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ORIGINAL ARTICLE

# Prognostic Models for Physical Capacity at Discharge and 1 Year Postdischarge From Rehabilitation in Persons With Spinal Cord Injury

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ABSTRACT. Haisma JA, van der Woude LH, Stam HJ, Bergen MP, Sluis TA, de Groot S, Dallmeijer AJ, Bussmann JB. Prognostic models for physical capacity at discharge and 1 year postdischarge from rehabilitation in persons with spinal cord injury. Arch Phys Med Rehabil 2007;88:1694-703.

**Objective:** To develop prognostic models for physical capacity at discharge and 1 year after discharge from inpatient rehabilitation in persons with spinal cord injury (SCI).

**Design:** Inception cohort; data collected at start of rehabilitation (n=104), at discharge (n=81), and 1 year later (n=74).

**Setting:** Eight Dutch rehabilitation centers.

**Participants:** Patients with SCI at initial rehabilitation.

**Interventions:** Not applicable.

**Main Outcome Measures:** Physical capacity determined by endurance capacity (peak oxygen uptake [$Vo_2$peak, in L/min] and power output [POpeak, in watts]) during a maximal exercise test, arm muscle strength, and respiratory function. Multiple regression models, either with or without prior outcome, evaluated subject, lifestyle, and lesion-related predictors.

**Results:** Only start $Vo_2$peak contributed to the prediction of discharge $Vo_2$peak ($R^2$=.51). Discharge $Vo_2$peak 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 conservative stabilization of the 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 in establishing prognoses. Although their accuracy warrants caution in their application, models could complement clinical expertise when informing patients about expected physical outcome and identifying those at risk of low physical capacity.

**Key Words:** Exercise test; Forced expiratory volume; Muscle strength; Prognosis; Rehabilitation; Spinal cord injuries.



AFTER SPINAL CORD INJURY (SCI), there are several reasons why it is important to predict a patient's physical capacity, defined as the ability of muscles and the cardiorespiratory system to maintain a certain level of activity.[1] 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.[2,3] Second, the prediction of physical capacity at discharge from rehabilitation may provide the patient with rehabilitation goals.[4] Third, prognosis of outcome 1 year after discharge may indicate the necessity of outpatient training, assistive devices, and other postdischarge care.[5,6] Finally, prognoses of physical capacity partly indicate functional consequences, expected levels of well-being, and patients who are at risk for complications.[7-9] In summary, during and after SCI rehabilitation, insight into a patient's expected physical and functional capacities could help set realistic goals, target screening and interventions, facilitate planning for postdischarge care, and justify follow-up visits.

Previous studies[3,10-12] 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. Furthermore, the prognostic models that were developed had different shortcomings.[13,14] First, the outcome measure may have been limited by a ceiling effect, which would hamper the prediction of outcome at a later phase of recovery.[2,4,14] Second, often only 1 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.[1,14] Furthermore, because most people with SCI use wheelchairs, the endurance capacity (ie, the peak oxygen uptake [$Vo_2$peak] and peak power output [POpeak] during a wheelchair exercise test) is related to functioning. Therefore, the endurance capacity may give a more valid functional prognosis than would muscle strength alone.[15,16] Third, earlier studies did not always report the prediction accuracy of models.[17] A model's accuracy, that is, whether the outcome it predicts corresponds with the observed outcome, partly determines its clinical relevance.[18,19]

The rehabilitation of patients with SCI would not only benefit from an accurate prediction of outcome, but also from the identification of predictors that can be modified. Unfortunately,

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most known determinants of physical capacity—such as age, sex, and level of the lesion—can be considered, but are not changeable.[11,12] Some modifiable aspects of lifestyle (eg, smoking or alcohol use) and management (eg, stabilization of the spine) have been associated with physical capacity[7,10,20-23]; however, causality cannot be established from the available cross-sectional data for subjects with SCI. If it could be demonstrated that giving up smoking, increasing participation in work and/or sports activities, moderating alcohol or dietary intake, and stabilizing the spine (by surgical fixation or by wearing a halo or corset) predict a favorable outcome, we might have means to enhance physical capacity during an early phase of recovery.

Our purpose in this study was to develop prognostic models for 4 aspects of physical capacity (ie, $V_{O_2}$peak, POpeak, arm muscle strength, respiratory function) in wheelchair-dependent subjects with SCI. We assessed the contributions of modifiable characteristics (smoking, alcohol consumption, body mass index [BMI], spine stabilization) and of nonmodifiable characteristics (age, sex, education, employment, lesion level) at the start of inpatient rehabilitation in predicting physical capacity at discharge, and the contribution of these characteristics at discharge in predicting outcome 1 year after discharge.

## 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 SCI patients. Patients were eligible for inclusion in the study if they were wheelchair dependent, were between 18 and 65 years of age, sufficiently comprehended the Dutch language to understand the study's purpose, and had no progressive disease or psychiatric condition.[11] All subjects followed a regular inpatient rehabilitation program in specialized spinal cord units. Clinicians at these units largely provide their care according to guidelines supported by the Dutch Flemish Spinal Cord Society.[24] Although these guidelines recommend the concentration of postdischarge care at specialized centers,[24] some subjects were seen for follow-up or training at these centers, whereas others visited an outpatient clinic closer to their homes. The Medical Ethics Committee of Rehabilitation Center Limburg approved the experimental protocol, and all subjects gave their written informed consent prior to participation.

### Procedure

Data were obtained at the start of active rehabilitation, when subjects began functional, endurance, and strength training in a wheelchair. Active rehabilitation began when a subject could sit in a wheelchair for at least 3 consecutive hours. Subsequently, data were obtained at discharge from inpatient rehabilitation and 1 year after discharge.[11] We used prior outcomes 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 active rehabilitation and at discharge (when predicting discharge outcome), or both at discharge and 1 year later (when predicting outcome 1 year after discharge). We followed a standardized protocol whereby 1 research assistant was responsible for data collection at each rehabilitation center, so as to optimize the quality of the data. Furthermore, all 8 research assistants were experienced rehabilitation professionals who received training and instructions both before and during the study. Additionally, the equipment (treadmill,[a] Oxycon Delta,[b] handheld dynamometer[c]) was calibrated before use; the same equipment was used at subsequent assessments.

### Physical Capacity

We determined endurance capacity by the $V_{O_2}$peak 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 in the 2 hours before the exercise test. Additionally, subjects were asked to void their bladder before the test. During 2 blocks of submaximal exercise, a suitable treadmill velocity was chosen for the maximal exercise test. The submaximal exercise was followed by 2 minutes of rest, after which the actual graded maximal exercise test began. They were encouraged to maintain the treadmill speed, even as its inclination was increased .36° every minute. The test ended when the subject was completely exhausted or could no longer maintain the treadmill speed.[11,16] The $V_{O_2}$peak (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.[25] It was defined as the power output at the highest inclination that the subject could maintain for at least 30 seconds.

The strength of both arms (shoulder abductors, internal and external rotators, elbow flexors and extensors [10 muscle groups]) was determined with the handheld dynamometer for those muscles with a strength of at least grade 3 during manual muscle testing.[11,26] Subsequently, we summed the maximum force (in newtons) of the 10 muscle groups.[11] Sum scores were only calculated if strength could be determined in those 10 muscle groups. Respiratory function was determined from a standardized lung function test.[27] 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.[27]

### Predictors

Because prior physical capacity may not be known at discharge or at follow-up 1 year after discharge, we made models with and without prior physical capacity. For the models that included 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 contributions of both modifiable and nonmodifiable characteristics.

### Subject and Lifestyle Characteristics

At the start of rehabilitation, we collected self-report information about date and place of birth, education, smoking habits, alcohol use, and hours of sports participation and employment before the injury. 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 subject as a smoker based on his/her cigarette use before the lesion (smoker, 1; nonsmoker, 0). Similarly, to determine their alcohol use, subjects were asked whether they drank beer, wine, or liquor before 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. We calculated age and BMI (calculated as $kg/m^2$) at each assessment.

### Lesion Characteristics

Also at each assessment, a physician determined the 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.[28] 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; 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.[29] Multiple linear regression analyses revealed several models predicting 4 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 at the start 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 ($P\leq.05$) 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 physical capacity 1 year after discharge. The physical capacity at discharge was included by forced entry, and the other 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 outcomes. 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.[18] 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, for example, that 81 subjects were included when predicting the POpeak at discharge. They had started their rehabilitation 104±66 days postinjury. Seventy-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.[11,30] Of all patients admitted with SCI during the study period, however, relatively few (48%) had a complete lesion.[30] The number of subjects included when predicting different aspects of physical capacity on the 2 occasions did not coincide for several reasons. First, hindered by cardiovascular contraindications or limited wheelchair skills or complications, not all subjects completed a maximal exercise test on all 3 testing occasions.[11] 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 shows the mean physical capacity of 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. Results of the model with prior outcome and the model without prior outcome for each

**Table 1: Subject, Lifestyle, and Lesion Characteristics at the Start and at Discharge From Rehabilitation as Potential Predictors of Endurance Capacity at Discharge and 1 Year Postdischarge From Rehabilitation, 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 ($kg/m^2$) | 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 stabilization of spine (%) | 54 | 57 |
| Halo or corset (%) | 28 | 37 |

NOTE. 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.

**Table 2: Physical Capacity as Predictor or as Outcome**

| | Predicting Physical Capacity at Discharge | | | Predicting Physical Capacity 1 Year After Discharge | | |
|---|---|---|---|---|---|---|
| Variable | n | Predictor (start) | Outcome (discharge) | n | Predictor (discharge) | Outcome (1y later) |
| Vo$_2$peak (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$_1$ (% of expected)* | 113 | 77±23 | 87±20 | 93 | 87±20 | 90±20 |

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

aspect of physical capacity are given. Table 4, for example, shows that the regression equation predicting discharge Vo$_2$peak is: 0.25+1.01×Vo$_2$peak at the start. This means that only Vo$_2$peak at the start contributed to the Vo$_2$peak at discharge. Table 5 shows that, again, only the discharge Vo$_2$peak contributed to its prediction 1 year later. The

**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$_2$peak (L/min) | | POpeak (W) | | Arm Muscle Strength (N) | | FEV$_1$ (%) | |
|---|---|---|---|---|---|---|---|---|
| Variable | Discharge | Year After Discharge | Discharge | Year After Discharge | Discharge | Year After Discharge | Discharge | Year After Discharge |
| Age at prior assessment (y) | | | | | | | | |
| <40 | 1.36±0.40 | 1.35±0.56 | 47±19 | 49±26 | 1981±531† | 1961±556 | 85±18 | 88±18 |
| ≥40 | 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±0.42* | 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 (h/wk) | | | | | | | | |
| <3 | 1.27±0.41 | 1.31±0.50 | 41±20 | 45±25 | 1756±522 | 1792±518 | 80±23 | 84±24 |
| ≥3 | 1.33±0.41 | 1.32±0.56 | 47±19 | 51±26 | 1879±596 | 1889±651 | 84±20 | 88±18 |

NOTE. Values are mean ± SD. Comparisons between subject groups made with independent *t* tests.
**P*≤.05; †*P*≤.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 Including Predictors Determined at the Start of Rehabilitation**

| | $Vo_2$peak (L/min) (n=75) | | | | POpeak (W) (n=81) | | | | Arm Muscle Strength (N) (n=63) | | | | $FEV_1$ (%) (n=113) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | With Start $Vo_2$peak | | Without Start $Vo_2$peak | | With Start POpeak | | Without Start POpeak | | With Strength at Start | | Without Strength at Start | | With Start $FEV_1$ | | Without Start $FEV_1$ | |
| Variable | $\beta \pm$ SE | % | $\beta \pm$ SE | % | $\beta \pm$ SE | % | $\beta \pm$ SE | % | $\beta \pm$ SE | % | $\beta \pm$ SE | % | $\beta \pm$ SE | % | $\beta \pm$ 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 | NE | | 0.80±0.08†† | 65 | NE | | 0.57±0.07†† | 70 | NE | | 0.72±0.05†† | 59 | NE | |
| Sex* | NS | | 0.40±0.10†† | 13 | 10±3†† | 5 | 20±3†† | 23 | 401±63†† | 9 | 674±73†† | 39 | NS | | NS | |
| Age (y) | NS | | NS | | −0.23±0.08** | 2 | −0.29±0.12 | 3 | −8.08±1.90†† | 4 | −12±3†† | 9 | NS | | NS | |
| Education† | NS | | 0.13±0.05 | 5 | NS | | NS | | NS | | 100±44 | 3 | NS | | NS | |
| Employment‡ | NS | | NS | | NS | | NS | | NS | | NS | | 0.12±0.06 | 2 | NS | |
| Smoking§ | NS | | NS | | NS | | −8±3 | 3 | NS | | NS | | NS | | −10±4 | 5 |
| BMI (kg/$m^2$) | NS | | NS | | NS | | 1.20±0.43** | 2 | NS | | 30±9** | 4 | NS | | NS | |
| Lesion level‖ | NS | | 0.26±0.11 | 6 | 8±3 | 2 | 21±4†† | 20 | 177±69 | 2 | 456±83†† | 15 | NS | | NS | |
| Surgically stabilized spine¶ | NS | | NS | | NS | | NS | | NS | | NS | | 6±2 | 2 | NS | |
| Halo or corset# | NS | | NS | | NS | | 8±3 | 4 | NS | | NS | | NS | | NS | |
| Accuracy | $R^2$=.51 | | $R^2$=.24 | | $R^2$=.73 | | $R^2$=.54 | | $R^2$=.84 | | $R^2$=.70 | | $R^2$=.63 | | $R^2$=.05 | |
| | RSD=.29 | | RSD=.36 | | RSD=10 | | RSD=13 | | RSD=203 | | RSD=277 | | RSD=12 | | *RSD=20 | |

NOTE. $P \leq .05$ unless as indicated below.
Abbreviations: NE, not entered; NS, not significant; PC, physical capacity; RSD, residual standard deviation; SE, standard error.
*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.
**$P \leq .01$; ††$P \leq .001$.

**Table 5: Prognostic Models for Physical Capacity 1 Year After Discharge: Stepwise-Forward Multiple Linear Regression Analyses Including Predictors Determined at Discharge From Inpatient Rehabilitation**

| | Vo2peak* (L/min) (n=73) | | | | POpeak† (W) (n=74) | | | | Arm Muscle Strength (N) (n=55) | | | | $FEV_1$ (%) (n=93) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | With Discharge $Vo_2$peak | | Without Discharge $Vo_2$peak | | With Discharge POpeak | | Without Discharge POpeak | | With Discharge Strength | | Without Discharge Strength | | With Discharge $FEV_1$ | |
| 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 | NE | | 0.86±0.06¶ | 79 | NE | | 1.04±0.06¶ | 82 | NE | | 0.86±0.05¶ | 74 |
| Sex* | NS | | NS | | NS | | 13±5 | 4 | NS | | 732±91¶ | 33 | NS | |
| Age (y) | NS | | NS | | NS | | −0.35±0.17 | 3 | NS | | −17±4¶ | 7 | NS | |
| Ethnicity | NS | | NS | | NS | | NS | | −190±75 | 2 | −383±112‖ | 5 | NS | |
| Education† | NS | | NS | | NS | | NS | | NS | | 127±50 | 4 | NS | |
| Employment‡ | NS | | 0.01±0.00‖ | 9 | 0.20±0.07‖ | 1 | 0.48±0.11¶ | 15 | NS | | NS | | NS | |
| Lesion level§ | NS | | 0.32±0.14 | 5 | 8±4 | 1 | 30±6¶ | 20 | NS | | 568±102¶ | 12 | NS | |
| BMI (kg/m²) | NS | | NS | | NS | | NS | | NS | | 46±12‖ | 7 | NS | |
| 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 | |

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

POpeak at the start, sex, age, and level of the lesion predicted POpeak at discharge (see table 4). The discharge POpeak, hours of employment before injury, and level of the lesion contributed to the prediction of POpeak 1 year later (see table 5).

Several nonmodifiable 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 further 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. Overall, POpeak and muscle strength were relatively well predicted, with explained variances ranging between 42% and 84%. Without prior outcome, $Vo_2$peak 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.[29] 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 nonmodifiable predictors. Considering the proportion of variance explained by our models, they compared favorably to those predicting physical capacity in different populations,[26,31] and to those predicting other health measures after SCI.[32-35] 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. This, however, hampers a constructive comparison with models that predict other outcome

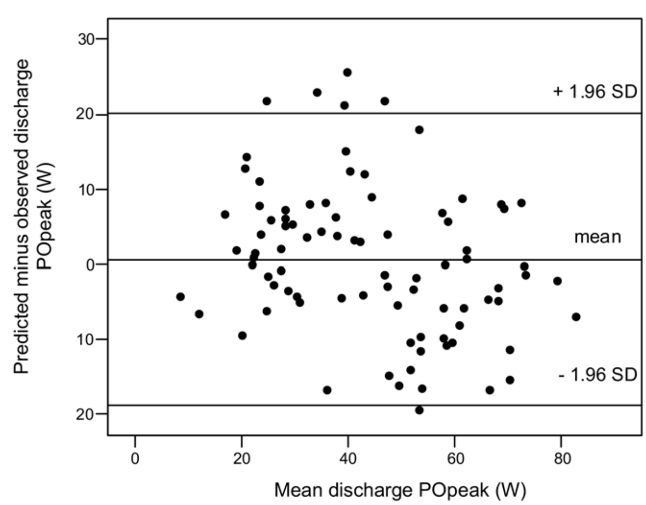


**Fig 1. Bland-Altman plot illustrates the distribution of the differences between the observed and the predicted discharge POpeak.**

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 after SCI, therefore, it may be more predictable than subjective measures such as life satisfaction.[1,32] At the same time, physical capacity may be influenced by natural recovery, training, motivation and concurrent disease,[1,5] which could make it less predictable than the ability to walk or the quality of life, which are both stable during different phases of recovery.[6,36] Second, unique predictors (such as level of lesion or stabilization of the spine) apply to those with SCI but are not generalizable.[8,26] 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.[10,19,20] Knowledge of the predicted physical capacity may provide objective information about a patient's expected functional status, which helps to evaluate symptoms, the effect of interventions, and the need to refer patients to postdischarge facilities.[2,19]

One must remember, however, that because the accuracy of prognostic models is limited,[18,19] they complement clinical expertise, and caution is needed when applying them as decision tools in rehabilitation practice. Below we discuss the possible value of these prognostic models as informative guidelines, and in identifying SCI patients who are at risk of 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,[17,32] which alone explained 51% to 82% of the variance. The finding that characteristics such as sex and level of lesion 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, beginning at an early phase of rehabilitation. Despite the strong association with prior physical capacity, a previous study[11] fortunately showed that physical capacity did change during rehabilitation and that some aspects continued to change after discharge. In agreement with that study,[11] 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. Additionally, factors such as 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. It would not have been rational, however, to include rehabilitation characteristics, unknown at the start of 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 investigated in this study (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 receive attention at follow-up visits.[37]

## 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 $Vo_2$peak and respiratory function. The POpeak may be influenced by a subject's skills and efficiency. Therefore, it is more closely related to functioning than $Vo_2$peak.[38] $Vo_2$peak is related to organ function and is therefore more influenced by complications.[39] Respiratory function was less predictable because of several possible reasons.

First, respiratory function was expressed as a percentage of the expected volume 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 predictors, such as comorbidity, that we did not investigate 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.[18] Because a small proportion in variance of respiratory function was explained, the clinical relevance of these models is limited. The prediction of POpeak and muscle strength could, however, complement clinical professional knowledge when patients are informed about the outcome and when training and follow-up programs are being planned.

## Prognostic Factors

Table 3 illustrates different levels of physical capacity in several subject groups, but these differences must be interpreted with care; multivariate models were needed to establish associations. The one-to-one associations we 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.[14,23,26,40] These models also identified other predictors, however, which made small but significant contributions to the explained variance, some of which are modifiable.

Not surprisingly, a history of smoking predicted a poor respiratory function, but the negative association found with the peak power output suggests that quitting smoking may lead to a more favorable physical capacity.[23,41] In the able-bodied population, moderate alcohol consumption is suggested to be protective of cardiovascular disease, 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 undetermined.[41] Another study[42] showed that alcohol use after SCI was similar to that of the able-bodied population, but revealed an increased incidence in alcohol abuse, which may negatively affect health. Therefore, future research should focus on a more detailed investigation of the effect of alcohol use and abuse after SCI.

BMI was, unexpectedly, a positive predictor of physical capacity. Just as with other indicators of body composition, such as skinfolds and abdominal circumference, it is difficult to interpret the BMI after SCI.[43] In an early phase of recovery, a low BMI may be attributed to a catabolic state after injury, concurrent pathology, or complications. Therefore, a low BMI may be negatively associated with physical capacity. In contrast, relative inactivity, altered metabolism, and fat distribution during a later phase of recovery may cause an increase in BMI to be negatively associated with physical capacity.[7,31]

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 participation in sports did not contribute to the prediction of physical capacity.[8,40] It may be that sports participation changed after the lesion. Prospective data on sports participation, its barriers, and its association with physical capacity are needed.[44] Contrary to others, our models revealed a positive predictive effect of both conservative and surgical stabilization of the spine.[17,21] Perhaps the immobilization period is shorter after surgical stabilization, resulting in an early start of rehabilitation and insignificant deconditioning.[24] Because stabilization appeared to have no prognostic value after discharge, its influence may be restricted to an early phase of recovery.

Predictors that cannot be modified are valuable because they may identify people at risk of having a low physical capacity. In this study, more hours of paid employment before injury positively predicted physical capacity, especially after discharge, which may correspond with findings that previously employed subjects had a shorter inpatient stay and that physical capacity was associated with employment after injury.[3,9,34] 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 subjects may return to a more active lifestyle because of being employed after discharge. Further prospective data are needed to establish these proposed explanations.[45] Although there was no significant colinearity 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 such as sex.[3,29] The promising outcomes for subjects with a habit of working indicates the importance of vocational rehabilitation, and clinicians must create and evaluate opportunities for patients to return to employment after discharge from rehabilitation.[45]

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 in an economic disadvantageous position and having less access to resources.[34,46] In this study, foreign subjects originated from different countries, had diverse cultural backgrounds, and each differed in their comprehension of the Dutch language. Therefore, our results cannot be generalized, and it is difficult to compare them with the above-mentioned American studies.

The positive predictive value of education has been reported previously,[17,47] but it seems contradictory to the finding by Eastwood et al[34] that the less educated had a shorter inpatient rehabilitation stay. Hypothesizing, it might be that those with lower levels 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 subjects who previously had desk jobs, for example. In contrast, those with a higher level of education may have had more knowledge of how (and the 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 and not just to those who show an interest in a healthy lifestyle.

### Study Limitations

Some methodologic limitations of the study must 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.[30] In comparison with other studies, however, which focused mainly on young male athletes with paraplegia,[14,40] our data seem to better reflect outcome in a general population with SCI.[30] Ideally the difference between the predicted and the observed outcome is as small as possible. This brings us to a second limitation because, as figure 1 illustrates, we found discrepancies between these values.[29] These discrepancies could be even larger if the models had been cross-validated, that is, if we had compared the predicted outcome based on these models with the observed outcome in another population. Therefore, future cross-validation with other populations seems essential before the clinical validity of the prognostic models can be established.

A third consideration is the variance that could not be explained by the models. Factors that we did not investigate (such as motivation, complications, rehabilitation or training, living conditions and social support) may have contributed to the level of physical capacity. In summary, some caution is needed when these models are used as clinical guidelines. We do not recommend them 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 that showed that POpeak and arm muscle strength are relatively predictable in comparison with $\text{V}\text{O}_2$peak and respiratory function. Because the prediction of physical capacity is more accurate with prior outcome, we recommend the assessment of physical capacity at an early phase of recovery. Furthermore, the systematic monitoring of physical capacity may help set realistic targets during and after inpatient rehabilitation. In addition to estimating prognoses, the models provide insight into the possible positive predictive effects of not smoking, employment, and stabilization of the spine. Caution is warranted concerning the accuracy of the prognostic models, but in combination with clinical expertise and knowledge of the individual patient, they may provide meaningful information about the patient's expected physical outcome. This could help in the evaluation of symptoms and the effect of interventions, and the need to refer patients to postdischarge facilities.

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## Suppliers

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