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

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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.

Design and setting: Prospective cohort study at eight rehabilitation centres.

Subjects: People with a spinal cord injury were assessed four times: at the start of active rehabilitation ($n = 110$), three months later ($n = 92$), at discharge ($n = 137$) and a year after discharge from inpatient rehabilitation ($n = 91$).

Main measures: Physical fitness was defined as aerobic capacity, determined at each occasion by the peak oxygen uptake (peak $\dot{V}O_2$; L/min) and the peak power output (peak PO; W) during a maximal exercise test. On these occasions, spasticity, musculoskeletal and neurogenic pain were determined (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 limiting 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 for several reasons.¹ 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 gold standard,^{2,3} and by the maximal maintainable workload, which is determined by the peak power output (peak PO; W).⁴ Interruption of the spinal cord causes muscle pareses and autonomic disturbance, both of which limit the level of fitness.^{3,5,6} In addition, the occurrence of complications is associated with a lower

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level of fitness.⁷ Therefore, patients with a spinal cord injury may enter a downward spiral of inherently low fitness, worsened by complications, which increases the vulnerability to more complications, further reducing fitness, and so on.⁸

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.^{3,9} The level of fitness is also modifiable; it changes over time and can give an indication of rehabilitation outcome.^{10,11} Longitudinal data show that the recovery of fitness over time is associated with age, gender and level of the lesion.^{10–12} 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.^{13,14} Complications are a common problem interfering with constructive rehabilitation,^{15,16} and although fitness improves during rehabilitation, it remains low.^{11,17} Prospective data, collected during and after inpatient rehabilitation, are needed to get insight into whether the effort put into a rehabilitation programme 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 a spinal cord injury?

Methods

Subjects

The present study was part of the Dutch research programme on the recovery of mobility

following a spinal cord injury. Between 2000 and 2005, all consecutive patients with a traumatic or non-traumatic spinal cord injury 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 contraindications for exercise, and could complete an exercise test on at least one occasion.^{2,11} For a detailed description of the in- and exclusion criteria, design and procedure, we refer the reader to a previous publication.¹¹ 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 3 hours at a time (t1), three months later (t2), at discharge (t3) and one year after discharge from inpatient rehabilitation (t4).¹¹ 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. On 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.¹⁸

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 spinal cord injury.¹ A detailed description of the procedure for this population was given previously.¹¹ The equipment was calibrated prior to each assessment. The peak oxygen uptake (L/min) was defined as the highest

value of oxygen consumption recorded over 30 seconds. The peak power output (W) was defined as the workload at the highest inclination that the subject could maintain for at least 30 seconds.¹⁹ The research manual provided normative values as a guideline.¹⁷ For the peak oxygen uptake, the expected mean score ranged from 0.61 to 0.83 L/min for those with tetraplegia, and from 1.34 to 1.44 L/min for those with paraplegia. For the peak power output, the expected mean score ranged from 14 to 24 W for those with tetraplegia, and from 54 to 75 W for those with 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,^{20,21} was assessed at the upper and lower limbs. The starting positions 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 13 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.²¹ A binary score was created for the presence

(score=1), or the overall absence (score=0) of neurogenic pain.

On 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 for more than 3 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.^{22,23} 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.¹¹ 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. First, to assess which variables were associated with the level of fitness, complication and rehabilitation related variables were added to the models one-by-one. Second, 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 a year after discharge from inpatient rehabilitation. Table 1 gives their characteristics and physical fitness on 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 on 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 a wheelchair, 12 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.¹¹ Overall, 22 (14%) subjects were assessed once, 46 (29%) twice, 53 (33%) on three

Table 1 Descriptive statistics of subject characteristics and physical fitness

	Start (<i>n</i> = 110)	Three months later (<i>n</i> = 92)	Discharge (<i>n</i> = 137)	One year after discharge (<i>n</i> = 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 ^a	Not applicable ^a	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 ^a	Not applicable ^a	67 (42%)	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%)
Peak $\dot{V}O_2$ (L/min)	1.01 (0.29)	1.13 (0.41)	1.21 (0.44)	1.31 (0.51)
Peak PO (W)	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 (%).

^aComplications or bed rest during inpatient rehabilitation; subjects assessed at start, three months and/or discharge are summarized and *n* = 160.

Peak $\dot{V}O_2$, peak oxygen uptake; peak PO, peak power output.

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. 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.

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

	Peak oxygen uptake (L/min)	Peak power output (W)
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	-10×10^{-4} (-16×10^{-4}, -4×10^{-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)	2×10^{-4} (-5×10^{-4} , 8×10^{-4})	n.s. ^f
Active rehabilitation* t2–t3 (days)	-2×10^{-4} (-8×10^{-4} , 5×10^{-4})	n.s.
Active rehabilitation* t4–t3 (days)	-8×10^{-4} (-14×10^{-4}, -2×10^{-4})	n.s.

All results are regression coefficients (95% CI) in the final multivariate model. Significant relations ($P \leq 0.05$) 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.

^aTime 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 a 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 -14W, (i.e. during active rehabilitation it improved 14W); the regression coefficient for t4–t3^a indicates that after inpatient rehabilitation it improved 7W.

^bn.e., variable not entered, because no relevant one-to-one association with fitness ($P > 0.10$).

^cIf 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').

^dIncrease in duration of 1 day was associated with a difference in peak oxygen uptake of -10×10^{-4} L/min, and peak power output of -0.06 W.

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

^fn.s., variable not significant in final multivariate model ($P > 0.05$).

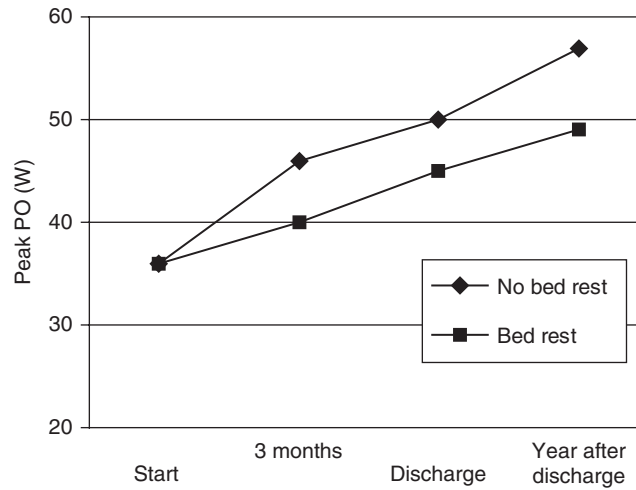


Figure 1 Data show the association between the peak power output (peak PO; W) and bed rest (0/1), when all other variables in the final model remain constant. During active rehabilitation (i.e. between start and discharge) the recovery of peak PO over time was negatively associated with bed rest.

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.²² 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 people with paraplegia.^{6,17} However, it does illustrate the necessity to utilize every opportunity to improve fitness following spinal cord injury. Our results may help clinicians to target prevention and treatment strategies more effectively 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 it is not the actual occurrence of complications but its consequences (i.e. bed rest) that are of influence. Our findings seem to correspond with studies in healthy, able-bodied subjects, which show the deconditioning effect of bed rest.^{24,25} Clinicians need to be aware of possible negative associations with bed rest. We would advise them to 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 programmes in the able-bodied population,^{26,27} but rehabilitation research needs to investigate how deconditioning during bed rest can be prevented in those with a spinal cord injury.

A possible increase in the severity of spasticity over time could explain the negative association found with fitness after discharge.²⁸ Both contractures and sudden contractions of muscles interfere with functioning in most patients.²⁹ Besides hampering performance during the actual exercise test, spasticity could lead to reduced activity, which may eventually affect fitness.²⁹ Considering this long-term effect, clinicians should assess spasticity at follow-up visits. Although the quantification

of spasticity is difficult,^{30,31} clinicians need to assess spasticity, investigate its interference with activities of daily life, and initiate treatment if necessary.^{21,29}

Results seem to correspond with the postulated downward spiral caused by the association between physical fitness and complications. The inherently low fitness may be negatively affected by its association with bed rest and spasticity. The association found with complications after discharge may 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.³² 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.³² 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.^{13,33} 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 programmes 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 postdischarge facilities, such as community care, home adaptations or assistive equipment.^{13,34} 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 second, because budgetary problems in health services ask for an efficient organization.¹⁴ 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.³⁵ In addition, we see it as a task for decision-makers, 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 tetraplegia. This may have influenced results, but the analyses allowed us to include longitudinal data with a different group composition.²² 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.⁴ 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,^{21,30,31} their binary scores need to be considered when interpreting data. This recoding enabled us to investigate their association with fitness, bearing in mind 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 unfortunately could 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.

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Competing interests

None declared.

Contributors

JBB, HJS, MPB, AJD and LHW initiated the study. All authors contributed to the design and monitored progress. JAH, JBB, LHW, AJD and MWP were responsible for the methodological strategy. JAH performed the data analyses. JAH, JBB, LHW, HJS, TAS and MPB interpreted the data. JAH wrote the manuscript. All authors

critically commented on drafts and revisions, and approved this version of the manuscript.

References

- 1 Stewart MW, Melton-Rogers SL, Morrison S, Figoni SF. The measurement properties of fitness measures and health status for persons with spinal cord injuries. *Arch Phys Med Rehabil* 2000; **81**: 394–400.
- 2 American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*, sixth edition. Lippincott, Williams and Wilkins, 2000.
- 3 Noreau L, Shephard RJ. Spinal cord injury, exercise and quality of life. *Sports Med* 1995; **20**: 226–50.
- 4 van der Woude LH, Bouten C, Veeger HE, Gwinn T. Aerobic work capacity in elite wheelchair athletes: a cross-sectional analysis. *Am J Phys Med Rehabil* 2002; **81**: 261–71.
- 5 Teasell RW, Arnold JM, Krassioukov A, Delaney GA. Cardiovascular consequences of loss of supraspinal control of the sympathetic nervous system after spinal cord injury. *Arch Phys Med Rehabil* 2000; **81**: 506–16.
- 6 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**: 642–52.
- 7 Hjeltnes N, Jansen T. Physical endurance capacity, functional status and medical complications in spinal cord injured subjects with long-standing lesions. *Paraplegia* 1990; **28**: 428–32.
- 8 Manns PJ, McCubbin JA, Williams DP. Fitness, inflammation, and the metabolic syndrome in men with paraplegia. *Arch Phys Med Rehabil* 2005; **86**: 1176–81.
- 9 Cress ME, Meyer M. Maximal voluntary and functional performance levels needed for independence in adults aged 65 to 97 years. *Phys Ther* 2003; **83**: 37–48.
- 10 Dallmeijer AJ, van der Woude LH, Hollander AP, van As HH. Physical performance during rehabilitation in persons with spinal cord injuries. *Med Sci Sports Exerc* 1999; **31**: 1330–35.
- 11 Haisma JA, Bussmann JB, Stam HJ *et al.* Changes in physical capacity during and after inpatient rehabilitation in subjects with a spinal cord injury. *Arch Phys Med Rehabil* 2006; **87**: 741–48.
- 12 Janssen TW, van Oers CA, Rozendaal EP, Willemsen EM, Hollander AP, van der Woude LH. Changes in physical strain and physical capacity

- in men with spinal cord injuries. *Med Sci Sports Exerc* 1996; **28**: 551–59.
- 13 Post MW, Dallmeijer AJ, Angenot EL, van Asbeck FW, van der Woude LH. Duration and functional outcome of spinal cord injury rehabilitation in the Netherlands. *J Rehabil Res Dev* 2005; **42**: 75–85.
 - 14 Eastwood EA, Hagglund KJ, Ragnarsson KT, Gordon WA, Marino RJ. Medical rehabilitation length of stay and outcomes for persons with traumatic spinal cord injury—1990–1997. *Arch Phys Med Rehabil* 1999; **80**: 1457–63.
 - 15 Cardenas DD, Hoffman JM, Kirshblum S, McKinley W. Etiology and incidence of rehospitalization after traumatic spinal cord injury: a multicenter analysis. *Arch Phys Med Rehabil* 2004; **85**: 1757–63.
 - 16 Chen D, Apple DF Jr., Hudson LM, Bode R. Medical complications during acute rehabilitation following spinal cord injury – current experience of the model systems. *Arch Phys Med Rehabil* 1999; **80**: 1397–401.
 - 17 Janssen TW, Dallmeijer AJ, Veeger DJ, van der Woude LH. Normative values and determinants of physical capacity in individuals with spinal cord injury. *J Rehabil Res Dev* 2002; **39**: 29–39.
 - 18 Maynard FM Jr., Bracken MB, Creasey G et al. International standards for neurological and functional classification of spinal cord injury. American Spinal Injury Association. *Spinal Cord* 1997; **35**: 266–74.
 - 19 van der Woude LH, de Groot G, Hollander AP, van Ingen Schenau GJ, Rozendal RH. Wheelchair ergonomics and physiological testing of prototypes. *Ergonomics* 1986; **29**: 1561–73.
 - 20 Lance JW. Spasticity: disordered motor control. In Feldman RG, Young RR, Koella WP eds. *Symposium synopsis*. Year Book Medical Publishers 1980: 485–95.
 - 21 Burchiel KJ, Hsu FP. Pain and spasticity after spinal cord injury: mechanisms and treatment. *Spine* 2001; **26**: S146–60.
 - 22 Twisk JW. *Applied longitudinal data analysis for epidemiology; a practical guide*. Cambridge University Press, 2003.
 - 23 Rasbash J, Browne W, Goldstein H et al. *A user's guide to MLwiN*. Institute of Education, London, 2002.
 - 24 Convertino VA. Cardiovascular consequences of bed rest: effect on maximal oxygen uptake. *Med Sci Sports Exerc* 1997; **29**: 191–96.
 - 25 Capelli C, Antonutto G, Kenfack MA et al. Factors determining the time course of VO₂(max) decay during bedrest: implications for VO₂(max) limitation. *Eur J Appl Physiol* 2006; **98**: 152–60.
 - 26 Rittweger J, Belavy D, Hunek P et al. Highly demanding resistive vibration exercise program is tolerated during 56 days of strict bed-rest. *Int J Sports Med* 2006; **27**: 553–59.
 - 27 Bleeker MW, De Groot PC, Rongen GA et al. Vascular adaptation to deconditioning and the effect of an exercise countermeasure: results of the Berlin Bed Rest study. *J Appl Physiol* 2005; **99**: 1293–300.
 - 28 Maynard FM, Karunas RS, Waring WP. Epidemiology of spasticity following traumatic spinal cord injury. *Arch Phys Med Rehabil* 1990; **71**: 566–69.
 - 29 Lechner HE, Frotzler A, Eser P. Relationship between self- and clinically rated spasticity in spinal cord injury. *Arch Phys Med Rehabil* 2006; **87**: 15–19.
 - 30 Biering-Sorensen F, Nielsen JB, Klinge K. Spasticity-assessment: a review. *Spinal Cord* 2006; **44**: 708–22.
 - 31 Patrick E, Ada L. The Tardieu Scale differentiates contracture from spasticity whereas the Ashworth Scale is confounded by it. *Clin Rehabil* 2006; **20**: 173–82.
 - 32 Braddom R, Buschbacher R, Dumitru D, Johnson E, Matthews D, Sinaki M. *Physical medicine and rehabilitation*, second edition. Saunders, 2000.
 - 33 Scivoletto G, Morganti B, Molinari M. Neurologic recovery of spinal cord injury patients in Italy. *Arch Phys Med Rehabil* 2004; **85**: 485–89.
 - 34 Bloemen-Vrencken JH, de Witte LP. Post-discharge nursing problems of spinal cord injured patients: on which fields can nurses contribute to rehabilitation?. *Clin Rehabil* 2003; **17**: 890–98.
 - 35 Burns AS, Ditunno JF. Establishing prognosis and maximizing functional outcomes after spinal cord injury: a review of current and future directions in rehabilitation management. *Spine* 2001; **26**: S137–45.