show an interest in a healthy lifestyle.

Limitations

Some methodological limitations need to be considered. First, the selected population limits the generalizability of our data. We included patients who required a wheelchair for daily functioning, which explains why a relatively large number of subjects with a complete lesion were included.[158] However, in comparison with other studies, which focused mainly on young male athletes with a paraplegia,[12,163] our data seem to better reflect outcome in a general population with SCI.[158] Ideally the difference between the predicted and the observed outcome is as small as possible. This brings us to a second limitation, because, as is illustrated in figure 1, we found discrepancies between these values.[157] These discrepancies could be even larger if the models were cross-validated, that is, if we compared the predicted outcome based on these models with the observed outcome in another SCI population. Therefore, future cross-validation with other populations seems essential before the clinical validity of the prognostic models can be established. The third consideration is the variance that could not be explained by the models. Factors not currently investigated (such as motivation, complications, rehabilitation or training, living conditions and social support) may all have contributed to the level of physical capacity. In summary, some caution is needed these models are used as clinical guidelines. We do not recommend these models as solitary clinical decision tools; they should only be used in combination with clinical expertise and knowledge of the individual patient.

Conclusions

This study revealed prognostic models for several aspects of physical capacity, which showed that POpeak and arm muscle strength were relatively well predicted in comparison with VO_2peak and respiratory function. Because the prediction of physical capacity is more accurate with prior outcome, the assessment of physical capacity at an early phase of recovery is recommended. Furthermore, the systematic monitoring of physical capacity may help set realistic targets during and after inpatient rehabilitation. Besides estimating prognoses, the presented models provide insight into the possible positive predictive effect of not smoking, employment and stabilization of the spine. Caution is warranted concerning the accuracy of the models, but in combination with clinical expertise and knowledge of the individual patient, they may provide meaningful information of a patient's expected physical outcome, which could help to evaluate symptoms, the effect of interventions and the necessity to refer the patient to postdischarge facilities.

Suppliers (a) Bonte Technology BV, Ampèrestraat 25b, 8013 PT Zwolle; (b) Jaeger Toennies, Nikkelstraat 2, 4823 AB Breda; (c) MicroFET; Biometrics Europe BV, Kabelstraat 11, 1322 AD Almere, The Netherlands, (d) Version 12.0.01; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.

5

Complications following spinal cord injury: occurrence and risk-factors in a longitudinal study during and after inpatient rehabilitation

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Abstract

Objective: To assess the occurrence and risk factors of complications following a spinal cord injury during and after inpatient rehabilitation.
Methods: Multicentre prospective study, which included persons with a spinal cord injury admitted to specialized rehabilitation centers. Complications were registered at the start of active rehabilitation (n=212), three months later (n=143), at discharge (n=191) and one year after discharge (n=143).
Results: Multilevel random coefficient analyses revealed that complications were common following a spinal cord injury. Most subjects reported neurogenic and musculoskeletal pain, or had spasticity at each assessment. The occurrence of complications did not change significantly. Therefore, during the year after discharge complications remained common. For example, urinary tract infections and pressure sores affected 49% and 36% of the population, respectively. The degree of pain decreased, whereas the degree of spasticity increased significantly during inpatient rehabilitation. Overall, an increase in age, increase in body mass index, a traumatic lesion, a tetraplegia and a complete lesion exposed to a risk of complications.
Conclusion: Complications are common following a spinal cord injury. They need specific attention after discharge from inpatient rehabilitation and within subpopulations.

Introduction

A spinal cord injury (SCI) is often followed by complications, which add to the detrimental effect that loss of motor, sensory and autonomic function have on a person's health, social participation and quality of life.[11,47,162,169] There is some debate on the operational definition of complications, on whether complications are strictly causally related to the SCI and on how to distinguish complications from co-morbidity.[19] However, a condition may only be defined as being a complication if it has a chronological relation with the SCI, i.e. the SCI needs to precede the condition. Additionally, although this condition may also occur in the general population, one assumes those with SCI to be at increased risk.[19]

The range of conditions following an SCI can be categorized into neurological consequences and secondary complications. Neurological consequences result from the injury itself, following interruption and decentralization of the nervous system, and may be regarded as sequelae to the injury.[170] Examples are neurogenic pain or spasticity; the latter being part of the upper motor neuron syndrome.[44,171] Secondary complications follow the ensuing loss of pulmonary function, loss of bladder control or reduced mobility. Examples are pulmonary infections and pressure sores.[11,172,173] Neurological consequences and secondary complications behave similarly; they often require, and react to, treatment, and they affect the rehabilitation process. Therefore, we refer to them all as complications of SCI.

Complications have a considerable impact on those with SCI. A high incidence in complications is associated with a lower level of health-related aspects such as physical capacity, activities and functional outcome.[11,13,47,162] Complications may interfere with the start of active rehabilitation, can form a disappointing set-back during rehabilitation, and frequently lead to rehospitalization.[14,44,174] Additionally, complications are an important cause of mortality following an SCI.[19,126] In order to optimize the individual rehabilitation process and outcome, it is important to timely predict and prevent complications or to recognize and treat complications them.[19]

Previous studies have investigated complications following SCI and their risk-factors. They illustrated the association between subject and lesion characteristics and the occurrence of complications.[11,42,171,175] They also showed that the diversity and the occurrence of complications changed over time.[11,172,173,176] However, these studies have limitations. Firstly, most studies were cross-sectional, whereas a longitudinal study in which data are collected prospectively could better establish which factors actually lead to complications. Secondly, in most studies only 1 or a few complications were assessed, whereas the simultaneous investigation of a range of complications will give insight into their diversity, and into how their occurrences compare. Therefore, we have formulated the following three research questions:

(1) What is the occurrence of complications (pain, spasticity, hypotension, autonomic dysreflexia, pressure sores, urinary tract infections, pulmonary infections, venous thromboembolism, edema, heterotopic ossification, other cardiovascular disease and other musculoskeletal complaints) in subjects with SCI during and after inpatient rehabilitation? (2) What is the degree of pain and spasticity and does this change during and after inpatient rehabilitation? (3) What are risk-factors of these complications?

Method

The present study was part of the Dutch research program on the restoration of mobility in persons with an SCI. Subjects admitted to 1 of the 8 participating rehabilitation centers between May 2000 and September 2003 were included if they met eligibility criteria. During their first period of inpatient rehabilitation, they were eligible for inclusion if they were between 18 and 65 years of age, were wheelchair-dependent, had sufficient comprehension of the Dutch language to understand the purpose of the study and did not have a progressive disease or a psychiatric condition interfering with constructive participation.

Design

Subjects were assessed 4 times according to a standardized protocol: at the start of active inpatient rehabilitation, defined as the moment when the subject was able to sit in a wheelchair for ≥ 3 h (t1), 3 months later (t2), at discharge (t3), and 1 year after discharge from inpatient rehabilitation (t4). If the subject was discharged within 1 month after t2, the assessment at t2 was considered a 'discharge' assessment, and was included in the analyses of t3. The Medical Ethics Committee approved the protocol and prior to participation all subjects gave a written informed consent.

Complications

Based on the subject's history and medical chart, the physicians registered each complication on a standardized list. At t1, complications then present or that had occurred since admission to rehabilitation were registered. At t2 and t3, complications then present or that had occurred since t1 and t2, respectively, were registered. At t4, complications then present or that had occurred since discharge were registered. The occurrence of a complication was registered as follows: 0 = no complication; 1 = presence or history of this complication. Other cardiovascular disease and musculoskeletal complaints were grouped, and included conditions such as myocardial disease and bursitis occurring after the lesion, respectively.

If the subject reported having pain the research assistants completed a standardized list addressing the nature of the pain. We defined musculoskeletal pain as nociceptive pain originating from bone, joint or muscle structures following trauma or overuse.[44] Thirteen locations (on the upper and lower limbs, the neck and the back) were assigned severity scores with a 5-point Likert-scale (1-5; ranging from 'not severe' to 'very severe'), and frequency scores (1-3; ranging from 'once a week or less' to 'more than 3 times a week'). We defined neurogenic pain as at level or below level pain originating from spinal cord ischemia or trauma.[44] Hence, nine neurogenic pain characteristics (other pain, numbness, itching, tingling, cold, warm, perspiration, girdle zone pain and phantom feeling) were assigned frequency and severity scores. A sumscore was made for the product (severity × frequency) of these locations or pain characteristics. Therefore, sumscores ranging from 1 to 195, or from 1 to 135 could be attained for musculoskeletal or neurogenic pain, respectively.

Additionally, the research assistant determined the presence of spasticity, defined as the velocity dependent increase in muscle tone combined with exaggerated reflexes, through a direct standardized examination.[44] The left and right hip adductors, knee flexors and extensors, ankle extensors, and elbow flexors and extensors were examined. In the presence of spasticity, each muscle group was assigned severity scores ranging from 1 to 3 ('1': catch; '2': clonus < 5 beats; '3': clonus ≥ 5 beats). These scores were summated, which gave a sumscore ranging from 1 to 36.

Risk-factors

The associations with the following potential risk-factors were assessed: age, gender, smoking status (smoker vs. non-smoker), body mass index (BMI: body mass in kilograms divided by height in meters squared; kg/m^2), the cause (traumatic vs. non-traumatic), the level and the completeness of the lesion. Although some smokers refrained from smoking during inpatient rehabilitation, nearly all resumed smoking after discharge. Therefore, subjects were defined as being a smoker if they smoked prior to the injury. Tetraplegia was defined as a lesion at or above the first thoracic segment, and paraplegia as a lesion below the first thoracic segment. A complete lesion was diagnosed in the absence of sensory or motor function in the sacral segments, i.e. American Spinal Injury Association (ASIA) category A. An incomplete lesion was defined as ASIA categories B, C or D.[1]

Statistics

Random coefficient analyses (MlwiN version 1.1; Centre for Multilevel Modelling, Institute of Education, London, United Kingdom) were used to estimate the occurrence of complications, the change in the degree of pain and spasticity, and the association with risk-factors.[138,139] The longitudinal aspect of the study is enhanced by the fact that the analyses can be done with missing values and varying group composition. Therefore, all assessments can be included in the analyses, which gives a more accurate description, compared with repeated measurements analysis of variance, for example, of complications and their risk-factors at each assessment time.

Complications. A logistic random coefficient model was made for the occurrence of each complication. Time was included in the model as a set of 3 dummy variables (each with their own regression coefficient). The discharge assessment was chosen as their reference and was estimated by the intercept. The occurrence of a complication during the other intervals was estimated as follows: 1/ {1 + exp[- (intercept + regression coefficient)]}.[138] The sumscores for pain and spasticity were estimated with similar models for continuous outcome variables. Again, time was modelled as 3 dummy variables, and the score at discharge was estimated by the intercept. The sumscores at the other assessments were calculated by adding the intercept to the regression coefficient of the dummy variable.

Risk-factors. All risk-factors were simultaneously added to the previously described models. With these multivariate models, we corrected for the contribution of each risk-factor. The regression coefficients for the risk-factors were converted to odds ratio's (ORs); OR = exp[regression coefficient]. An OR of 1 indicated there was no association with this particular variable, whereas an OR <1 indicated a decreased risk, and an OR >1 indicated an increased risk of this complication in the presence of the risk-factor. For the continuous outcome variables, the regression coefficient indicated the difference in the sumscore associated with the difference in the risk-factor of 1 unit.

Results

Table 1 gives the descriptive characteristics of the subjects. Subjects were lost to follow-up for several reasons: 9 subjects died, 5 moved abroad, 26 refused further participation, 7 developed psychiatric disease or a progressive condition, 5 were irretraceable and 3 subjects dropped-out for unknown reasons. Forty-four subjects were discharged within 1 month after t2, and therefore, no data were included for them at t2. The mean (SD) duration between injury and admission to rehabilitation was 44 (43) days.

Table 1 Descriptive subject characteristics

Characteristic	*start*	*3 months*	*discharge*	*1 yr after discharge*
Subjects (n)	212	143	191	143
Age (years)	40 (14)	41 (14)	41 (14)	41 (14)
Gender (% male)	74	75	73	73
Body mass index (kg/m^2)	22.7 (3.8)	23.1 (4.0)	23.4 (4.0)	24.5 (4.5)
Smoker (% smoker)	44	44	45	48
Days since previous assessment*	49 (44)	103 (33)	162 (125)	397 (57)
Cause (% traumatic)	74	78	75	76
Level (% tetraplegia)	41	48	40	35
Completeness (% complete)	45	44	49	50

* At the start days since admission to rehabilitation are given.

Complications

Figure 1 shows the estimated occurrence of a complication during each interval. All data are derived from random coefficient analyses. Most subjects reported neurogenic and musculoskeletal pain, or had spasticity at each assessment. Common secondary complications were urinary tract infections and pressure sores, reported by 47% and 36% of the population at t1, respectively. Like most complications, they remained common during the year after discharge, occurring in 49% and 36% of the population at t4, respectively. Additionally, Figure 1 shows the estimated degree of pain and spasticity at each assessment time. The degree of pain decreased, whereas the degree of spasticity increased significantly during inpatient rehabilitation.

Risk-factors

Table 2 gives the ORs for the association between the risk-factors and the occurrence of a complication. An increase in age, tetraplegia and completeness of the lesion were the most frequently identified risk-factors. Those with a high BMI and those with a traumatic lesion were at increased risk of several complications; the largest effect was seen for cardiovascular disease. The risk associated with gender or smoking varied for different complications.

Table 3 gives the regression coefficients for the association between the degree of pain or spasticity and the risk-factors. Overall, an increase in age was associated with an increase in pain. Men and those with a traumatic lesion had a higher degree of spasticity. Those with a tetraplegia and those with an incomplete lesion reported more musculoskeletal pain and showed a higher degree of spasticity.

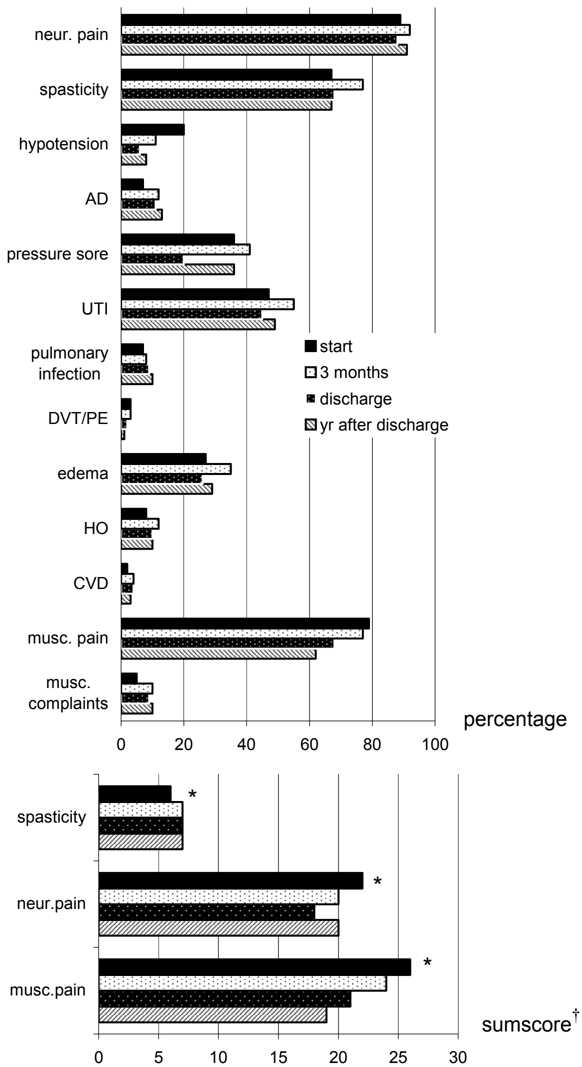

Figure 1 The estimated occurrence of complications & reported degree of pain or spasticity: random coefficient modelling. * significant difference ($p \leq 0.05$) between the sumscore at start and that at discharge. †sumscores determined in those who reported pain or had spasticity. Abbreviations: AD = autonomic dysreflexia; UTI = urinarytract infection, DVT/PE = thromboembolism; HO = heterotopic ossification; CVD = other cardiovascular disease

Discussion

Complications

The present study showed that the occurrence of a range of complications was high both during and after inpatient rehabilitation. Most of our findings coincided with

Table 2 Association with risk-factors: multivariate logistic random coefficient modeling

	Potential Risk Factors						
Complication	*Age (yrs)*	*Gender*[*]	*Smoking*[*]	*BMI (kg/m²)*	*Cause*[*]	*Level*[*]	*Complete*[*]
Neur. pain	1.02 (0.99–1.05)	0.52 (0.23–1.21)	1.20 (0.63–2.27)	0.99 (0.91–1.08)	0.99 (0.41–2.41)	0.86 (0.44–1.70)	0.57 (0.29–1.11)
Spasticity	**0.97** (0.96–0.99)	**2.53** (1.60–3.98)	1.42 (0.93–2.16)	**1.11** (1.04–1.18)	1.07 (0.64–1.79)	**0.13** (0.08–0.23)	0.95 (0.61–1.48)
Hypotension	0.99 (0.97–1.02)	0.82 (0.43–1.54)	0.73 (0.41–1.29)	0.97 (0.90–1.04)	1.38 (0.59–3.25)	**0.09** (0.05–0.18)	**2.44** (1.32–4.52)
Autonomic dysreflexia	0.98 (0.95–1.00)	1.69 (0.81–3.52)	1.21 (0.68–2.15)	1.07 (0.99–1.15)	0.94 (0.40–2.21)	**0.14** (0.07–0.27)	**2.36** (1.26–4.42)
Pressure sore	1.01 (1.00–1.03)	1.08 (0.72–1.63)	1.34 (0.93–1.93)	0.98 (0.93–1.03)	1.08 (0.67–1.74)	**0.53** (0.36–0.78)	**1.73** (1.17–2.56)
Urinary tract infection	1.00 (0.99–1.02)	0.87 (0.60–1.28)	0.78 (0.56–1.11)	0.97 (0.93–1.02)	**1.59** (1.02–2.47)	**0.52** (0.36–0.75)	**1.81** (1.26–2.60)
Pulmonary infection	**1.05** (1.02–1.08)	1.03 (0.51–2.07)	1.49 (0.79–2.80)	0.93 (0.85–1.01)	1.04 (0.45–2.42)	**0.26** (0.13–0.53)	**3.53**[†] (1.74–7.17)
Thrombo embolism	1.01 (0.97–1.06)	0.69 (0.22–2.12)	2.10 (0.72–6.11)	0.92 (0.79–1.08)	- [‡]	1.35 (0.42–4.32)	1.84 (0.59–5.74)
Edema	**1.04** (1.03–1.06)	0.81 (0.53–1.24)	**1.62** (1.09–2.41)	**1.10** (1.04–1.16)	**2.05** (1.23–3.43)	1.09 (0.72–1.65)	1.46 (0.97–2.21)
Heterotopic ossification	0.98 (0.96–1.01)	**11.38** (2.74–47.32)	**0.50** (0.27–0.91)	1.01 (0.93–1.09)	0.79 (0.35–1.78)	0.80 (0.42–1.49)	**2.45** (1.29–4.67)
Cardiovasc. disease	**1.05** (1.01–1.10)	0.71 (0.24–2.13)	1.28 (0.41–3.96)	**1.28** (1.11–1.46)	**5.06** (1.25–20.46)	0.90 (0.31–2.63)	0.60 (0.19–1.94)
Musc. pain	1.00 (0.98–1.02)	**0.63** (0.40–0.99)	0.78 (0.53–1.14)	**1.07** (1.01–1.13)	**1.92** (1.17–3.15)	0.66 (0.43–1.00)	0.73 (0.48–1.09)
Other musc. complaints	**1.02** (1.00–1.05)	1.11 (0.56–2.19)	1.06 (0.58–1.93)	0.96 (0.89–1.04)	1.33 (0.60–2.96)	0.86 (0.45–1.64)	1.53 (0.81–2.89)

Odds ratio's (CI) are given; significant associations ($p \leq 0.05$) printed bold. [*] Gender: men =1, women =0; smoking: smoker =1, non-smoker =0; cause: traumatic =1, non-traumatic =0; level: paraplegia =1, tetraplegia =0; completeness: complete =1, incomplete =0. [‡]'Cause' could not be modeled; in this population all subjects with thromboembolism had a traumatic lesion.

Table 3 Determinants of degree of pain or spasticity: multivariate random coefficient modeling

Degree	*Age (yrs)*	*Gender**	*Smoking**	*BMI** (kg/m²)*	*Cause**	*Level**	*Complete**
neur. pain	**0.12** (0.01–0.23)	-2.20 (-5.30–0.89)	-2.29 (-5.10–0.52)	0.27 (-0.11–0.64)	-1.28 (-4.86–2.30)	**-9.84** (-12.81–-6.88)	2.86 (-0.10–5.82)
spasticity	0.00 (-0.03–0.03)	**1.02** (0.13–1.90)	0.64 (-0.11–1.38)	0.02 (-0.09–0.12)	**2.33** (1.35–3.32)	**-1.07** (-1.86–-0.28)	**-2.21** (-3.02–-1.39)
musc.pain†	**0.14** (0.01–0.28)	-2.33 (-6.08–1.43)	-2.13 (-5.58–1.32)	0.06 (-0.39–0.50)	-1.24 (-5.76–3.27)	**-10.03†** (-13.61–-6.44)	**-4.60** (-8.26–-0.94)

Regression coefficients (CI) are given; significant associations ($p \leq 0.05$) are printed bold. *gender: men =1, women =0; smoking: smoker =1, non-smoker =0; cause: traumatic =1, non-traumatic =0; level: paraplegia = 1, tetraplegia = 0; completeness: complete =1, incomplete =0. ** BMI = body mass index.

previous studies, but inconsistencies may be attributed to the variation in both the selected population and in the design. Excluding those with progressive disease or those over the age of 65, for example, will have influenced our findings. We registered complications based on clinical symptoms often confirmed by additional examination, whereas some others searched for pathology in the absence of clinical symptoms. Furthermore, our longitudinal design will have revealed different information on the association with risk-factors than previous cross-sectional data did.

Although pain and spasticity were common, understanding their impact remains challenging. The reported degree of pain is influenced by both psychosocial and physical factors, which interfere with the interpretation of changes over time and the associations with risk-factors.[177,178] It remains to say, that when pain is experienced, it does often necessitate intervention. Besides increased stretch reflexes, spasticity encompasses increased muscle tone, involuntary movements and primitive reflexes. Lack of effective measurement techniques makes the quantification of all components of spasticity difficult.[44] Furthermore, in contrast to pain, the degree of spasticity is not necessarily related to individual functional complaints or to the required treatment. Because pain and spasticity are common sequelae to SCI, which may require intervention, it is important to reach consensus on how to monitor their clinical impact.

Several mechanisms may explain why complications are common after discharge from inpatient rehabilitation.[14,172,173] After discharge, both the demanding activities of daily living (ADLs) and the reduction in structured training moments could make subjects susceptible to complications associated with overuse.[11] Additionally, many subjects have less guidance or peer-control in self-care.[179] The higher demands of ADLs, together with the reduced feed-back, could make subjects less conscientious towards preventive measures, like skin-checks and bladder management. The active involvement of the spouse may contribute to the prevention of complications, and further analyses of our data showed a tendency for those living alone to be at increased risk. Although the interval evaluated after discharge is long as compared to the intervals during rehabilitation, complications remain a common problem. This should warrant decision makers to invest in effective follow-up programs.[14,162,179] We think it an important task for rehabilitation medicine to strife for the long-term prevention of complications.

Risk-factors

This study indicated subpopulations inherently at risk of complications. Level and completeness of the lesion determine the extent of pareses and loss of respiratory and autonomic function,[11,22,151] which are inevitably associated with the risk of complications.[11,173,178] The physiological age-related decline in cardiorespiratory function and mobility, leave the elderly susceptible to complications.[172,180] Concurrent extraspinal injury may be an additional risk-factor.[2] Although concurrent injury was poorly registered in the present study, further investigation revealed it seemed more common in traumatic lesions. This may partly explain why those with a traumatic lesion were at risk of some complications. However, a standardized registration of concurrent injury is needed to establish these relations. A predisposition of men may partly explain their risk of heterotopic ossification.[174] Additionally, it could be that in men symptoms were more apparent, or more often attributed to heterotopic ossification. Although type of lesion, age and gender cannot be influenced, their identification as important risk-factors allows us to target screening and prevention programs.

Besides these unchangeable risk-factors, the effect of some life-style risks was investigated. An increase in BMI exposed to a risk of several complications. However, the interpretation of the BMI is difficult in those with SCI, especially during the early phase of rehabilitation.[165] Changes in body weight may be attributed to the increase in upper body muscle mass, to the decrease in muscle mass of the lower limbs, to the collection of extra-vascular fluids and to an increase in fat-mass.[165] The associations with other modifiable life-style risks, like alcohol consumption and inactivity, remain ambiguous.[164,181] We anticipate that the cumulative damaging effect of smoking, alcohol consumption, dietary intake and inactivity becomes more evident at a later phase post-injury. Therefore, the relation between lifestyle exposure and complications needs to be investigated in a longitudinal study with a longer follow-up period.

Limitations

The present study design needs some consideration. One should bear in mind that we investigated medical complications, whereas SCI also has psychosocial complications beyond the scope of this investigation. In general, data on the occurrence of complications during an interval, do not inform us on their severity or duration. Because the occurrence of a complication may have delayed discharge, the population assessed three months into active rehabilitation was probably more prone to complications. The assessed population and the varying intervals should be considered when interpreting results. However, random coefficient analyses have allowed us to include all present subjects at each assessment time and this has provided more realistic data on the occurrence of complications during each interval. Our longitudinal design gave insight into the timing of complications, and contributed to the understanding of the nature of risk-factors during different phases of rehabilitation.

In conclusion, complications are common following an SCI and subpopulations are at increased risk. Educational programs for patients and their relatives need to focus on the prevention and early recognition of complications. Structural follow-up visits after inpatient rehabilitation need to be implemented at specialized rehabilitation centers. Besides addressing functional outcome and social participation, these visits need to also focus on complications. Only through the timely prevention, surveillance and treatment of complications can their impact be reduced, and can the individual rehabilitation outcome be optimized.

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6

Physical fitness in people with spinal cord injury: the association with complications and duration of rehabilitation

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Abstract

Objective: To assess the association between physical fitness and its recovery over time on the one hand, and complications and duration of phases of rehabilitation on the other.

Methods: Persons with a spinal cord injury admitted for initial rehabilitation were assessed at the start of active rehabilitation (n= 110), three months later (n= 92), at discharge (n= 137) and one year after discharge from inpatient rehabilitation (n= 91). Physical fitness was defined as aerobic capacity, determined at each occasion by the peak oxygen uptake (peak Vo_2; l/min) and the peak power output (peakPO, Watt). Spasticity, pain, the occurrence of complications, bedrest and duration of rehabilitation were potential determinants of physical fitness. Spasticity, musculoskeletal and neurogenic pain were determined on each occasion ('1'= present; '0'= absent). During inpatient rehabilitation, complications (urinary tract infection, pulmonary infection or pressure sore) and bed rest were registered ('1'= complication; '0'= no complications, and '1'= bed rest; '0'= no bed rest). Complications and bed rest occurring during the year after discharge were registered similarly.

Results: Multilevel random coefficient analyses revealed associations in multivariate models ($p \leq 0.05$). The peak oxygen uptake was negatively associated with complications after discharge. The recovery of peak power output over time was negatively associated with bed rest and spasticity. Both physical fitness and its recovery were negatively associated with the duration of active rehabilitation.

Conclusion: Results suggest that reducing complications, spasticity or bed rest may improve fitness. A longer duration of active rehabilitation is not associated with an increase in physical fitness.

Introduction

Physical fitness, defined as the ability of the cardiorespiratory and musculoskeletal systems to attain a certain level of activity, is reduced following a spinal cord injury (SCI) for several reasons.[17] The level of fitness is established by the aerobic capacity, for which the peak oxygen uptake (peak $\dot{V}O_2$; l/min) is the golden standard,[9,132] and by the maximal maintainable workload, which is determined by the peak power output (peak PO; Watt).[25] Interruption of the spinal cord causes muscle pareses and autonomic disturbance, which both limit the level of fitness.[9,153,182] Additionally, the occurrence of complications is associated with a lower level of fitness.[31] Therefore, patients with SCI may enter a downward spiral of an inherently low fitness, worsened by complications, which increases the vulnerability to more complications, further reducing fitness, and so on.[46]

Physical fitness is a meaningful health indicator, not only because of its proposed relation to complications, but also because it is associated with functioning and quality of life.[9,183] Additionally, the level of fitness is modifiable; it changes over time and can give an indication of rehabilitation outcome.[49,151] Longitudinal data show that the recovery of fitness over time is associated with age, gender and level of the lesion.[49,141,151] Unfortunately, these data do not indicate modifiable determinants and, therefore, do not provide tools to improve rehabilitation practice.

During spinal cord rehabilitation effort is put into the treatment of complications and into the improvement of the physical fitness. Therefore, the duration of this rehabilitation not only depends on the severity of the injury, but also on the occurrence of complications and on rehabilitation goals.[13,160] Complications are a common problem interfering with constructive rehabilitation,[14,176] and although fitness improves during rehabilitation, it remains low.[12,151] Prospective data, collected during and after inpatient rehabilitation, are needed to get insight into whether the effort put into a rehabilitation program is accompanied by an improved outcome.[13] The complex relations between fitness, the occurrence of complications and the duration of rehabilitation need to be unravelled. This will provide tools to optimize individual outcome and rehabilitation strategies. Therefore, we formulated the following research question: what is the association between physical fitness and its recovery over time during and after inpatient rehabilitation on the one hand, and the occurrence of complications and the duration of different functional phases of rehabilitation on the other, in wheelchair dependent subjects with SCI?

Methods

Subjects

The present study was part of the Dutch research program on the recovery of mobility following SCI. Between 2000 and 2005, all consecutive patients with a traumatic or non-traumatic SCI admitted to one of the eight participating rehabilitation centres were included if they were wheelchair dependent, between 18 and 65 years of age, if they had no contra-indications for exercise, and could complete an exercise test on at least one occasion.[132,151] For a detailed description of the in- and exclusion criteria, design and procedure, we refer the reader to a previous publication.[151] The Medical Ethics Committee approved the experimental protocol, and prior to participation all subjects gave a written informed consent.

Design

In this prospective cohort study, subjects were assessed four times: at the start of active rehabilitation, when the subject was able to sit in a wheelchair more than three hours at a time (t1), three months later (t2), at discharge (t3) and one year after discharge from inpatient rehabilitation (t4).[151] At each rehabilitation centre, one trained research assistant was responsible for the data collection. Date of birth and gender were noted at the start of the study, and on each occasion the age was calculated. At each occasion, a physician determined level and completeness of the lesion. Paraplegia (score = 1) was defined as a lesion below the first thoracic segment; tetraplegia (score = 0) as a lesion at or above the first thoracic segment. A complete lesion (score = 1) was defined as motor complete, i.e. ASIA category A or B; an incomplete lesion (score = 0) as ASIA category C or D.[1]

Procedure

The level of physical fitness. To establish the peak oxygen uptake and peak power output, subjects performed a graded maximal wheelchair exercise test on a motor-driven treadmill, which is a valid method to determine physical fitness following SCI.[17] A detailed description of the procedure for this population was given previously.[151] The equipment was calibrated prior to each assessment. The peak oxygen uptake (l/min) was defined as the highest value of oxygen consumption recorded during 30 seconds. The peak power output (Watts) was defined as the workload at the highest inclination that the subject could maintain for at least 30 seconds.[27] The research manual provided normative values as a guideline.[12] For the peak oxygen uptake, the expected mean score ranged from 0.61 to 0.83 l/min for those with a tetraplegia, and from 1.34 to 1.44 l/min for those with a paraplegia. For the peak power output, the expected mean score ranged from 14 to 24 Watts (W) for those with a tetraplegia, and from 54 to 75 W for those with a paraplegia.

Complications and duration of rehabilitation. On each occasion, the research assistant determined spasticity (physical examination) and pain (reported at interview). Spasticity, defined as the velocity dependent increase in muscle tone combined with exaggerated reflexes,[44,184] was assessed at the upper and lower limbs. Starting position of subject and research assistant, and the direction and speed of movements were standardized. Movements were tested during a slow passive stretch, and then spasticity was determined by a fast passive stretch (< 1 second). Spasticity was scored as follows: '0' = no spasticity, '1' = spasticity and catch during stretch (i.e. sudden increase in muscle tone blocking further movement), '2' = clonus (involuntary rhythmic muscle contraction) less than five beats, '3' = clonus five beats or more. To facilitate analyses, the score was recoded into one binary score: '0' was recoded as 'no spasticity' (score = 0); '1', '2' and '3' were recoded as 'spasticity present' (score = 1). Self-report information on musculoskeletal pain (due to trauma, inflammation or overuse) at the upper and lower extremities, and the neck and back was registered. For thirteen locations, the presence and severity of pain was scored on a 5-point Likert scale. These scores were recoded into one binary score for the presence of pain (score = 1, regardless of location, severity or frequency), or the overall absence of musculoskeletal pain (score = 0). Similarly, neurogenic pain (due to spinal cord or nerve root trauma) was registered if a numb, tingling, burning, phantom, hot or cold feeling was reported.[44] A binary score was created for the presence (score = 1), or the overall absence (score = 0) of neurogenic pain.

At each occasion, the physician used medical charts and self-report information to determine whether a complication (urinary tract infection, pulmonary infection or pressure sore) had occurred during the previous period, and whether this had resulted in bed rest. Binary scores were created for both complications and bed rest. Either the subject experienced at least one complication during rehabilitation (score = 1), or the subject had no complications (score = 0). Subsequently, this resulted in bed rest during rehabilitation (score = 1), or not (score = 0). Similarly, both complications and bed rest after inpatient rehabilitation were assigned binary scores.

The inpatient rehabilitation period was divided into two functional phases for each subject. The first, the acute rehabilitation, was defined as the number of days between admission to rehabilitation, and the moment when the subject could sit in a wheelchair more than three hours at a time (i.e. the start of active rehabilitation). The second, the active rehabilitation, was defined as the number of days between the start of active rehabilitation, and discharge from inpatient rehabilitation.

Statistics

Random coefficient analysis (MlwiN version 1.1; Centre for Multilevel Modelling, Institute of Education, London, UK) was used to assess the association between physical fitness and its recovery over time on the one hand, and complications and duration of rehabilitation on the other.[138 139] Separate models were made for the peak oxygen uptake and the peak power output. In a previous publication we have described a similar modelling procedure.[151] Because we investigated fitness and its recovery, time was consistently modelled as three variables; the regression coefficients of these variables each represented the difference between the level of fitness at one occasion, and the fitness at discharge. Then, we expanded these models. Firstly, to assess which variables were associated with the level of fitness, complication and rehabilitation-related variables were added to the models one-by-one. Secondly, to assess whether these variables were associated with the recovery of fitness over time, interaction terms (between time and the variable) were added to the models.

Subsequently, all variables and interaction terms found to be associated with fitness in one-to-one relations ($p \leq 0.10$) were simultaneously entered into a multivariate model. By alternately removing non-significant variables and repeating the analyses, a final model with significantly associated variables remained ($p \leq 0.05$). To permit valid assessments, both components of a significant interaction term had to be included in the model. Furthermore, three interactions with time had to be modelled, even if an association proved significant over one time interval. We tested and corrected for the confounding effect of gender and level or completeness of the lesion by adding these variables to the models.

Results

The study-population consisted of 160 subjects. Of these subjects, we assessed 110 at the start, 92 three months later, 137 at discharge, and 91 one year after discharge from inpatient rehabilitation. Table 1 gives their characteristics and physical fitness at each occasion. The mean (SD) duration of acute rehabilitation was 47 (42) days, and the mean active rehabilitation was 93 (113) days. In 29 subjects, no assessment was done at the start of active rehabilitation, in which case subjects were included three months later. Fifty-four subjects were discharged within three months after admission; hence they did not perform an assessment three months into active rehabilitation. There were other reasons for not collecting data at a specific occasion or for dropping out: four subjects died, seven moved abroad or could not be contacted, two developed psychological problems interfering with participation, seven became independent of

Table 1 Descriptive statistics of subject characteristics and physical fitness

Characteristic and physical fitness	*start n = 110*	*three months n = 92*	*discharge n = 137*	*year after discharge n = 91*
age (years)	40 (14)	38 (14)	39 (14)	37 (13)
men	81 (74%)	72 (78%)	101 (74%)	69 (76%)
tetraplegia	24 (22%)	23 (25%)	37 (27%)	16 (18%)
complete lesion	69 (63%)	64 (70%)	85 (65%)	63 (72%)
traumatic lesion	80 (73%)	69 (76%)	103 (76%)	70 (78%)
spasticity	62 (56%)	70 (76%)	92 (67%)	61 (67%)
neurogenic pain	97 (88%)	83 (90%)	122 (89%)	83 (91%)
musculoskeletal pain	83 (76%)	69 (75%)	92 (67%)	56 (62%)
complications total	not applicable	not applicable	130 (81%)[a]	57 (63%)
pressure sore			73 (46%)	32 (35%)
urinary tract infection			110 (69%)	40 (44%)
pulmonary infection			19 (12%)	5 (6%)
bed rest total	not applicable	not applicable	67 (42%)[a]	21 (23%)
due to pressure sore			45 (28%)	13 (14%)
due to urinary tract infection			29 (18%)	6 (7%)
due to pulmonary infection			12 (8%)	3 (3%)
peakVo_2[b] (l/min)	1.01 (0.29)	1.13 (0.41)	1.21 (0.44)	1.31 (0.51)
peak PO[c] (Watts)	29.7 (15.5)	36.9 (20.8)	40.8 (22.8)	47.8 (25.0)

Values are mean (SD), or number of subjects with this characteristic (%). [a] complications or bed rest during inpatient rehabilitation; subjects assessed at start, three months and/or discharge are summarized and n = 160; [b] peak Vo_2 = peak oxygen uptake; [c] peak PO = peak power output.

a wheelchair, twelve refused further participation, and in two instances there were technical problems. Reasons for not collecting data in this population have previously been described in more detail.[151] Overall, 22 (14%) subjects were assessed once, 46 (29%) twice, 53 (33%) on three occasions, and 39 (24%) were assessed on all four occasions.

The association with complications and duration of rehabilitation

Table 2 gives the results of the final multivariate models. There were one-to-one associations between the level of peak oxygen uptake and complications during rehabilitation, between the recovery of peak oxygen uptake over time and spasticity, and between the recovery of peak power output and pain ($p \leq 0.10$). However, these associations were not significant ($p > 0.05$) in multivariate models. Below Table 2 examples are given for the interpretation of the regression coefficients.

The level of the peak oxygen uptake was negatively associated with complications after discharge. Both the level of peak oxygen uptake and its recovery over time were negatively associated with the duration of active rehabilitation. The level of peak power output was also negatively associated with active rehabilitation. Figure 1 illustrates the association between the peak power output and bed rest.

Table 2 The multivariate association between the (recovery of) physical fitness, and complications & duration of rehabilitation: multilevel random coefficient analyses

Independent variable	*peak VO2 (l/min)*	*peak PO (Watt)*
discharge	1.16 (0.97, 1.35)	50 (41, 59)
t1 – t3 (0/1)[a]	**-0.24 (-0.37, -0.12)**	**-14 (-18, -10)** [a]
t2 – t3 (0/1)[a]	-0.03 (-0.17, 0.11)	**-4 (-8, 0)**
t4 – t3 (0/1)[a]	**0.20 (0.07, 0.33)**	**7 (3, 12)** [a]
spasticity (0/1)	n.e.[b]	0 (-4, 5)
bed rest during rehabilitation (0/1)	n.e.	-5 (-11, 3)
complication after rehabilitation (0/1)[c]	**-0.12 (-0.21, -0.03)**[c]	n.e.
active rehabilitation (days)[d]	**$-10{\cdot}10^{-4}$ ($-16{\cdot}10^{-4}$, $-4{\cdot}10^{-4}$)**	**-0.06 (-0.08, -0.03)**
bed rest* t1 – t3 (0/1)[e]	n.e.	**5 (0, 10)**
bed rest* t2 – t3 (0/1)	n.e.	-1 (-4, 3)
bed rest* t4 – t3 (0/1)	n.e.	-3 (-8, 3)
spasticity* t1 – t3 (0/1)	n.s [f]	-3 (-8, 2)
spasticity* t2 – t3 (0/1)	n.s.	-1 (-5, 4)
spasticity* t4 – t3 (0/1)	n.s.	**-7 (-12, -1)**
active rehabilitation* t1 – t3 (days)	$2{\cdot}10^{-4}$ ($-5{\cdot}10^{-4}$, $8{\cdot}10^{-4}$)	n.s.
active rehabilitation * t2 – t3 (days)	$-2{\cdot}10^{-4}$ ($-8{\cdot}10^{-4}$, $5{\cdot}10^{-4}$)	n.s.
active rehabilitation * t4 – t3 (days)	**$-8{\cdot}10^{-4}$ ($-14{\cdot}10^{-4}$, $-2{\cdot}10^{-4}$)**	n.s.

All results are regression coefficients (95% CI) in the final multivariate model. Significant associations ($p \leq 0.05$) are printed bold. The regression coefficient indicates the difference in fitness associated with an increase in the independent variable of one unit. Interaction terms are joined by asterisks (*). A correction was made for gender, level and completeness of the lesion.

[a] time modelled as three variables; t1–t3 indicates the difference between fitness at the start and that at discharge, t2–t3 indicates the difference between fitness at three months and that at discharge; t4–t3 indicates the difference between fitness one year after discharge and that at discharge. For the peak power output, for example, the regression coefficient for t1–t3[a] indicates the difference between start and discharge was –14 Watts (W), i.e. during active rehabilitation it improved 14 W; the regression coefficient for t4– t3[a] indicates that after inpatient rehabilitation it improved 7 W.

[b] n.e. = variable not entered, because no significant one-to-one association with fitness ($p > 0.10$).

[c] if a complication occurred (variable takes on a '1') the peak oxygen uptake was 0.12 l/min lower than in the absence of a complication (variable takes on a '0').

[d] increase in duration of 1 day was associated with a difference in peak oxygen uptake of $-10{\cdot}10^{-4}$ l/min, and peak power output of –0.06 W.

[e] the interaction term, bed rest*t1– t3, for example, indicates that the difference between start and discharge peak power output was 5 W smaller in the presence of bed rest, i.e. there was less recovery during rehabilitation.

[f] n.s. = variable not significant and removed from multivariate model ($p > 0.05$).

During active rehabilitation, the recovery of the peak power output was negatively associated with bed rest. After discharge, this recovery was negatively associated with spasticity.

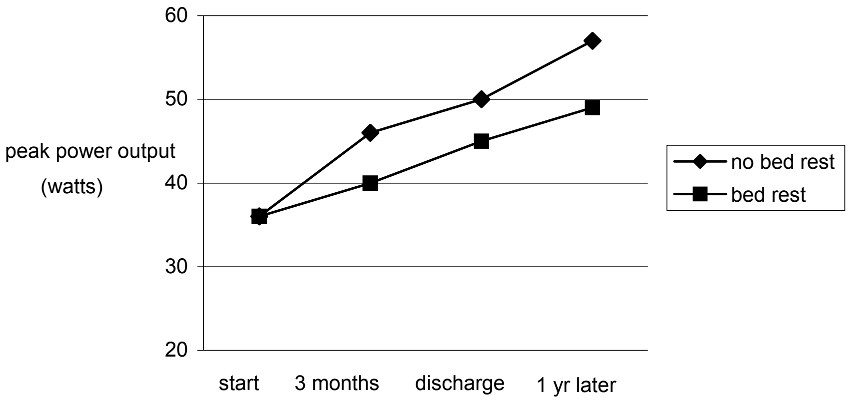

Figure 1 The association between the peak power output (peak PO; Watt) and bed rest (0/1), when all other variables in the final model remain constant. During active rehabilitation, i.e. between start and discharge, the recovery of peak PO over time was negatively associated with bed rest.

Discussion

This study revealed associations between physical fitness, and both complications and the duration of rehabilitation. Although causality cannot be established, the associations found describe a combination of longitudinal and cross-sectional relations and, therefore, provide more valid information than cross-sectional data alone.[138] The overall level of fitness was low, which may partly be attributed to the fact that this study did not limit itself to men or wheelchair athletes or persons with a paraplegia.[12,153] However, it does illustrate the necessity to utilize every opportunity to improve fitness following SCI. Our results may help clinicians more adequately target prevention and treatment strategies and, therefore, interpretations and suggestions for clinical practice are presented.

The association with complications

Unexpectedly, physical fitness and its recovery over time were not associated with complications during inpatient rehabilitation in our multivariate models. However, the recovery of fitness was negatively associated with bed rest, which suggests that not the actual occurrence of complications, but its consequences, i.e. bed rest, are of influence. Our findings seem to correspond with studies in healthy able bodied subjects, which show the deconditioning effect of bed rest.[185,186] Clinicians need to be aware of the possible negative associations with bed rest. We would recommend them to carefully minimize bed rest, prevent deconditioning if bed rest is required, and to anticipate a lower level of fitness after bed rest by gradually resuming activities. Studies have shown the positive effect of exercise programs in the able bodied population,[187,188] but rehabilitation research needs to investigate how deconditioning during bed rest can be prevented in those with SCI.

A possible increase in the severity of spasticity over time could explain the negative association found with fitness after discharge.[189] Both contractures and sudden contractions of muscles interfere with functioning in most patients.[190] Besides hampering the performance during the actual exercise test, spasticity could lead to a reduced activity, which may eventually affect fitness.[190] Considering this long-term effect, clinicians should assess spasticity at follow-up visits. Although the quantification of spasticity remains challenging,[191,192] clinicians need to assess spasticity, investigate its interference with activities of daily life, and initiate treatment if necessary.[44,190]

Results seem to correspond with the postulated downward spiral caused by the association between physical fitness and complications. Its association with bed rest and spasticity may negatively affect the inherently low fitness. The association found with complications after discharge suggest that those with a lower physical fitness are at risk of complications, further reducing fitness, and so on. However, whether complications affect fitness, or whether a low physical fitness predisposes to complications after discharge remains undecided. Although cause and effect cannot be established with the present design, we recommend structural follow-up visits, not only to address functioning and community reintegration, but also to determine the level of fitness, the presence of spasticity and the occurrence of complications.

The association with duration of rehabilitation

Goals change during rehabilitation, and this may explain the negative association found between fitness and the duration of active rehabilitation. Initially treatment will focus on medical stability, psychological adaptation, strengthening and aerobic training, which will contribute to an increase in fitness.[193] When a certain level of fitness has been reached, rehabilitation may become dominated by functional goals, such as community ambulation or vocational rehabilitation; aerobic training will become a secondary goal.[193] As a consequence, one would expect an increase in duration of rehabilitation to be positively associated with functioning, but others failed to establish this relation.[13,155] These seemingly remarkable findings call for a more detailed evaluation of the effect of rehabilitation. Therefore, we assessed the association between fitness and the hours of exercise-related therapy by means of Spearman correlations. This exploratory investigation revealed no association for the absolute level of fitness, or the relative recovery of fitness over time. Because of the negative association with the duration of active rehabilitation, we recommend aerobic training and activity programs to be continued to prevent deconditioning during later phases of rehabilitation.

Subsequently, results could imply that the duration of rehabilitation was not determined by a training goal, but by arranging post-discharge facilities, such as community care, home adaptations or assistive equipment.[13,179] If this is the case, we believe that the realization of these facilities needs to be improved. First, because patients need to adjust to life outside the rehabilitation centre, and secondly, because budgetary problems in health services ask for an efficient organization.[160] With early insight into the expected individual outcome, procedures could be started sooner, sometimes even prior to inpatient rehabilitation. Therefore, the early evaluation of patients' predicted outcome and needs, and the structural monitoring of their progress is important.[121] Additionally, we see it as a task for decision-makers, and financers and suppliers of equipment to reduce procedural difficulties.

The current design and analytic procedure need some consideration. One year after discharge the population comprised fewer subjects with a tetraplegia. This may have influenced results, but the analyses allowed us to include longitudinal data with a different group composition.[138] Since the peak power output is more influenced by the technique of wheelchair-propulsion, results for the peak oxygen uptake and peak power output differed to some extent.[25] Those not restricted by bed rest or spasticity, may adapt to wheelchair skills more easily and, as a consequence, these variables may be associated with the peak power output. Besides the described difficulties in defining and objectively quantifying spasticity or pain,[44,191,192] their binary scores need to be considered when interpreting data. This recoding enabled us to investigate their association with fitness, whilst regarding the duration of rehabilitation, in one multivariate model. This statistical choice may have resulted in the loss of information on the association with the degree of spasticity, pain or complications. However, secondary analyses revealed that, although one-to-one associations with more detailed variables (i.e. variables not recoded into binary scores) existed, these were not significant in multivariate models. Therefore, recoding had no effect on the conclusive findings of this study. In the present study, the association between fitness and given (medical) therapy, guidance or education could unfortunately not be evaluated. Although difficult to quantify, the thorough registration of rehabilitation characteristics and their conditions and intensities, will facilitate an investigation of the effect of rehabilitation in future.

Clinical messages

- The level of physical fitness is negatively associated with the occurrence of complications after discharge
- The recovery of physical fitness over time is negatively associated with bed rest and spasticity
- Fitness and its recovery over time are negatively associated with the duration of active rehabilitation

7

Physical independence and health-related functional status following a spinal cord injury: a prospective study on the association with physical capacity and complications

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Abstract

Objective: To determine changes in physical independence during and after inpatient rehabilitation for spinal cord injury (SCI). To investigate the associations between physical capacity and complications on the one hand, and (changes in) physical independence and health related functional status on the other.
Methods: Physical independence, physical capacity and complications were determined at the start of rehabilitation (n = 176), 3 months later (n= 124), at discharge (n= 160), and 1 year after discharge from inpatient rehabilitation (n= 133). The Functional Independence Measure was computed as FIMmotor, and as a dichotomous rating for physical independence, whereby a subject was categorized as independent if FIMmotor was ≥ 78 (score = 1), and as dependent if FIMmotor was < 78 (score = 0). One year after discharge, physical and social dimensions of health-related functional status (Sickness Impact Profile 68) were determined.
Results: Multilevel random coefficient analyses revealed that physical independence improved during inpatient rehabilitation. Hereafter FIMmotor stabilized, whereas the probability of independence significantly improved from 0.33 to 0.55. Physical independence was positively associated with peak power output, and negatively associated with complications and a complete lesion. Multiple regression analyses showed these factors also predicted 16 to 29% of health-related functional status.
Conclusion: Physical independence improves during rehabilitation, and physical independence and health related functional status are associated with peak power output and complications.

Introduction

A spinal cord injury (SCI) affects previously undemanding daily activities. Patients may suddenly rely on the assistance of others for seemingly straightforward tasks, and may need to adapt to the prospect of physical dependence.[6] Although regaining physical independence is perhaps not the sole purpose of rehabilitation, independent functioning does form a key to being active and socially involved, and may contribute to a sense of control over one's life.[3,53] Clinicians require insight into changes in physical independence to adequately inform patients and relatives about the expected level of activity and participation, to evaluate progress, and to determine the necessity of post-discharge care and assistance.[194]

Aspects of activity and participation following SCI can be determined validly in different ways.[195,196] The Functional Independence Measure (FIM) establishes independence in the performance of several activities; its items on mobility and self-care (FIMmotor) focus on physical independence.[195,197] The abbreviated Sickness Impact Profile (SIP68) determines health-related functional status; its physical and social dimensions establish whether a health condition affects activity and participation.[196,198] The FIMmotor and the SIP68 complement one another as outcome measures of spinal cord rehabilitation: the FIMmotor provides more detailed information on the actual level of independence in mobility and self-care, and the SIP68 covers higher levels of activities, like difficulties in doing handwork, it determines participation, and it is less limited by a ceiling effect than the FIMmotor.[196,198]

As is illustrated in the International Classification of Functioning, Disability and Health (ICF), body function, health condition, and personal or environmental factors each influence activity and participation.[15,52] In previous retrospective studies, patients indicated that their level of activity and their participation were threatened by physical limitations, such as inadequate strength or endurance capacity, and by poor health condition and complications related to pain, incontinence and ageing.[37,199] In agreement with these subjective findings, cross-sectional studies showed that physical capacity, complications, spasticity, type of lesion and age were associated with activity limitations.[13,20,33,133] Factors like type of injury and age cannot be changed. However, the level of physical capacity is low in those with SCI and training can improve this.[200] Furthermore, complications are common and rehabilitation programs aim to minimize their consequences.[3,201] Cross-sectional associations have been established, but if a prospective study can confirm the relation between changes in physical independence on the one hand, and changes in physical capacity and complications on the other, this will help clinicians to adequately target training, treatment and screening programs. Furthermore, if physical capacity and complications at discharge from inpatient rehabilitation predict outcome at follow-up, this suggests the beneficial effect of training, treatment and screening programs on the level of physical independence and health-related functional status.

This prospective study of a cohort of wheelchair-bound subjects with SCI had 3 objectives. The first objective was to determine changes in physical independence (FIMmotor and the probability of independence) over time. Therefore, we established physical independence on 3 occasions during inpatient rehabilitation, and once again, 1 year after discharge. The second objective was to investigate the association between changes in physical independence on the one hand, and changes in physical capacity and complications on the other. Therefore, we also determined physical capacity and complications on each occasion. Because the likelihood of independence after discharge provides a clear message about prognoses, and because the prediction of health-related functional status becomes especially meaningful after discharge when higher levels of activities and participation are required, the third objective was to determine whether discharge physical capacity and complications predicted the probability of independence, and health-related functional status. Therefore, besides independence, physical capacity and complications, we determined health-related functional status 1 year after discharge from inpatient rehabilitation.

Method

This study was part of the Dutch research program on 'Physical strain, work capacity and mechanism of restoration of mobility in the rehabilitation of persons with SCI'. Between July 2000 and November 2005 the program included patients with SCI admitted to 1 of the 8 participating Dutch rehabilitation centres. At their initial inpatient rehabilitation, patients were eligible to participate in the research program if they were between 18 and 65 years of age, were wheelchair-bound, had sufficient comprehension of the Dutch language to understand the purpose of the study, and did not have a progressive disease or psychiatric condition interfering with constructive participation. For patients to be included in our study sample, both their physical independence and physical capacity had to be assessed at least once. Reasons for excluding patients from the maximal exercise test, e.g. cardiovascular disease or musculoskeletal complaints, have been described previously.[151] The Medical Ethics Committee approved the protocol, and prior to participation all patients gave a written informed consent.

Procedure

Subjects were assessed according to a standardized protocol on 4 occasions: at the start of active inpatient rehabilitation, defined as the moment when the subject could sit in a wheelchair for at least 3 hours at a time (t1), 3 months into active rehabilitation (t2), at discharge (t3), and 1 year after discharge from inpatient rehabilitation (t4). On each assessment occasion, we determined physical independence, physical capacity and complications. Additionally, health-related functional status was assessed at t4. At each rehabilitation centre, an experienced rehabilitation professional was appointed as research assistant and was, therefore, responsible for the data collection. To optimize the quality of the collected data, research assistants were trained prior to and during the program, and data were collected and registered according to a strict protocol.

Physical independence and health-related functional status

At each assessment (t1-t4), the Dutch FIM (version 5.0) was completed.[195] The FIMmotor score was computed as the sum score of 13 FIM items on mobility and self-care.[197] In addition, a dichotomous rating for physical independence was derived from the FIM. This meant that if the FIMmotor was ≥ 78, a subject was categorized as independent (binary score = 1), and if FIMmotor was < 78, a subject was categorized as dependent on the assistance of others (binary score = 0). The percentage of the study sample categorized as independent reflects the probability of independence. Health-related functional status was determined 1 year after discharge (t4) with the SIP68. For each SIP68 item subjects indicated whether their health condition currently limited this activity (score = 1) or not (score = 0). The physical dimension of the SIP68 was the sum score of items on somatic autonomy and mobility control (range 0 to 29). The social dimension was the sum score of items on social behaviour and mobility range (range 0 to 22).[196] The higher the score, the more health-related functional status was affected. Because subjects were wheelchair-bound, items on mobility were recoded as recommended by Post et al.[198]

Independent variables

Physical capacity. At each assessment, physical capacity was established by the endurance capacity (peak oxygen uptake and peak power output) and muscle strength. The endurance capacity was determined during a graded peak wheelchair exercise test on a motor-driven treadmill. The peak oxygen uptake (L/min) was defined as the highest average oxygen consumption recorded during 30 seconds, and the peak power output (Watts) as the workload at the highest inclination that the subject could maintain for at least 30 seconds.[27] Muscle strength was tested in 10 muscle groups (shoulder abductors, internal and external rotators and elbow flexors and extensors).

For those muscle groups with a strength of at least grade 3 during manual muscle testing, strength was determined with handheld dynamometry.[119,202] Subsequently, arm muscle strength was derived from a summation of the strength of these 10 muscle groups (Newton).[151]

Complications. At each assessment, the occurrence of complications and the presence of pain and spasticity were registered.[201] The physician used medical charts and self-reported information to determine whether a complication (urinary tract infection, pulmonary infection or pressure sore) had occurred since admission (reported at the start, t1) or since the previous assessment (reported at t2, t3 or t4, respectively), and whether this had resulted in bed rest during this period. Either the subject had at least 1 complication since the previous assessment (score = 1), or the subject had no complications (score = 0). Subsequently, these complications resulted in bed rest (score = 1) or not (score = 0). Self-reported information on musculoskeletal pain at the arms, legs, neck and back was registered with a 5-point Likert scale. These scores were recoded into the presence of pain (score = 1), or the overall absence of musculoskeletal pain (score = 0). Similarly, neurogenic pain (numb, tingling, burning, phantom, hot or cold feeling) was recorded as being present (score = 1) or absent (score =0).[44] Spasticity was assessed at the arms and legs by a fast passive stretch.[184] The presence of spasticity (score = 1), or the overall absence of spasticity (score = 0) was registered.

Subject and lesion characteristics. Age, level and completeness of the lesion were registered at each occasion. Tetraplegia (score = 0) was defined as a lesion at or above the first thoracic segment, and paraplegia (score = 1) as a lesion below the first thoracic segment. A complete lesion was defined as motor complete, i.e. American Spinal Injury Association (ASIA) category A or B, and an incomplete lesion as ASIA category C or D.[1]

Statistics

Descriptive statistics (SPSS version 12.0.01) summarized subject and lesion characteristics and outcome at each occasion (Table 1). The total study sample included 182 subjects, of whom 176 were included at the start (t1), 124 were assessed at 3 months (t2), 160 were assessed at discharge (t3), and 133 were assessed 1 year after discharge (t4). At the start of active rehabilitation, the mean (SD) time since injury was 88 (61) days, and at discharge from inpatient rehabilitation, 290 (140) days had passed since injury.

Changes in physical independence over time

Random coefficient analyses (MlwiN version 1.1; Centre for Multilevel Modelling, Institute of Education, London, UK) determined changes in physical independence over time, whereby we took into account the repeated assessments within 1 subject

Table 1 Descriptive statistics of subject characteristics and physical independence

	Start	*Three months*	*Discharge*	*One yr after discharge*
Characteristic *	n = 176	n = 124	n = 160	n = 133
Age (years)	40 (14)	41 (14)	40 (14)	41 (14)
Men (%)*	76 (133)	77 (95)	74 (118)	72 (96)
Paraplegia (%)	69 (121)	67 (83)	70 (111)	74 (97)
Complete lesion (%)†	67 (117)	48 (58)	48 (75)	53 (68)
Peak oxygen uptake (L/min)	1.03 (0.36)	1.15 (0.42)	1.22 (0.44)	1.32 (0.51)
Peak power output (watts)	31 (18)	37 (21)	41 (23)	48 (25)
Arm muscle strength (Newton)	1547 (533)	1678 (554)	1805 (538)	1864 (608)
Complications (%)‡	62 (109)	71 (87)	52 (82)	66 (87)
Bed rest (%)¶	24 (42)	35 (43)	17 (27)	30 (39)
Musculoskeletal pain (%)	79 (139)	77 (95)	68 (109)	64 (85)
Spasticity (%)	66 (102)	74 (89)	68 (104)	70 (86)
Neurogenic pain (%)	92 (161)	93 (114)	90 (144)	94 (124)
Independence and functional status				
FIMmotor**	44 (18)	58 (20)	69 (17)	69 (19)
Independent (%)	5 (8)	17 (21)	34 (55)	45 (60)
Physical SIP68**	n.a.	n.a.	n.a.	12 (7)
Social SIP68**	n.a.	n.a.	n.a.	6 (4)

* Mean (SD) or percentage of study sample (N) with this characteristic is given. †Complete lesion: motor complete, i.e. American Spinal Injury Association (ASIA) category A or B; ‡Complications: those who had at least 1 complication since admission (reported at the start of active rehabilitation) or since previous occasion; ¶Bed rest: those who had bed rest for these complications. **FIMmotor = level of functional independence (range 13 to 91); physical SIP68 = physical dimension of Sickness Impact Profile 68 (range 0 to 29); social SIP68 = social dimension of SIP68 (range 0 to 22); n.a. = not applicable, because not determined at these occasions.

and within 1 rehabilitation centre.[138] One model was made for changes in FIMmotor, and a separate model was made for changes in the probability of independence. In the FIMmotor model, the intercept represented discharge FIMmotor (t3). Three dummy variables were modelled (for t1, t2 and t4) and their regression coefficients each represented the difference between the FIMmotor at t1, t2 or t4, and that at discharge (t3), respectively. Therefore, these regression coefficients and their confidence intervals reflected changes in FIMmotor over time and the significance of these changes.

The model for the probability of independence was a logistic random coefficient model. Therefore, the regression coefficients for the dummy variables for t1, t2 and t4 indicated the ratio between the odds of independence on 1 occasion (t1, t2 or t4, respectively) and these odds at discharge (t3). The probability of independence at each occasion was then calculated as follows: probability = 1/ {1 + exp[- (regression equation)]}.[157] This probability gave insight into the likelihood a subject would be independent at this specific occasion. The regression coefficients and their confidence intervals reflected changes in the probability of independence over time and the significance of these changes.

Changes in physical independence over time in association with changes in physical capacity and complications

We determined which independent variables were associated with changes in physical independence. To determine the significance of their individual influence, the independent variables were first separately added to the model for FIMmotor, and also to the model for the probability of independence. The following independent variables were tested: peak oxygen uptake (L/min), peak power output (Watts), muscle strength (Newton), complications (0/1), bed rest (0/1), spasticity (0/1), musculoskeletal pain (0/1) and neurogenic pain (0/1). To investigate whether the associations changed over time, we modeled 3 interaction terms (between the dummy variables for t1, t2 and t4, and the independent variable, respectively) for each independent variable and determined their significance. Because age, gender, level and completeness of the lesion could have influenced physical independence, or could have confounded the association between physical independence on the one hand, and physical capacity or complications on the other, the associations with age, gender, level and completeness of the lesion were tested.

Based on all individual associations, we made 1 multivariate model for FIMmotor and 1 for the probability of independence. Because the peak power output, peak oxygen uptake and muscle strength are related measures of physical capacity, possibly leading to collinearity,[151,157] the multivariate models included the measure of physical capacity with the strongest association with physical independence. Therefore, in this case, peak power output and all other significant independent variables and interaction terms ($p \leq 0.10$) were simultaneously added to the respective models. Age, gender, level and completeness of the lesion were treated in a similar way as the other independent variables. We narrowed down the multivariate models by alternately removing a non-significant ($p > 0.05$) independent variable, and rerunning the analyses.

This resulted in 1 final multivariate model with significantly associated variables for the FIMmotor, and another with significantly associated variables for the probability of independence. The regression coefficients in the FIMmotor model indicated an increase in FIMmotor associated with an increase in the independent variable of 1 unit. In the model for the probability of independence, the oddsratio (OR= exp[regression coefficient]) reflected the increase in the odds of independence associated with an increase in the independent variable of 1 unit.[138]

Physical capacity and complications as predictors of the probability of independence and the SIP68

We made 1 multiple logistic regression model to establish whether discharge physical capacity and complications predicted the probability of independence 1 year after discharge (t4), and 2 multiple regression models to establish whether these factors predicted the social and physical dimensions of health-related functional status at t4, respectively (SPSS version 12.0.01). Because the multilevel random coefficient analyses provided knowledge on associations with the probability of independence, and because this probability was determined both at discharge (t3) and 1 year later (t4), whereas the SIP68 was only determined at t4, different modelling procedures were chosen for the probability of independence and for the SIP68.

A hierarchical entering procedure was used for the probability of independence model. First, we entered independency status at discharge (0/1), which was followed by other independent variables (t3) of significant value in the individual multilevel models. Therefore, the discharge peak power output (Watts), completeness of the lesion (0/1), complications (0/1) and musculoskeletal pain (0/1) at discharge were entered following the stepwise-forward procedure. From the resultant multivariate model, the odds of independence in the presence of a variable were calculated.

For the 2 models that predicted physical and social dimensions of the SIP68, respectively, a stepwise-forward procedure was chosen. The following independent variables were tested: discharge peak oxygen uptake, peak power output, muscle strength, complications, bed rest, musculoskeletal pain, neurogenic pain, spasticity, gender, age, level and completeness of the lesion. Variables were cross-tabulated, and if independent variables were individually associated (correlation coefficient > 0.80), the variable with the strongest association with health-related functional status was included for further analyses.[157] Of the measures of physical capacity, the peak power output was again most strongly associated with both domains of health-related functional status and was, therefore, included in the modelling procedure. In the resultant final multivariate models, the regression coefficients indicated an increase in score associated with an increase in the independent variable of 1 unit.

Results

Changes in physical independence over time

Figures 1 and 2 illustrate changes in physical independence over time as estimated with multilevel random coefficient models. They indicate that the FIMmotor increased during inpatient rehabilitation, but did not change significantly after discharge. How-

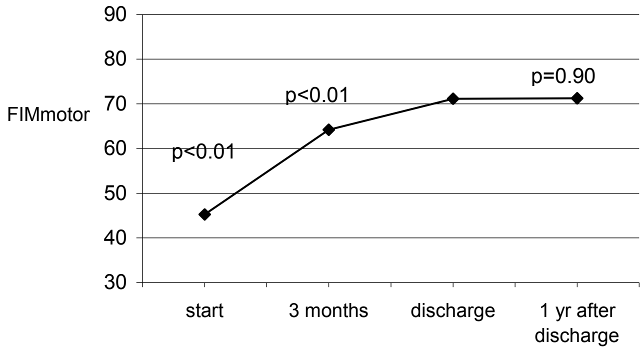

Figure 1 Functional Independence Measure (FIMmotor) during and after inpatient rehabilitation; p-values for significance of the difference between FIMmotor at this occasion and that at discharge as estimated with the multilevel random coefficient model.

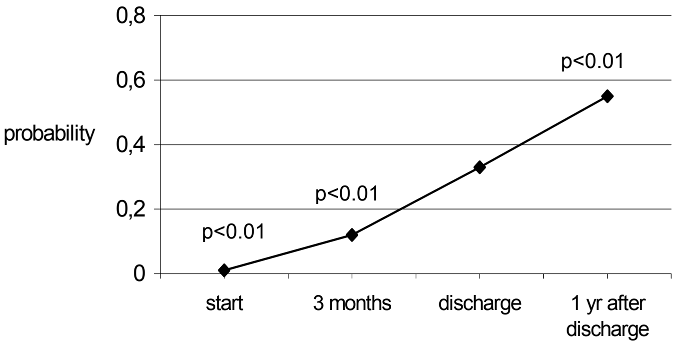

Figure 2 Probability of independence during and after inpatient rehabilitation; p-values for significance of the difference between the odds of independence at this occasion and those at discharge as estimated with the multilevel logistic random coefficient model

ever, the probability of independence increased significantly both during inpatient rehabilitation and during the year after discharge.

Changes in physical independence over time in association with physical capacity and complications

Table 2 gives the individual associations between physical independence and separate independent variables. Both measures of physical independence were associated with peak oxygen uptake, peak power output and complications. The FIMmotor was additionally associated with muscle strength, whereas the probability of independence was also associated with musculoskeletal pain. The final multivariate multilevel model for FIMmotor showed a positive association with peak power output and a negative association with complications (Table 3). An increase in peak power output of 10 Watt was associated with an increase in FIMmotor of nearly 4 points (10 Watt multiplied by 0.36), and if complications had occurred the FIMmotor was nearly 3 points less. The

Table 2 Individual associations with physical independence

	Functional Independence Measure (FIMmotor score)		*Probability of independence*	
Independent variable	Regression coefficient	Confidence Interval	Oddsratio	Confidence Interval
Peak oxygen uptake (L/min)	**14.3**	**10.6 to 18.1**	**9.5**	**3.2 to 27.9**
Peak power output (Watt)	**0.40**	**0.32 to 0.48**	**1.1**	**1.0 to 1.1**
Muscle strength (Newton)	**0.02**	**0.01 to 0.02**	1.0	1.0 to 1.0
Complications (0/1)	**-2.15**	**-4.25 to –0.05**	**0.3**	**0.1 to 0.6**
Bed rest (0/1)	-0.04	-2.31 to 2.23	0.8	0.3 to 1.8
Spasticity (0/1)	-1.44	-4.44 to 1.56	0.7	0.3 to 2.0
Musculoskeletal pain (0/1)	-1.08	-3.37 to 1.21	**0.4**	**0.2 to 0.9**
Gender (1 = men; 0 = women)	5.23	-10.0 to 20.5	1.51	0.44 to 5.18
Age (yrs)	-0.09	-0.25 to 0.07	0.99	0.95 to 1.03
Level (1 = PP; 0 = TP)	**9.04**	**6.69 to 11.4**	1.13	0.37 to 3.45
Completeness (1 = complete.; 0 = incomplete)	-0.97	-3.64 to 1.70	**0.16**	**0.06 to 0.44**

Independent variables were separately added to the model, which included 3 dummy variables for changes over time. Significant associations are printed bold. The regression coefficient and oddsratio indicate the increase in FIMmotor score or in the odds of independence, associated with an increase in the independent variable of 1 unit. Complications, bedrest, pain or spasticity were either present (0) or not (1). Abbreviations: PP= paraplegia; TP= tetraplegia.

Table 3 Functional Independence Measure (FIMmotor) in association with physical capacity and complications: multivariate multilevel random coefficient analyses

	Association with FIMmotor score		
Independent variable	Regression coefficient*	95% Confidence interval	p-value
Discharge; t3	58.82	53.02 to 64.62	<0.01
Start minus discharge; t1 – t3 (0/1)	-22.18	-27.16 to -17.20	<0.01
3 months minus discharge; t2 – t3 (0/1)	-12.20	-17.30 to -7.10	<0.01
1 yr post discharge minus discharge; t4 – t3 (0/1)	2.40	-2.93 to 7.73	0.37
POpeak (Watt)	0.36	0.20 to 0.46	<0.01
POpeak * t1 – t3†	0.06	-0.06 to 0.18	0.32
POpeak * t2 – t3†	0.20	0.08 to 0.32	<0.01
POpeak * t4 – t3†	-0.03	-0.13 to 0.07	0.55
Complications (1 = present; 0 = absent)	-2.70	-4.93 to -0.47	0.02

*Regression coefficient indicates the increase in FIMmotor score associated with an increase in the independent variable of 1 unit. † Interaction terms are linked by asterisks (*).

significant interaction term (between peak power output and dummy variable 't2 minus t3') indicated that the association with peak power output changed over time: between t2 and t3, the higher the peak power output, the smaller the change in FIMmotor. The final multivariate multilevel model for the probability of independence showed that the likelihood of independence increased with an increase in peak power output, that

Table 4 Probability of independence in association with physical capacity and complications: multivariate multilevel random coefficient analyses

Association with the probability of independence			
Independent variable	Odds ratio*	95% Confidence Interval	p-value
Discharge; t3	0.23	0.05 to 1.15	0.07
Start compared to discharge; t1 – t3 (0/1)	0.05	0.01 to 0.21	<0.01
3 months compared to discharge; t2 – t3 (0/1)	0.30	0.11 to 0.81	0.02
1 yr after discharge compared to discharge; t4 – t3 (0/1)	2.92	1.21 to 7.04	0.02
Peak power output (Watt)	1.06	1.04 to 1.08	<0.01
Complications (0= present; 1= absent)	2.89	1.24 to 6.70	0.01
Completeness (0= complete; 1= incomplete)	8.85	3.13 to 25.00	<0.01

*Oddsratio indicates the increase in the odds of independence associated with an increase in the variable of 1 unit.

the likelihood of independence was nearly 9 times higher in those with an incomplete lesion, and nearly 3 times higher in the absence of complications (Table 4).

Physical capacity and complications as predictors of the probability of independence and health-related functional status

The predictive model for the probability of independence 1 year after discharge showed that, in addition to independence at discharge, peak power output and completeness of the lesion at discharge (t3) were significant predictors (Table 5 and Figure 3). The predictive models for health-related functional status 1 year after discharge showed that discharge peak power output significantly contributed to the prediction of both dimensions. Additionally, complications reported at discharge, completeness of the lesion at discharge and gender contributed to the prediction of the physical dimension (Table 6).

Table 5 Predictive model for the probability of physical independence 1 yr after discharge: multiple logistic regression analyses (n= 106)

Probability of independence 1 year after discharge				
Independent variable at discharge	Oddsratio*	Confidence Interval	p-value†	Correct classification‡
Constant	0.08	n.a.	n.a.	52%
Independence (0=dependent; 1=independent)	11	3 to 34	<0.01	77%
Peak power output (Watts)	1.04	1.02 to 1.07	<0.01	79%
Completeness of the lesion (0=complete; 1=incomplete)	14	4 to 52	0.02	81%

*Oddsratio indicates the increase in the odds of independence associated with an increase in the independent variable of 1 unit. †p-value for the association between the odds of independence and this independent variable. ‡percentage of study sample correctly classified as independent or as dependent by this predictive model. Abbreviation: n.a. not applicable.

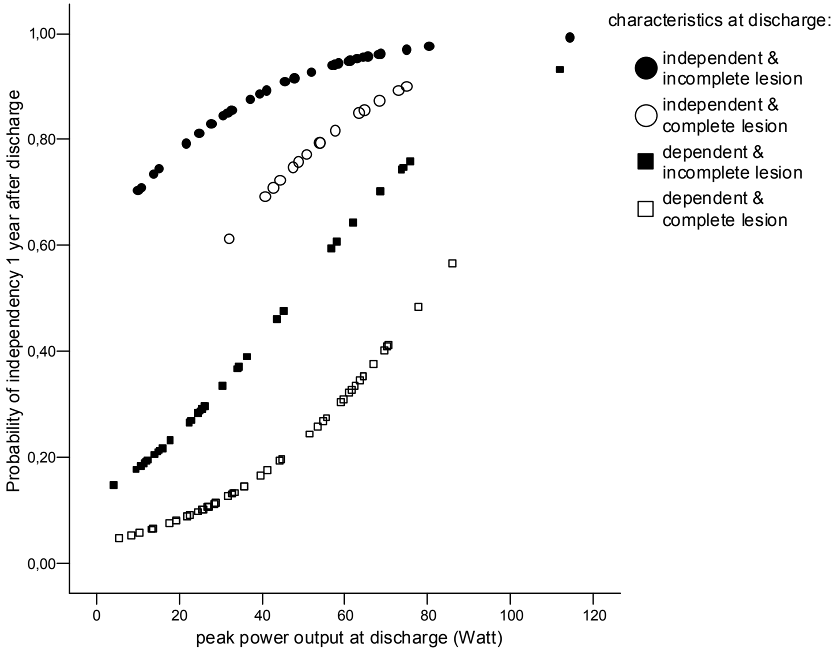

Figure 3 Predicted probability of independence 1 year after discharge in association with discharge peak power output, independence at discharge and completeness of the lesion at discharge: estimated with multiple logistic regression analysis

Table 6 Predictive models for the physical and social dimension of the Sickness Impact Profile (SIP68) 1 year after discharge: multiple linear regression analyses (n = 102)

	Physical dimension			*Social dimension*		
Independent variable at discharge	Regression coefficient (SE)*	Variance†	p-value	Regression coefficient (SE)	Variance	p-value
Constant	11.7 (1.3)	n.a.	n.a.	8.8 (0.8)	n.a.	n.a.
Peak power output (watts)	-0.13 (0.02)	18%	<0.01	-0.08 (0.02)	16%	<0.01
Complication‡ (0/1)	3.0 (1.0)	8%	<0.01	n.s.	n.a.	n.a.
Completeness (0/1)	2.3 (1.0)	3%	0.02	n.s.	n.a.	n.a.
Gender (0=women; 1 =men)	2.4 (1.2)	2%	0.04	n.s.	n.a.	n.a.
Accuracy¶	RSD = 5.0 R^2 = .31			RSD = 3.9 R^2 = .16		

*Regression coefficient indicates the difference in SIP68 score associated with an increase in the independent variable of 1 unit. †Percentage of variance explained by this independent variable. ¶Adjusted R^2 and residual standard deviation (RSD) indicate the accuracy of the model. Abbreviation n.a. not applicable; n.s. non significant. Complications: 0=absent; 1=complications reported at discharge. Completeness: 0=incomplete; 1=complete.

Discussion

Changes in physical independence over time

This prospective study of subjects with SCI showed that physical independence improved during active rehabilitation, but that the FIMmotor stabilized after discharge from inpatient rehabilitation. This unaltered FIMmotor is in agreement with other studies and may be explained by several factors.[13,195,203] First, in the Netherlands patients are usually not discharged from rehabilitation until certain skills have been acquired.[3,13] Therefore, it is understandable that after discharge no recovery could be measured in these specific activities. Second, outside the rehabilitation centre, patients may face an environment not adapted to their individual needs; they have acquired skills, but their surroundings do not allow them to put these skills into practice. At outpatient follow-up, clinicians need to address whether activities are limited by environmental factors, like home adaptations, transport facilities and recreational opportunities. Third, the FIMmotor only determines physical independence during basic activities of daily living.[195,204] For some patients, higher levels of activities and participation may need to be addressed at follow-up visits and in prospective studies.

The seemingly contrasting findings that after discharge the FIMmotor stabilized, whereas the probability of independence increased, called for an examination of our data. The distribution of FIMmotor at discharge was used to divide the study sample into deciles. Subsequently, comparisons between changes in FIMmotor after discharge showed that subjects in the middle deciles improved. Because their FIMmotor at discharge approximated 78 points, they often progressed from being categorized as dependent to being categorized as independent. Those in the higher deciles showed few changes, which suggests that FIMmotor may have plateaued in these subjects.[195] Finally, the lower deciles showed an actual decline in FIMmotor, which explains why, overall, the FIMmotor did not improve significantly. The decline in functioning after discharge in those subjects who were already categorized as dependent may partly be ascribed to the finding that a patient's ability to do something does not necessarily coincide with everyday performance or behaviour.[15,52] For example, if a patient can carry out one activity, but gets help for another activity, it is conceivable that he is also assisted with the former. Similarly, if a patient can ride a manual wheelchair indoors but requires an electric wheelchair for outdoor activities, he could choose to use the electric wheelchair indoors too. Furthermore, although a patient may be able to carry out his own self-care, he may choose to be assisted in order to be able to spend his energy on recreational activities or work. These choices may negatively affect the measured level of physical independence. However, being able to make these choices contributes to a sense of control and wellbeing.[37,53] Therefore, we recommend rehabilitation professionals to strive for the optimal development of skills, because this allows patients to make a choice. Furthermore, clinicians need to regularly regard the patient's individual needs in the evaluation of the necessity of continuing or starting up post-discharge care.

Changes in physical independence over time in association with physical capacity and complications

Conform the cross-sectional associations, changes in physical capacity were associated with changes in physical independence.[33,133] Because we included wheelchair users, the endurance capacity determined on a wheelchair treadmill was expected to be associated with the physical independence.[33] The peak power output was more strongly associated with independence than were peak oxygen uptake and muscle strength, probably because it is a more comprehensive measure of body function, more closely related to activities and influenced by the technique of wheelchair propulsion.[25,133] Furthermore, peak power output showed stronger associations with physical independence than did subject and lesion characteristics. We hypothesize that subject and lesion characteristics are embodied in the peak power output, and that the influence of skills and technique make the power output especially associated with activities in a wheelchair-bound population. Because of its consistent association with physical independence, we recommend the regular assessment of peak power output as an objective measure of rehabilitation outcome in wheelchair-bound patients with SCI.

The negative association between complications and physical independence found in our prospective study coincides with cross-sectional data reported by others.[20,34] Although bed rest may result in deconditioning, it was not associated with an expected functional decline in our study sample.[163] Therefore, bed rest may have caused subjects to temporarily carry out fewer activities, but did not affect physical independence. Future investigation of the effect of the duration of bed rest or of the severity of complications may provide meaningful information. Spasticity and pain have different consequences in different situations and this is probably why they were not associated with physical independence in our multivariate models.[34,44] Whilst spasticity may limit arm function, it may become useful in the legs when making a transfer.[34] Similarly, patients who are active may be exposed to overuse and, therefore, susceptible to pain. Conversely, pain may directly limit activities in others.[178] Although clinicians, patients and relatives are aware of the continuous threat of complications, they need to address concomitant changes in physical independence and, conversely, need to consider the presence of complications if sudden changes in physical independence occur.

Physical capacity and complications as predictors of the probability of independence and the SIP68

Multilevel random coefficient models gave insight into a combination of longitudinal and cross-sectional associations,[138] but to establish causality we needed to extrapolate longitudinal associations. Although our results showed the significant predictive value of peak power output and complications, these variables made a modest contribution to the likelihood of independence at follow-up as compared to independence at discharge.[157] Therefore, intervention studies are needed to establish whether training physical capacity, and the prevention or treatment of complications is actually beneficial. Peak power output also contributed to the prediction of the physical and social dimensions of health-related functional status. However, a large proportion of variance remained unexplained, which may be due to several reasons.[33] First, discharge health-related functional status was not determined at discharge and, therefore, did not contribute to the predictive model. Second, we explained less variance than did Dallmeijer et al., probably because our study sample was larger and less heterogeneous than theirs.[33] Finally, after discharge other factors, such as education, relatives and social support, may also be associated with health-related functional status.[20,33]

Limitations

Our inclusion and exclusion criteria need to be considered when interpreting results. We included those subjects whose level of physical capacity could be established, which hampers the generalizability to all patients with a tetraplegia or a complete lesion. However, it could explain why physical independence at discharge was higher than that reported by others,[195,203] and why the association with the level of lesion was not as strong as expected.[13,20,203] The outcome measures may need some consideration. This study focussed on physical independence, and although SCI can also influence emotional and psychological function, we did not investigate psychological, communicative and emotional items of the FIM or SIP68, which are considered to be stable and less informative following SCI.[195,198] The chosen threshold for the dichotomous rating of physical independence means that those categorized as independent were on average independent for the FIMmotor items. If, for example, one defines physical independence as independent on all separate FIMmotor items, only 22% of the sample would be considered independent 1 year after discharge.[205] Because subjects may require assistance for other, not specified, activities, the choice of threshold remains arbitrary. One has to consider that our finding that 55% of the study sample depends on others 1 year after discharge may be an underestimation of their level of dependency. This study did not determine changes in health-related functional status. However, health-related functional status is probably especially informative after discharge, when a higher level of activities is required, and patients face different restrictions in participation. Therefore, we recommend that health-related functional status and its determinants are investigated in future follow-up studies of patients with SCI. Finally, one needs to consider the accuracy of the models. Some variance in outcome remained unexplained, the observed outcome may differ considerably from the predicted outcome and, although the associations with peak power output and complications were consistent, intervention studies are needed to establish complete causality.[157]

In conclusion, we recommend physical independence and health-related functional status to be determined both during rehabilitation and after discharge. Furthermore, clinicians may need to evaluate possible discrepancies between the measured level of activity and participation, the expected level of activity, and actual behaviour. In anticipation of their association with physical independence and health-related functional status, peak power output and complications also need to be determined regularly. Although the contribution of physical capacity and complications in the predictive models is modest, the results indeed suggest that not only functional training, but also training physical capacity, and the prevention or treatment of complications contribute to physical independence and health-related functional status, but future intervention studies are needed to confirm these proposed beneficial effects.

8

Discussion

Main findings

This thesis describes physical capacity and medical complications in wheelchair-bound patients with SCI both during inpatient rehabilitation and during the year after discharge. The critical review in Chapter 2 discusses reasons behind the differences in the reported level of physical capacity. Prospective data of the Umbrella project allowed us to illustrate changes in physical capacity, in the occurrence of complications, and in physical independence in Chapters 3, 5 and 7, respectively. Furthermore, the data gave insight into interactions between aspects of functioning, and between functioning and contextual aspects. We showed associations among components of physical capacity in Chapter 3. Then we illustrated the influence of contextual factors and complications on physical capacity (Chapters 4 and 6), and determined risk factors of complications (Chapter 5). Finally, we showed the associations between physical independence and functional status on the one hand, and physical capacity and medical complications on the other (Chapter 7).

Following SCI, the level of physical capacity and physical independence is generally low. Most patients have complications, report pain and show spasticity at examination both during and after discharge from inpatient rehabilitation. This is especially worrying, because complications may necessitate readmission to hospital, and are negatively associated with physical independence and well-being.[14,20,30]

Fortunately, the overall level of functioning (in this case both the physical capacity and physical independence) improves during inpatient rehabilitation (Figure 1). Recovery of partially innervated muscles and the recovery from concurrent pathology contribute to this improvement,[148,206] and rehabilitation programs have additional beneficial effects.[60,200] During rehabilitation patients are taught and trained to optimize their physical capacity and to learn new ways to perform daily activities. In agreement with others, we find muscle strength to be positively associated with peak endurance capacity, and endurance capacity to be positively associated with physical independence.[54,69,144,200] Therefore, we hypothesize that training muscle strength contributes to the performance of newly learnt activities and to physical independence, either directly, or through its association with endurance capacity.[35,207] Conversely, during the recurrent performance of activities, physical capacity may be enhanced.[69] Similarly, once patients acquire wheelchair skills, their physical capacity improves not only by training, but also by daily use of the wheelchair and by a more efficient wheelchair propulsion.[35,79,140] Although these proposed mechanisms are beneficial, it is important to evaluate progress after discharge.

After discharge, some aspects of this generally low physical functioning improve, whereas others remain unchanged (Figure 1). The estimated improvements are

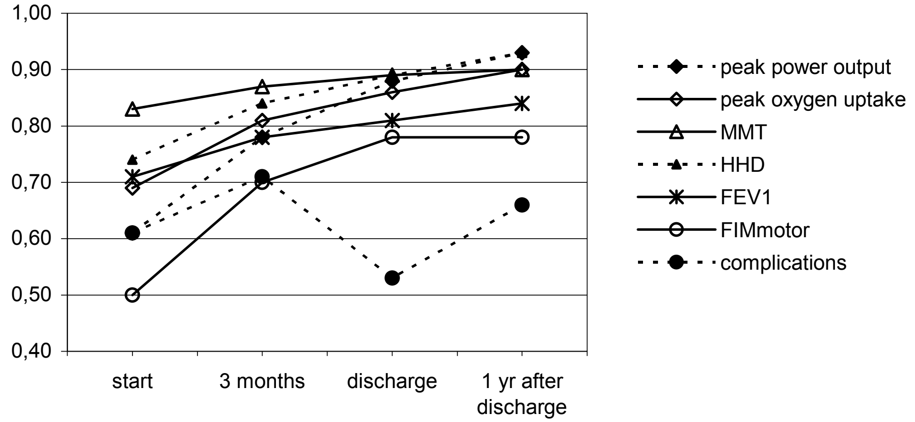

Figure 1 Changes in physical capacity and functioning over time as determined with multilevel regression analyses. Outcomes were standardized as follows: peak power output as a proportion of 47W, peak oxygen uptake as a proportion of 1.40 L/min, and HHD (handheld dynamometry sumscore) as a proportion of 2000N. The FEV1 (forced expiratory flow per second) is a proportion of that expected in a matched able-bodied population. The MMT (manual muscle test sumscore) and FIMmotor (motor Functional Independence Measure) are expressed as a proportion of their maximum score. For complications, the proportion of the sample affected during the previous period is indicated.

comparatively small, and may be clinically less relevant as compared to changes found during inpatient rehabilitation.[183,208] This seems logical because improvements will be more pronounced at the start of active rehabilitation when there is much to be learnt and gained.[49,209] However, because the recovery after discharge is relatively small, the resultant physical capacity is still low and most patients rely on the assistance of others. Perhaps the environment outside the rehabilitation centre does not encourage an active lifestyle, which may eventually lead to a low level of physical capacity.[36,38,39,46,57,210,211] An investigation of 40 patients with SCI shows an initial decline in their level of activity after discharge. This decline has largely recovered one year after discharge, but the activity level one year after discharge does not exceed the discharge level of activity and, therefore, remains distinctly low.[212] Obviously, patients are entitled to choose a physically less active life style or to get assistance from others for their daily activities, but they need to be aware that the cumulative effect of a low level of activity could eventually lead to a decline in physical capacity, and could expose them to the risk of complications. Although physical functioning has not actually declined during the year after discharge, patients and clinicians need to anticipate a potential decline during the following years.

The low level of physical capacity in patients with SCI is largely explained by the limited active muscle mass and cardiovascular changes.[88,90,112] In addition to these neurological consequences, factors such as education, hours of employment,

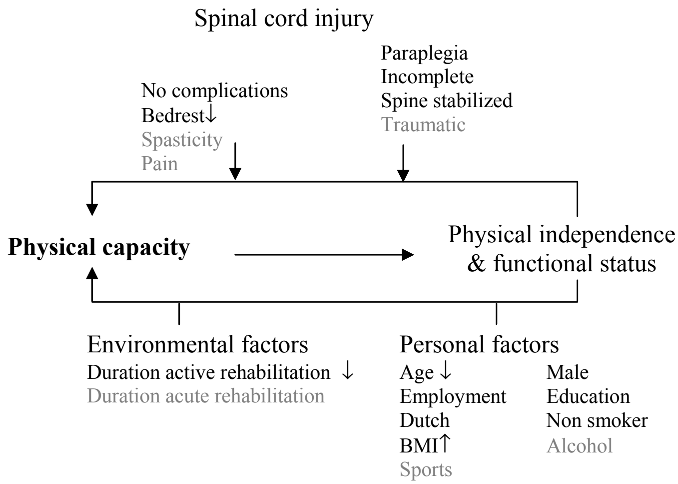

Figure 2 Positive interactions between physical capacity on the one hand, and complications and contextual factors on the other as established in this thesis; non-significant determinants are printed grey. Adapted from International Classification of Disability, Functioning and Health (ICF).[15]

body mass index, stabilisation of the spine, a brief period of active rehabilitation and the absence of complications are all positively associated with physical capacity (Figure 2). Although the effects of some lifestyle characteristics remain unequivocal, the associations found identify patients at risk of a low physical capacity, which helps target training programs and evaluate progress.[12,36,45,213]

Lesion characteristics are predominant risk factors of complications following SCI. Furthermore, ageing, smoking and an increase in body mass index were associated with an increased risk (Figure 3). Because the occurrence of complications after discharge is additionally associated with physical capacity, we hypothesize that a low physical capacity predisposes to complications.[214,215] It is likely that the adverse effects of the neurological impairments cannot simply be prevented, which means that a low physical capacity, complications and physical dependency remain a constant threat.[172,178] We hypothesize that functional training, enhancement of physical capacity and the consistent prevention and treatment of complications will all contribute to an improvement in physical functioning following SCI.

Methodological considerations

Considerations of a prospective multi-centre research program

Methodological strengths and weaknesses of this multi-centre research program need to be considered. The contribution of eight Dutch rehabilitation centres provides information on a relatively large and representative sample of patients with SCI, but

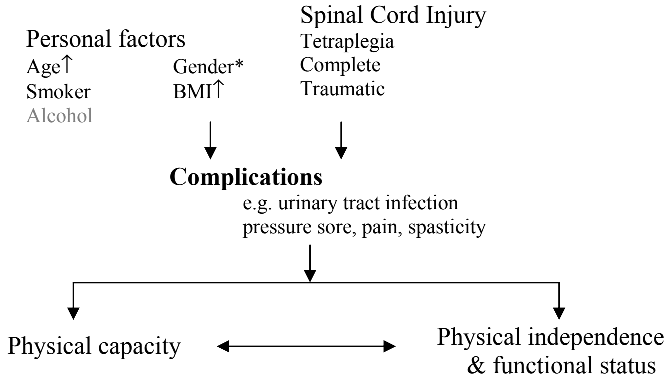

Figure 3 The interactions between complications and risk factors as established in the current thesis *Gender: for some complications, men were at risk, for others women were at risk; tested but non-significant risk factors are printed grey (adapted from ICF model).[15]

one needs to consider whether the results can be generalised. Obviously, we could not include those who died soon after injury or who were discharged home at the end of their hospital stay. But because the program determined the recovery of mobility in wheelchair-bound patients, community walkers and those with progressive disease were also excluded, which makes our data less characteristic for all patients with SCI. Furthermore, the care for patients with SCI differs between countries which will influence, for example, the populations admitted for rehabilitation, the duration or contents of rehabilitation, and the follow-up care.[13] These differences have to be considered when one extrapolates our findings to rehabilitation settings elsewhere. A core dataset for patients with SCI has recently been developed and evaluated. The collection of these data in future investigations would facilitate the comparison of results between different studies.[216]

Another consideration of a multi-centre research program is that differences between observers or instruments may affect the reliability of the data, but we minimized these influences. The observers were rehabilitation professionals who were trained prior to and during the program and who followed a strict protocol. Furthermore, before use, all instruments were calibrated. The calculation of the peak power output was standardized.[217] The data were noted in identical measurement books, and finally collected in one database. In the multilevel random coefficient analyses, we additionally corrected for the dependency of more assessments by one observer at each rehabilitation centre on theoretical grounds.[138]

The prospective data allow us to evaluate interactions between changes in functioning on the one hand and changes in contextual factors on the other, but the timing of the assessments does need to be considered.[138] The assessments were marked by clinical interference (the start of active rehabilitation or discharge) or by actual moments in time (three months into active rehabilitation or one year after discharge). Therefore, the periods between assessments differed in duration, and during these periods different interventions may have been given. These differences need consideration when interpreting changes in physical functioning, and especially warrant caution when interpreting the reported occurrence of complications. However, the timing of the assessments was the same for all subjects, which facilitates the interpretation of the investigated interactions within subjects. Furthermore, it is important to evaluate a patient's progress, and because we assumed this progress to be determined by rehabilitation interventions rather than time alone, we believe it clinically more relevant to report on changes during phases of rehabilitation than to report, for example, on changes during six calendar months.

Another consideration of the prospective design is that those deceased, those discharged within three months of rehabilitation, those less motivated, and those who suffered from complications may not have completed one or more assessments.[138] Additionally, technical difficulties could have prevented data collection.[217] In unpublished data, no differences were found between subjects who performed the assessment one year after discharge and those who did not with regards to lesion characteristics, physical capacity or physical independence. Because both well-performing subjects and poorly-performing subjects missed assessments the net effect on outcome could have been positive, negative, or none at all.

Considerations of the outcome measures

We chose to focus on physical capacity and complications, because we hypothesized that these form the foundation of other aspects of functioning. Furthermore, because spinal cord rehabilitation puts effort into the improvement of physical capacity and the prevention or treatment of complications, we found it meaningful to investigate their progress. Overall, motivation and mood probably influenced the performance of tests and the completion of the questionnaires, but the accuracy and validity of some outcome measures need to be considered further.

Both the endurance capacity (as determined with a wheelchair on a treadmill) and respiratory function (as determined with spirometry) are valid and reliable measures of physical capacity in wheelchair-bound patients with SCI.[17 124] Similarly, the Functional Independence Measure (FIM) and the Sickness Impact Profile (SIP) have proven to be valid to determine aspects of activity and participation following SCI.[52,198,218] However, handheld dynamometry, although more informative than a manual muscle testing grade, provides information on muscle strength in only those muscles with moderate strength and its validity depends on the relative strength of the examiner.[119,202] Furthermore, although adding up the strength of 10 muscle groups provides a comprehensive measure for arm muscle strength, it does not contribute to the validity of the results, and does not provide information on individual muscle groups.[41]

The registration of complications also needs to be considered, because in this study no objective guidelines were given for documenting the presence of different complications. Therefore, the clinical expertise of the physician may have influenced the data.

Although the FIM is valid and well established in rehabilitation practice, one could argue for more SCI-specific alternatives. However, the Quadriplegia Index of Functioning (QIF) is limited to those with a tetraplegia.[219] Furthermore, although the newly developed Spinal Cord Independence Measure (SCIM) accommodates SCI-related problems with items on wheelchair use, it had not been validated at the start of the research program.[220,221]

Information on many other aspects of physical functioning or complications (e.g. bladder and bowel control, sexual function, daily level of activity, medication use or glucose intolerance) may have been meaningful.[3,222] Furthermore, the Impact on Participation and Autonomy (IPA), which determines the perception of participation, and the Craig Handicap Assessment and Reporting Technique (CHART), which determines community reintegration, could have been informative in this population especially after discharge.[223,224] However, choices had to be made, and because the completion of all the assessments already took up nearly one complete day, we did not want to burden patients with additional tests.

Statistical considerations

The prospective collection of data implies that outcome in a subject at one occasion is associated with his or her outcome at a later occasion.[17,52] Multilevel random coefficient analysis incorporates the association between outcome at successive occasions in the analyses of incomplete data sets. Because not all of our subjects completed four assessments, we chose to use this analysis to investigate changes over time.[138] Although this allowed us to make optimal use of the data, we need to emphasize that even subjects who completed only one assessment were included, and that this single assessment contributed to the estimated outcome in the sample.[41] An alternative would have been to include only those subjects for whom outcome and determinants were collected at all occasions. This strategy was chosen in Chapter 4 when we made prognostic models for physical capacity with multiple regression analyses. However, this has the limitation that these models are representative for an even smaller selection of patients with SCI.

The associations with determinants and risk factors need to be considered. The interactions found in the random coefficient models were based on combinations of longitudinal and cross-sectional comparisons, but conclusions on cause and effect must be interpreted with caution.[138,157] The prognostic models give more insight into causality, because they investigate the influence of contextual factors at baseline on physical capacity at follow-up.[154] However, when we validated the models in our sample, their accuracy was limited and cross-validation with another population would probably have given even less promising results.[154] This inaccuracy means that the models may be complementary to clinical expertise, but that they cannot be used as a solitary decision tool. The arrows in Figures 2 and 3 indicate significant interactions and how we interpreted them, but we cannot rule out whether arrows need to be drawn in the opposite direction, whether associations are bidirectional, or whether associations are partly attributable to a third characteristic.

We investigated a selection of potential determinants and risk factors, and it is possible that other characteristics (e.g. living condition or social support) also influence physical functioning following SCI. However, in a sample of just over 200 subjects it would not have been statistically acceptable to investigate many characteristics simultaneously in one model, and choices had to be made. Therefore, we investigated the association with only a selection of those determinants suggested to be of influence in previous studies, those proven important in the able-bodied population, or those potentially modifiable.

Clinical implications

This thesis shows that the generally low level of physical capacity is associated with several contextual factors. However, before we can use this knowledge to improve physical functioning, it is imperative to translate the estimated differences in physical capacity into clinical messages. What does it mean for a patient if his or her peak oxygen uptake is estimated to be 1.20 L/min at discharge from inpatient rehabilitation? Or, what does a difference in peak power output of 8 W between smokers and non-smokers suggest? An investigation in elderly able-bodied subjects, for example, showed that a peak oxygen uptake of >1.33 L/min was associated with a substantial increase in the likelihood of physical independence.[183] Another study showed that a power output of at least 30 W is required to ride a manual wheelchair at 4 km/h across high pile carpet.[208] If we assume that the mean level of peak power output is 30 W at the start of active rehabilitation, being a smoker or not can then actually make functional differences. For our sample, Chapter 7 shows the association between physical capacity and independence: the likelihood of becoming independent is nearly 20% higher if a patient with an incomplete lesion has a peak power output of 60 W, than if this same patient has a peak power output of 40 W. Because of the limited accuracy of the prognostic models and because interactions may work in both directions, they have to be interpreted with care. Furthermore, although many may acknowledge that taking certain precautions may improve physical functioning and reduce the risk of complications in future, it is difficult to change behaviour accordingly.

At admission to rehabilitation, patients with SCI and their relatives often ask about the prognoses.[121] Will they be dependent on others, will their house need to be changed, or will they be able to resume employment? This thesis does not answer these understandable individual questions. However, it does provide insight into the expected recovery of physical capacity and complications in this population. The expected recovery, together with insight into the influence of contextual factors and risk factors, enables clinicians to more adequately inform patients and relatives about functional prognoses and to evaluate progress. A deviation from the expected pattern or an unexpected decline in functioning could indicate the presence of complications and warrant further investigation. However, one does need to consider that a downward deviation from the expected curve of recovery may be within a normal range, and should not lead to unnecessary disappointment. Furthermore, a promising rate of recovery does not always guarantee that all is well, and does not, for example, justify an unhealthy lifestyle or the omission of follow-up visits.

The only way to ascertain whether a patient performs as expected is by regularly monitoring progress. Structural monitoring provides insight into individual progress, but could also inform about the effectiveness of rehabilitation programs.[194] Until now patient monitoring is not an integrated part of rehabilitation practice in The Netherlands. However, in answer to the first results of the rehabilitation research program, a patient-monitoring project has been developed. This project aimed to implement the repeated and structural assessment and evaluation of several aspects of functioning during spinal cord rehabilitation.[225] The first evaluation of this project among rehabilitation professionals showed that 94% of the respondents indicated that monitoring would improve the quality of rehabilitation practice, and 87% indicated patient monitoring needed to be a consistent component of rehabilitation practice.[225] Therefore, in order to accurately formulate rehabilitation goals and to plan follow-up care, we suggest that physical functioning be monitored at the start of active rehabilitation, during rehabilitation and at discharge. Both patient monitoring and the registration of the contents and intensity of training programs are needed to establish the effectiveness of rehabilitation and in order to practice evidence-based rehabilitation.

Although we found no significant decline in functioning one year after discharge, the overall level of physical capacity is still low, complications remain a threat, and most patients depend on the assistance of others. Outside the rehabilitation centre patients may find the environment not adapted to their needs, which could eventually influence functioning. Furthermore, the negative associations found with age, probably coincide with the hypothesis that the cumulative effects of ageing, an inactive lifestyle, and extensive use of the arms and shoulders become more apparent longer than one year after discharge.[8] This may eventually lead to a noticeable decline in functioning and well-being, and an increase in morbidity, hospital or rehabilitation admissions, and costs attributable to health care or loss of productivity.[7] Rehabilitation professionals need to be aware of these cumulative effects over time and, in anticipation of a potential decline, we recommend them to continue monitoring their patients' functioning and complications at yearly follow-up visits.

It may be unpractical to repeatedly monitor all components of physical capacity, and because of the interactions among these components as reported in Chapter 3, it may also be unnecessary to monitor all.[52,129] However, we suggest that the following components of physical capacity be determined during rehabilitation and at yearly intervals after discharge. Because of its association with cardiovascular disease, we suggest that the endurance capacity be determined.[214,215] Because of its association with mechanical efficiency, wheelchair skills and physical independence, the assessment of endurance capacity should include an assessment of the peak power output.[25] Because of its association with activities of daily living muscle strength needs to be determined,[203] and we suggest the use of a handheld dynamometer.[202] If muscle strength is insufficient for handheld dynamometry, manual muscle testing can be a practical alternative.[21] Because of its possible association with respiratory complications, we suggest that respiratory function be assessed.[22,124] Furthermore, because respiratory function can be determined in most patients, it forms an alternative for patients in whom the endurance capacity or muscle strength cannot be assessed.

Besides determining impairments in body function, it is important to evaluate limitations in activities and restrictions in participation.[16,37] In rehabilitation programs, the FIMmotor is the most widely recognized and uniform measure of physical independence, and we suggest that it be used when monitoring patients during rehabilitation. After discharge, a higher level of functioning needs to be addressed, and we suggest the use of the SIP68 at outpatient follow-up.[198] In addition to addressing performance at follow-up visits, it may be important to concomitantly address a patient's needs, and whether the provided care or assistive devices correspond with individual requirements.

Complications are a persistent problem, and may be of increasing importance in an ageing population.[8] Because of its association with physical capacity and independence, sudden changes in performance should make patients and relatives aware of the possible presence of complications. Patients need to learn how to recognize these changes, to learn how to take preventive measures, and to recognize the necessity to consult professionals in good time. In addition to this self-care, we recommend that screening for complications takes place at regular intervals after discharge from rehabilitation.

Suggestions for future research

This thesis illustrates changes in physical capacity and in the occurrence of complications following SCI, and how these changes interact with physical independence. Physical capacity and complications are also important aspects of health in patients with other conditions (e.g. stroke). Therefore, we propose that the work in this thesis, as based on the ICF model, may function as an example for future rehabilitation research among other patient populations.

Future research needs to explore other methods to determine physical capacity in all patients with SCI. For example, it is especially problematical to establish endurance capacity in patients with a cervical lesion or in those who only use an electrical wheelchair. Therefore, we may not be able to draw conclusions on changes in the endurance capacity for all persons with SCI population, and researchers need to develop and evaluate other methods to determine endurance capacity in these vulnerable patients. Perhaps the anaerobe capacity, the sprint power or the results of a sub-maximal exercise test will become suitable alternatives.[144]

The interactions with several determinants have been established, but some associations are worth investigating in future. For example, Chapter 6 gives insight into the association with duration of rehabilitation, but until now little is known about the effectiveness of rehabilitation following SCI. Does rehabilitation optimally improve functioning? Can rehabilitation programs be targeted more effectively? How do rehabilitation programs become more efficient? Answers to these questions could advance rehabilitation practice, but can only be given if individual progress is monitored and compared to the carefully registered rehabilitation input.[226] Furthermore, some modifiable determinants are proposed, but controlled trials need to determine whether stabilisation of the spine, the treatment of complications, a reduction in bed rest or the cessation of smoking, for example, actually improve physical capacity, reduce the risk of complications and consequently lead to an improved level of physical independence or functional status. Finally, before we can determine whether an activity program to promote a healthy lifestyle will enhance physical capacity, the level of activity needs to be objectively quantified in this population.[227,228] The future use of objective measures to quantify the level of activity are recommended.[229] The effect of leading a relatively inactive lifestyle may only become noticeable later post-injury. Therefore, future follow-up studies need to continue longer after discharge from inpatient rehabilitation.[46]

Summary

Neurological deficit following a spinal cord injury (SCI) results in a low physical capacity and a high risk of medical complications. The low physical capacity makes activities of daily living (ADLs) more strenuous, and could make patients dependent on the assistance of others for seemingly straightforward activities. Most patients with SCI are wheelchair-bound, which interferes with accessibility. This, together with the constant threat of complications, the strain of ADLs and the physical dependence, might discourage participation in work or social activities. We hypothesized that the following sequence of events occurs: a low physical capacity and complications make activities strenuous, this reduces activity and social participation, the resultant inactive lifestyle further reduces physical capacity, and exposes the patient to more complications, which in turn reduce activity, and so on.

By analyzing changes in physical capacity and the occurrence of complications, their respective determinants and risk factors, and their interactions with physical independence and functional status, this thesis aimed to provide knowledge to help prevent this proposed sequence of events, and to help improve rehabilitation for SCI. The thesis was based on prospective data collected in the Umbrella project, which is part of the eight rehabilitation research programs of The Netherlands Organization of Research and Development (Zon-Mw): 'Physical strain, work capacity and mechanisms of restoration of mobility in the rehabilitation of persons with a spinal cord injury'. Research assistants in eight Dutch rehabilitation centres, with a specialized SCI unit collected data on 225 patients with SCI, who were wheelchair-bound at initial rehabilitation.

The introductory *Chapter 1* describes SCI and its possible consequences. Physical capacity and medical complications are positioned in the International Classification of Functioning, Disability and Health (ICF) model of health. This model shows how physical capacity and complications could interact with other aspects of functioning. Chapter 1 provides a description of the Umbrella project and concludes with an outline of this thesis.

Physical capacity is defined as the joint ability of muscles and respiratory and cardiovascular systems to attain a peak level of activity. Both the separate functions of these systems, and their combined functions, inform us about the level of physical capacity. This means that in addition to components of physical capacity, such as muscle strength and respiratory function, the endurance capacity (peak oxygen uptake and peak power output) is investigated.

In order to address the complexity of defining or quantifying physical capacity, *Chapter 2* provides a literature review, which summarizes the reported level of physical capacity, and critically evaluates how physical capacity was measured following SCI. Based on topic-related criteria and methodological criteria, we selected 52 articles for the review. Overall, the reported level of physical capacity was low, and because those with a tetraplegia and women were underrepresented in the study samples, the actual level of physical capacity may be even less promising following SCI. Variation in results between the publications was caused by differences in the study population and in research protocols, e.g. the chosen mode of exercise or measuring device. Chapter 2 provides suggestions as to which components of physical capacity should be determined, and the appropriate methods to be used. As long as one takes into consideration the effect of differences in populations and protocols, the descriptive data reported in Chapter 2 can be used as reference material in rehabilitation and training.

Low physical capacity following SCI has been described in Chapter 2. However, we assume that during initial rehabilitation strength or endurance training will improve physical capacity. After discharge, when the environment may not be fully adapted to the patient's needs, a decline in activity may negatively influence physical capacity. To gain insight into these influences *Chapter 3* used the prospective data to describe changes in physical capacity over time, how these changes interact with age, gender and level and completeness of the lesion, and how changes in components of physical capacity interact with one another. All the investigated components of physical capacity improved significantly during inpatient rehabilitation. The peak oxygen uptake and the peak power output, for example, improved by 24% and 41%, respectively. Not all components continued to improve during the year after discharge, and the overall level of physical capacity remained relatively low. In anticipation of a potential decline in physical capacity in association with an expected level of relative inactivity after discharge, we recommend the structural registration and evaluation of physical capacity at follow-up visits. Women, the elderly and those with a tetraplegia had a lower physical capacity. Over time, gender-related differences and the negative association with age became larger, whereas the negative association with a tetraplegia became smaller after discharge. In order to allow patients to develop their maximal potential of physical capacity, we recommended a further exploration of the reasons behind the differences in recovery between subpopulations. The separate components of physical capacity were in fact related. However, whether training of one component actually improves the other needs to be established in future intervention studies.

At the start of rehabilitation, patients, relatives and clinicians need to be informed about the expected prognosis, which will help to set realistic rehabilitation targets.

In Chapter 3 we established changes over time as well as several associations, which allow us to estimate prognoses for different populations. However, these results were based on combinations of cross-sectional and longitudinal associations. Furthermore, they included differences between subpopulations that can be taken into account but, however, cannot be changed. Therefore, the aim of *Chapter 4* was to use the prospective data to make prognostic models, which also included some modifiable potential predictors. Muscle strength and peak power output were relatively well predicted, with explained variances ranging between 42% and 84%. Not surprisingly, most variation in outcome (51% to 82%) was explained by prior physical capacity, but (although their contribution was modest) former education and employment, stabilization of the spine, smoking, and body mass index were significant predictors of physical capacity at follow-up. When we compared the predicted outcome with the observed outcome in the same study sample, the accuracy of the models was limited. Therefore, we suggested that the models be used to estimate prognosis only in combination with clinical expertise and knowledge of the individual patient.

Impairment and disability may not only be caused by the neurological deficit following SCI, but can also arise from complications. A complication is defined as a condition that follows the SCI in time, and for which the risk is increased after SCI. *Chapter 5* describes changes in the occurrence of complications during and after inpatient rehabilitation, as well as risk factors of these complications. Most patients reported pain or showed spasticity at physical examination. There were no significant changes in the occurrence of complications and, therefore, complications remained a threat even during the year after injury, when urinary tract infections and pressure sores, for example, affected 49% and 36% of the study population, respectively. Those with a tetraplegia, a complete lesion or a traumatic lesion were at risk of several complications. Additionally, increases in age or in body mass index were significant risk factors. During rehabilitation and at regular follow-up visits clinicians need to systematically address and investigate the presence of complications.

Initial spinal cord rehabilitation programs include the treatment or prevention of complications, and the enhancement of physical capacity. Changes in physical capacity have been described in Chapter 3, but an exploration of the effect of rehabilitation programs on the recovery of physical capacity was considered additionally meaningful. Unfortunately, we could not determine the effect of the contents and intensity of training programs. However, we assumed that the duration of active rehabilitation, during which the patient participated in functional, strength and endurance training in the wheelchair, would correlate with the given hours of therapy. Therefore, in *Chapter 6* we investigated the complex interactions between the level of physical capacity on the one hand, and the duration of phases of rehabilitation and the occurrence of complications on the other. Results showed that the duration of active rehabilitation, bed rest and the occurrence of complications after discharge were negatively associated with the level of physical capacity. Furthermore, duration of active rehabilitation and spasticity were negatively associated with the recovery of physical capacity over time. Future studies need to systematically investigate the effect of rehabilitation programs on the level of physical capacity.

Besides insight into physical capacity, the expected level of physical independence or functional status provides important and meaningful information for patients, relatives and clinicians. We hypothesized that patients require a basic level of physical capacity and no hindrance from complications before they can be active and involved. Therefore, *Chapter 7* describes changes in physical independence over time. Furthermore, we determined the value of physical capacity and complications in predicting physical independence and functional status one year after discharge. The level of physical independence improved during inpatient rehabilitation and remained unchanged thereafter, whereas the likelihood of independence continued to improve. In addition to discharge dependency status and completeness of the lesion, physical capacity and the absence of complications at discharge were positively associated with physical independence and functional status at follow-up. These interactions suggest that not only functional training, but also the training of physical capacity and the treatment or prevention of complications could contribute to functional prognosis, but future intervention studies need to establish these proposed effects.

Finally, *Chapter 8* discusses the main findings of the studies, how these fit into the ICF model, and whether they correspond with the aforementioned sequence of events following SCI. We also addressed considerations related to the multi-centre prospective study and discussed issues applying specifically to the outcome measures and analyses in this thesis. We aimed to translate the findings of this thesis into meaningful clinical messages, and have provided suggestions for future research.

Samenvatting

Na een dwarslaesie leiden het verlies van spierkracht en de verandering in cardiovasculaire controle tot een lage fysieke capaciteit en een hoog risico op complicaties. Door de verminderde fysieke capaciteit en het optreden van complicaties worden dagelijkse activiteiten meer belastend. Daarnaast is een groot deel van de patiënten rolstoelgebonden en aangewezen op de hulp van anderen. Door de relatief ontoegankelijke omgeving en de fysieke afhankelijkheid kunnen activiteit en deelname aan arbeid of aan sociale activiteiten verder worden bemoeilijkt. Dit kan op zijn beurt weer verdere achteruitgang van fysieke capaciteit veroorzaken en de kans op complicaties verder vergroten. In navolging op deze constateringen was onze hypothese dat de volgende kettingreactie ontstaat: een lage fysieke capaciteit maakt dagelijkse activiteiten belastend, wat leidt tot een vermindering in activiteit en participatie en een verhoogd risico op complicaties, die vervolgens de fysieke capaciteit verminderen, de activiteit verder belemmeren, en zo verder. Door veranderingen in fysieke capaciteit en in het optreden van complicaties te bestuderen, hun determinanten of risicofactoren te onderzoeken, en vervolgens fysieke capaciteit en complicaties te relateren aan fysieke zelfstandigheid en functionele status, beoogt dit proefschrift te leiden tot kennis die kan bijdragen aan het voorkomen of tegengaan van de omschreven negatieve kettingreactie en de verbetering van het revalidatieproces van mensen met een dwarslaesie.

Het proefschrift is gebaseerd op data die zijn verzameld in het landelijke Koepelproject. In het kader van dit project hebben acht gespecialiseerde revalidatiecentra gegevens verzameld van 225 rolstoelgebonden patiënten tijdens hun initiële dwarslaesie revalidatie. Het Koepelproject maakt onderdeel uit van een van de 8 onderzoeksprogramma's van het eerste Revalidatieonderzoeksprogramma van Zon-Mw: 'Mobiliteitsherstel in de revalidatie van patiënten met een dwarslaesie'.

In het inleidende *Hoofdstuk 1* worden de gevolgen van een dwarslaesie omschreven. Met behulp van het ICF (International Classification of Functioning, Disability and Health) model worden onze onderzoeksvragen betreffende fysieke capaciteit en complicaties in een kader geplaatst. Hoofdstuk 1 eindigt met een omschrijving van de opzet van het Koepelproject, en van de onderzoeksvragen die in het proefschrift aan bod komen.

Fysieke capaciteit is de gezamenlijke capaciteit van neuromusculaire, respiratoire en cardiovasculaire systemen om een bepaalde mate van activiteit of inspanning vol te houden. Het is een complex begrip dat zowel de afzonderlijke functies van de verschillende systemen als hun onderlinge samenwerking behelst. Om een goed beeld van fysieke capaciteit te krijgen moet men dus zowel de spierkracht als de respiratoire functie als de aërobe inspanningstolerantie (piek zuurstofopname en piek vermogen) evalueren. Veel studies hebben zich gericht op het meten of verbeteren van fysieke capaciteit na een dwarslaesie, maar de gerapporteerde waarden van fysieke capaciteit zijn niet samengevat tot referentiewaarden voor een algemene populatie patiënten met een dwarslaesie. Daarom heeft *Hoofdstuk 2* als doel deze studies te evalueren. Na de selectie van publicaties op basis van inhoudelijke en methodologische criteria, zijn de methoden en resultaten van 52 studies samengevat. De gerapporteerde mate van fysieke capaciteit bleek uiteenlopend, maar de fysieke capaciteit was over het algemeen laag in vergelijking met de fysieke capaciteit van mensen zonder een dwarslaesie. We concludeerden dat de gerapporteerde resultaten misschien zelfs een te rooskleuring beeld gaven wegens de ondervertegenwoordiging van vrouwen, patiënten met een tetraplegie en inactieve patiënten. We verklaarden de uiteenlopende resultaten doordat de bestudeerde studies verschilden in onderzoekspopulaties en in meetmethoden om fysieke capaciteit te kwantificeren. Wanneer het effect van deze verschillen in ogenschouw wordt genomen, geeft Hoofdstuk 2 bruikbare referentiewaarden voor de evaluatie van de individuele mate van fysieke capaciteit en het effect van revalidatie en training.

De revalidatie besteedt ruime aandacht aan het verbeteren van de inspanningstolerantie, en daarom namen we aan dat de fysieke capaciteit tijdens de klinische revalidatie verbetert. Omdat de omgeving buiten het revalidatiecentrum misschien onvoldoende is aangepast aan de mogelijkheden van een patiënt, kan een patiënt na ontslag zijn belemmerd in het uitvoeren van dagelijkse activiteiten. We veronderstelden dat deze mogelijke belemmering in activiteit kan leiden tot een afname van de fysieke capaciteit. *Hoofdstuk 3* heeft als doel de veranderingen in fysieke capaciteit tijdens en na ontslag van klinische revalidatie te omschrijven, deze veranderingen te relateren aan leeftijd, geslacht, en niveau en compleetheid van de laesie en vervolgens de interacties tussen componenten van fysieke capaciteit onderling (spierkracht, longfunctie en inspanningstolerantie) te bestuderen. Uit de resultaten bleek dat de fysieke capaciteit verbetert tijdens klinische revalidatie. De piek zuurstofopname en het piek vermogen verbeteren respectievelijk 24% en 41%. Sommige componenten van de fysieke capaciteit verbeteren ook na ontslag, maar een jaar na ontslag blijft de totale fysieke capaciteit laag. Verder bleek dat mannen, jongeren en patiënten met een paraplegie een hogere fysieke capaciteit hebben dan vrouwen, ouderen en patiënten met een tetraplegie. Na verloop van tijd wordt de voorsprong van mannen en jongeren groter, maar het verschil tussen patiënten met een paraplegie en patiënten met een tetraplegie wordt dan kleiner. De componenten van fysieke capaciteit bleken onderling gerelateerd te zijn. Geconcludeerd werd dat het raadzaam is om de evaluatie van fysieke capaciteit te integreren in de poliklinische nazorg, omdat de fysieke capaciteit een jaar na ontslag nog steeds laag is. De achterliggende redenen voor het verschil in herstel tussen de patiëntgroepen dienen te worden onderzocht.

Met informatie over de functionele prognose kunnen clinici en patiënten realistische revalidatiedoelen stellen en kan de noodzaak van nazorg vroegtijdig worden geëvalueerd. *Hoofdstuk 4* heeft als doel voorspellende modellen te maken voor de fysieke capaciteit bij ontslag en een jaar na ontslag, waarbij de voorspellende waarde van specifiekere en mogelijk veranderbare factoren wordt geëvalueerd. Resultaten lieten zien dat spierkracht en piek vermogen relatief voorspelbaar zijn (R^2 = 0.42 tot 0.84) in vergelijking met respiratoire functie of piek zuurstofopname. De grootste variantie (51% tot 82%) wordt verklaard door de fysieke capaciteit op een eerder meetmoment. De modellen toonden echter ook dat roken, body mass index, de stabilisatie van de wervelkolom, opleiding en arbeid voor de dwarslaesie een bescheiden maar significante bijdrage leveren aan het voorspellen van fysieke capaciteit. Wanneer de voorspelde uitkomst wordt vergeleken met de geobserveerde fysieke capaciteit bleek dat de nauwkeurigheid van de modellen te wensen overlaat. Dus adviseerden we dat de voorspellende modellen alleen een bijdrage kunnen leveren aan het evalueren van herstel of het plannen van zorg, wanneer ze worden gebruikt in aanvulling op professionele ervaring en kennis over de individuele patiënt.

Beperkingen ontstaan niet alleen ten gevolge van het neurologische functieverlies na de dwarslaesie, maar ook ten gevolge van complicaties. Complicaties zijn aandoeningen die optreden na het ontstaan van een andere aandoening; in dit geval na de dwarslaesie. We veronderstellen dat deze complicaties vaker voorkomen bij patiënten met een dwarslaesie dan bij mensen zonder dwarslaesie. *Hoofdstuk 5* heeft als doel het bestuderen van het optreden van complicaties, en het bepalen van hun risicofactoren. Uit de resultaten bleek dat de meerderheid van de patiënten pijn of spasticiteit heeft, zowel tijdens als na klinische revalidatie. Er weinig verandering op in het voorkomen van complicaties. Dit leidt ertoe dat ook gedurende het jaar na de revalidatie (wanneer bijvoorbeeld 49% en 36% van de patiënten respectievelijk een urineweginfectie of decubitus heeft) complicaties een veelvoorkomend probleem zijn. Naast een tetraplegie of een complete laesie, bleken een toename in leeftijd en in body mass index significante risicofactoren te zijn. We raadden dan ook aan dat de systematische preventie of behandeling van complicaties een integraal onderdeel dient te worden van zowel de klinische revalidatie als van de poliklinische nazorg.

Tijdens revalidatie wordt getracht de fysieke capaciteit te vergroten en complicaties te voorkomen of te behandelen. Het is belangrijk om inzicht te krijgen in de effectiviteit van deze revalidatie. Helaas zijn gedetailleerde gegevens over de inhoud, duur en intensiteit van revalidatieprogramma's voor dit onderzoeksproject niet beschikbaar. We veronderstelden echter dat de duur van klinische revalidatie correleert met de duur van therapie, en dat tijdens acute revalidatie (d.w.z. wanneer de patiënt nog niet een aaneengesloten periode kan zitten), mogelijk een andere behandelingsintensiteit wordt gehanteerd dan tijdens de actieve revalidatie, wanneer de patiënt langer dan drie uur in een rolstoel kan zitten. Daarom onderzochten we in *Hoofdstuk 6* de complexe relatie tussen fysieke capaciteit enerzijds, en het optreden van complicaties, de duur van acute revalidatie en de duur van actieve revalidatie anderzijds. Uit de resultaten bleek dat de duur van actieve revalidatie, bedrust en het optreden van complicaties na ontslag negatief geassocieerd zijn met het niveau van fysieke capaciteit. Bovendien zijn de duur van actieve revalidatie en spasticiteit negatief geassocieerd met het herstel van de fysieke capaciteit. We concludeerden dat systematische registratie van revalidatietherapie en het monitoren van het herstel van individuele patiënten noodzakelijk zijn om de effectiviteit van therapie in de toekomst in meer detail te bepalen.

Naast informatie over fysieke capaciteit of complicaties, is inzicht in de verwachte fysieke zelfstandigheid en de functionele status belangrijk. Een doel van de revalidatie is om het niveau van activiteit en participatie zo optimaal mogelijk te ontwikkelen. We veronderstelden dat een bepaald niveau van fysieke capaciteit en de afwezigheid van complicaties voorwaarden zijn voor het uitvoeren van bepaalde activiteiten of voor deelname aan bijvoorbeeld arbeid of andere sociale activiteiten. Daarom heeft *Hoofdstuk 7* als doel veranderingen in de mate van fysieke zelfstandigheid gedurende en na klinische revalidatie te omschrijven en deze te relateren aan fysieke capaciteit en het optreden van complicaties, om vervolgens voorspellende modellen te maken voor fysieke zelfstandigheid en functionele status een jaar na ontslag. Resultaten toonden aan dat de mate van zelfstandigheid en de kans op fysieke zelfstandigheid verbeteren tijdens opname, terwijl gedurende het jaar na ontslag alleen de kans op zelfstandigheid toeneemt. Behalve de mate van zelfstandigheid bij ontslag en compleetheid van de laesie, zijn ook piek vermogen en het optreden van complicaties geassocieerd met fysieke zelfstandigheid en functionele status. Resultaten suggereerden dat niet alleen het oefenen van vaardigheden, maar ook het trainen van fysieke capaciteit en het voorkomen en behandelen van complicaties kunnen bijdragen aan het verbeteren van de fysieke zelfstandigheid en de functionele status. Interventiestudies dienen deze mechanismen en hun mogelijke effecten in de toekomst te onderzoeken.

Ten slotte bediscussieert *Hoofdstuk 8* de belangrijkste bevindingen van dit proefschrift. Methodologische kanttekeningen van een prospectief onderzoek binnen meerdere centra, en van de statistische procedures komen aan bod. Uiteindelijk vertaalden we de bevindingen van dit proefschrift in een aantal klinische boodschappen. Ten slotte deden we suggesties voor toekomstig onderzoek.

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