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A Single Dermatome Clinical Prediction Rule for Independent Walking 1 Year After Spinal Cord Injury

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Abstract

Objective: To derive and validate a simple, accurate CPR to predict future independent walking ability after SCI at the bedside that does not rely on motor scores and is predictive for those initially classified in the middle of the SCI severity spectrum.

Design: Retrospective cohort study. Binary variables were derived, indicating degrees of sensation to evaluate predictive value of pinprick and light touch variables across dermatomes. The optimal single sensory modality and dermatome was used to derive our CPR, which was validated on an independent dataset.

Setting: Analysis of SCI Model Systems dataset.

Participants: Individuals with traumatic SCI. The data of 3679 participants (N=3679) were included with 623 participants comprising the derivation dataset and 3056 comprising the validation dataset.

Main Outcome Measures: Self-reported ability to walk both indoors and outdoors.

Results: Pinprick testing at S1 over lateral heels, within 31 days of SCI, accurately identified future independent walkers 1 year after SCI. Normal pinprick in both lateral heels provided good prognosis, any pinprick sensation in either lateral heel provided fair prognosis, and no sensation provided poor prognosis. This CPR performed satisfactorily in the middle SCI severity subgroup.

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Conclusions: In this large multi-site study, we derived and validated a simple, accurate CPR using only pinprick sensory testing at lateral heels that predicts future independent walking after SCI.

Keywords

Clinical prediction rule; Pinprick; Rehabilitation; Spinal cord injury; Walking

The recovery of walking ability is a top priority early after traumatic spinal cord injury (SCI).[1] Because this patient group is so heterogeneous in nature, predicting future independent walking ability is challenging.[2] Clinical prediction rules (CPRs) have been derived to aid in this task.[3-6] However, problems with these CPRs include complex equations with multiple predictor variables limiting true clinical utility as well as suboptimal definitions of independent walking.[3,7,8] As an example, van Middendorp et al's CPR uses 5 predictor variables (1 age, 2 motor, and 3 sensory) that are then weighted and summed to first calculate the CPR score, the CPR score is then input into a logistical regression model (ie, sigmoid function) to calculate the probability of walking.[3] Hicks et al simplified this CPR to only 3 predictor variables (1 age, 1 motor, and 1 sensory), but their CPR still requires calculating a weighted sum, which is then input into a logistical regression model (also sigmoid function) to calculate the probability of walking.[4] A recent study found that the van Middendorp CPR provided clinical utility for only 45% of patients with traumatic SCI and also found that only 18% of experienced clinicians found this CPR useful for established prognosis.[9] There is a need for a more simplified CPR that offers better clinical translation.

Using existing residual lower extremity motor function as a walking predictor works for those on either end of the SCI severity spectrum (ie, no motor recovery vs substantial motor recovery),[10,11] but this is arguably a clinically-obvious prognosis. Indeed, motor-based CPRs do not work as well for those initially classified in the middle of the SCI severity spectrum where only minimal sensorimotor function is present.[12] There is need for a clinical tool to predict future independent walking ability after SCI that works for those in the middle of the SCI severity spectrum and does not rely on motor scores.

The presence or absence of sensing pinprick below the level of SCI has demonstrated promise to serve as a predictor variable for future walking ability.[10,13-17] Per the American Spinal Injury Association Impairment Scale (AIS), people classified with AIS B injuries (sensory sparing but motor complete) under 50 years old, having substantial pinprick sensation in the lower extremities was associated with an increased likelihood of household ambulation 1 year after SCI.[15] Dermatomal testing of pinprick sensation is 1 part of the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) examination,[18] which is the criterion standard SCI clinical exam. The full ISNCSCI exam may take longer than 45 minutes to complete[19] and may not be feasible during the acute phase of SCI due to sedation or long bone fracture. Thus, a CPR using more targeted sensory information may be beneficial.

Light touch sensation may be another variable to consider for the prediction of ambulation, as dermatomal testing of light touch is another part of the ISNCSCI exam and also does not

rely on motor scores.[18] Two established CPRs included S1 dermatome lower extremity light touch scores as predictor variables for future walking.[3,4] Questions remain as to what type of sensory testing may best predict independent walking after SCI.

The objective of this study was to use a large, multisite SCI dataset to derive and independently validate a simple and accurate CPR to predict future independent walking ability after SCI at the bedside that does not rely on motor scores and is predictive for those initially classified in the middle of the SCI severity spectrum (AIS B and C injuries).

Methods

This was a retrospective analysis of SCI Model Systems (SCIMS) data from 12 centers in the United States of America. This study was approved by the local Institutional Review Board and complies with the Declaration of Helsinki standards.

Inclusion criteria

To be included in the study, each participant's dataset required the following variables to be available for analysis: diagnosis of traumatic SCI; cervical, thoracic, or lumbar level of injury; lower extremity pinprick and light touch sensory scores within 31 days after SCI; walking outcomes at 1 year after SCI; and data available from the national SCIMS database from April 2004 to March 2021.

Outcome measure and independent variables

Similar to previous studies, 2 outcome variables collected 1 year after SCI with yes/no answers were selected from the SCIMS Data Dictionary for the National SCI Database Form II: "Are you able to walk (with or without mobility aid) for 150 feet in your home?"[20] and "Are you able to walk (with or without mobility aid) for one street block outside?"[6,21] Independent walking was defined based on a "yes" answer to both self-reported ability to walk indoors 150 feet and outdoors 1 street block. Bilateral lower extremity sharp/dull discrimination (pinprick) and light touch sensory scores from the L3 through S4-5 dermatomes from the ISNCSCI examination, collected at the time of rehabilitation admission (≤31 days from SCI), were used to predict walking. Those who were not independent walkers were defined by a lack of an answer "yes" to both walking outcome questions. Thus, the outcome being tested was a binary variable, either independent walkers or not.

Deriving and validating the clinical prediction rule

Binary variables were derived for pinprick and light touch sensory scores at each dermatome that indicated normal sensation bilaterally (both left and right), normal sensation unilaterally (left or right), any sensation (normal or altered) bilaterally (left and right), and any sensation unilaterally (left or right). Next, a SCIMS center that had a large sample size and balanced number of independent walkers and non-independent walkers was chosen to derive the CPR (derivation dataset). Statistical analyses were conducted using Python (version=3.7.11) Scikit-Learn (version=0.21.2), and Scipy (version=1.7.3) libraries for machine-learning and scientific computing.

Positive and negative predictive values (PPV and NPV, respectively) are values that can be used to appraise the success of a clinical test for predicting whether a patient will truly have a desired outcome based on a positive or negative test result.[22] Using true and false positive counts along with true and false negative counts, the PPV assesses the probability of having the desired outcome based on a positive test result (ie, "yes" response to predictor variable), while NPV assesses the probability of not achieving the desired outcome based on a negative test result (ie, "no" response to predictor variable).[22] For this study, PPVs and NPVs were calculated across the full derivation dataset as well as the derivation subset including only those in the middle of the recovery spectrum (AIS B and C). Across 10,000 bootstrapped samples, 95% confidence intervals (CI) were calculated for each PPV and NPV of the binary variables. Considering both the whole derivation dataset along with a subset including only those in the middle of the recovery spectrum (AIS B and C), the single sensory modality and dermatome that first maximized the PPV (primary measure) and then the NPV (secondary measure) was identified. Pinprick and light touch predictor variables across all dermatomes (L3 through S4-5) were considered and assessed (see fig 1). The most optimal sensory modality (either pinprick or light touch) at the most optimal dermatome was selected to be used as the predictor variable. This single-sensory-modality-and-dermatome predictor variable was then used to derive the CPR (see fig 1), which was then validated on an independent dataset, using the patients from the other SCIMS centers (validation dataset). Attempting to boost predictive performance in the AIS B and C validation dataset subgroup, the CPR was applied to those under the age of 50 vs those 50 years and older. To investigate the possible influence of upper vs lower motor neuron injury, the derived CPR was also tested separately on participants within the validation dataset with only cervicothoracic neurologic level injuries (n=2826) and only lumbar neurologic level injuries (n=185). Finally, to study potential influence of the time of pinprick exam on predictive performance, we performed a sub-analysis on the validation dataset for 3 time windows of pinprick testing: within 0-3 days of SCI, within 4-7 days of SCI, or within 8-31 days of SCI.

Results

The derivation dataset consisted of 623 participants, with 261 independent walkers and 362 non-walkers. See table 1 for a summary of both the derivation and validation datasets. Pinprick at the L4 and S1 dermatomes yielded the optimal PPV (primary measure, 89% and 89%, respectively) and NPV (secondary measure, 82% and 81%, respectively) for predicting independent walking in the whole derivation dataset (fig 1). When considering the AIS B and C subset of the derivation dataset, pinprick at the S1 dermatome yielded the optimal PPVs (primary measure, 69%) and NPVs (secondary measure, 68%) for predicting independent walking (fig 2). Therefore, pinprick sensation at S1 was used to derive the CPR. See table 2 for a breakdown of the CPR prediction statistics, including true and false positives, true and false negatives, accuracy, sensitivity, specificity, PPV, and NPV.

In the whole derivation dataset, *normal pinprick sensation bilaterally at S1* had a PPV of 89% (95% CI=82%-95%) for independent walking. *Any pinprick sensation unilaterally at S1* had a PPV of 76% (95% CI=71%-81%) for independent walking. *Any pinprick sensation unilaterally at S1* had an NPV of 81% (95% CI=77%-85%) for independent walking. In the AIS B and C derivation subset (n=179, AIS B=61, AIS C=118), *normal pinprick*

sensation bilaterally at S1 had a PPV of 69% (95% CI=42%-93%), *any pinprick sensation unilaterally at S1* had a PPV of 60% (95% CI=49%-71%) and *any pinprick sensation unilaterally at S1* had an NPV of 68% (95% CI=59%-77%). Two variables, *normal pinprick sensation unilaterally at S1* and *any pinprick sensation bilaterally at S1*, provided inferior PPVs and NPVs in comparison with *normal pinprick sensation bilaterally at S1 and any pinprick sensation unilaterally at S1*. Therefore, these 2 variables (*normal pinprick sensation unilaterally at S1* and *any pinprick sensation bilaterally at S1*) were not considered for the CPR.

The validation dataset consisted of 3056 participants, with 1191 independent walkers and 1865 non-walkers. In the whole validation dataset, *normal pinprick sensation bilaterally at S1* had a PPV of 86% (95% CI=82%-89%) for independent walking. *Any pinprick sensation unilaterally at S1* had a PPV of 76% (95% CI=74%-79%) for independent walking. *Any pinprick sensation unilaterally at S1* had an NPV of 83% (95% CI=82%-85%) for independent walking.

In the AIS B and C validation subset (N=1034; AIS B=398, AIS C=636), *normal pinprick sensation bilaterally at S1* had a PPV of 67% (95% CI=55%-78%). *Any pinprick sensation unilaterally at S1* had a PPV of 54% (95% CI=50%-59%). *Any pinprick sensation unilaterally at S1* had an NPV of 75% (95% CI=72%-78%).

In the AIS B and C validation subset of those age less than 50 (N=575), *normal pinprick sensation bilaterally at S1* had a PPV of 81% (95% CI=66%-94%). *Any pinprick sensation unilaterally at S1* had a PPV of 63% (95% CI=56%-69%). *Any pinprick sensation unilaterally at S1* had an NPV of 74% (95% CI=69%-78%).

In the AIS B and C validation subset of those age 50 years and older (N=452), *normal pinprick sensation bilaterally at S1* had a PPV of 54% (95% CI=38%-70%). *Any pinprick sensation unilaterally at S1* had a PPV of 45% (95% CI=38%-52%). *Any pinprick sensation unilaterally at S1* had an NPV of 76% (95% CI=71%-81%).

In the validation dataset, 45 participants had missing neurologic injury level data and were excluded from the cervicothoracic and lumbar neurologic injury level analysis. In the lumbar SCI validation subset (N=185), *normal pinprick sensation bilaterally at S1* had a PPV of 96% (95% CI=88%-100%). *Any pinprick sensation unilaterally at S1* had a PPV of 83% (95% CI=76%-91%). *Any pinprick sensation unilaterally at S1* had an NPV of 44% (95% CI=34%-54%). In the cervicothoracic SCI validation subset (N=2826), *normal pinprick sensation bilaterally at S1* had a PPV of 85% (95% CI=81%-88%). *Any pinprick sensation unilaterally at S1* had a PPV of 75% (95% CI=73%-78%). *Any pinprick sensation unilaterally at S1* had an NPV of 85% (95% CI=84%-87%). See table 2 for a breakdown of the CPR prediction statistics for the lumbar SCI and cervicothoracic SCI validation subsets.

In the validation subset of those who received pinprick testing within 0-3 days of SCI (N = 49), *normal pinprick sensation bilaterally at S1* had a PPV of 87% (95% CI=67%-100%). *Any pinprick sensation unilaterally at S1* had a PPV of 93% (95% CI=81%-100%). *Any pinprick sensation unilaterally at S1* had an NPV of 59% (95% CI=38%-79%). In the validation subset of those who received pinprick testing within 4-7 days of SCI (N=599),

normal pinprick sensation bilaterally at S1 had a PPV of 93% (95% CI=88%-97%). *Any pinprick sensation unilaterally at S1* had a PPV of 87% (95% CI=83%-91%). *Any pinprick sensation unilaterally at S1* had an NPV of 72% (95% CI=67%-77%). In the validation subset of those who received pinprick testing within 8-31 days of SCI (N=2408), *normal pinprick sensation bilaterally at S1* had a PPV of 82% (95% CI=77%-87%). *Any pinprick sensation unilaterally at S1* had a PPV of 72% (95% CI=69%-75%). *Any pinprick sensation unilaterally at S1* had an NPV of 86% (95% CI=84%-87%). See table 3 for a breakdown of the CPR prediction statistics by time window of pinprick testing. See figure 3 depicting the CPR.

Discussion

In this large multi-site retrospective study, we derived and validated a CPR using only pinprick sensory testing at the lateral heels (ie, S1 dermatomes) within 31 days of SCI to accurately identify future independent walkers 1 year after SCI. For our full validation dataset, ≈9 of 10 people with SCI and normal pinprick sensation at both the left and right lateral heels endorsed independent walking, and ≈8 of 10 people with any pinprick at either the left or right lateral heels endorsed independent walking. In contrast, ≈8 of 10 people without any pinprick sensation unilaterally (ie, no pinprick sensation at either the left or right lateral heel) did not endorse independent walking. Importantly, for people initially classified within the middle of the SCI severity spectrum (ie, AIS B and C classification), who present the greatest challenge when predicting clinical trajectory, ≈7 of 10 with normal pinprick sensation at both the left and right lateral heels endorsed independent walking, while ≈8 of 10 people with no pinprick sensation at either the left or right lateral heel did not endorse independent walking.[12] This CPR provides clinicians with a tool that has predictive value for people across the recovery spectrum including those with AIS B and C injuries. Overall, we demonstrate that pinprick sensory testing at the S1 dermatome(s) can be used to accurately predict high level walking ability 1 year after SCI (both indoors and outdoors). Limiting the CPR to only the S1 dermatome provides a simple and accurate tool for predicting independent walking 1 year after SCI. Furthermore, the variable for this CPR can easily be obtained by assessing pinprick sensation at the lateral heels at bedside.

Our results are in alignment with previous studies that found pinprick sensation to be important in the prediction of future functional recovery. Waters et al found that 16% of people with motor complete SCI who had bilateral sacral pinprick sensation eventually regained some voluntary movement in the lower extremities.[10] In another study by Crozier et al in 27 people with initial motor complete SCI, 89% of those with pinprick sensation below the zone of injury recovered walking ability of at least 200 feet.[13] In a more recent study of 131 people with initial motor complete SCI, Oleson et al found that walking ability was significantly better 1 year post injury for a subgroup of people with pinprick preserved in at least 50% of lower extremity dermatomes (L2 through S1).[14]

We believe that our CPR is straightforward to implement at the bedside. After SCI, if the individual can perceive pinprick sensation at the right and left lateral heels and it feels normal, then there is a good prognosis for recovering future independent walking ability. If the individual reports any pinprick sensation in either lateral heel, even if it feels different

than other unimpaired skin areas (ie, face), then there is a fair prognosis for recovering future independent walking ability. If the individual cannot feel pinprick sensation at either lateral heel, then there is a poor prognosis for recovering future independent walking ability. For these fair and poor prognosis cases, wheelchair training and compensatory strategies may be prioritized,[23,24] and additional neuromodulation may be necessary to achieve improved voluntary mobility and/or walking.[25-29]

Regarding an optimal time window of pinprick exam to optimize predictive performance, we found that the earlier time windows (within 0-3 days and 4-7 days of SCI) provided better PPV than the later time window (within 8-31 days of SCI). However, the later time window provided better NPV. These data suggest that our CPR may work best for ruling in future independent walkers when applied within 0-7 days of SCI, yet may work best for ruling out future independent walkers when applied later on.

The underlying reasons for the importance of pinprick sensation regarding future motor recovery may be rooted in the anatomic locations of the human spinal cord's ascending and descending tracts. The lateral corticospinal tracts, responsible for volitional motor output, are in close proximity to the lateral spinothalamic tracts which convey sharp pinprick sensation.[13,30,31] The main tracts that convey light touch sensation lie in the dorsal columns, which are farther away from the motor pathways.[31] Co-localization of the corticospinal and spinothalamic tracts may explain the relation between residual pinprick sensation and independent walking—pinprick sensation may act as a surrogate marker of corticospinal tract integrity.

In alignment with our findings, several past CPRs identified sensory function at the S1 dermatome as an important predictor for future walking.[3-6] From a clinical perspective, S1 is a distal spinal cord segment that provides innervation to the lower extremity extensor muscle groups necessary for forward propulsion during walking. On the other hand, for our CPR, S1 pinprick sensation may be serving as a more global measure for spared sensation across the sacral segments and especially the most caudally innervated at S4-5.[32]

In their 2020 study, Engel-Haber et al found improved CPR accuracy when using an age cut-off of 50 years old.[33] In alignment with these findings, when considering our AIS B and C validation subset with age less than 50, we found that, while other predictive metrics were not substantially improved, the PPV of having normal S1 bilateral pinprick sensation improved from 67% to 81%. This suggests that our CPR may work even better at ruling in future independent walkers if they are in the middle of the SCI severity spectrum and younger than 50 years old.

When applying our CPR to the cervicothoracic SCI and lumbar SCI validation subsets, the PPVs for normal bilateral pinprick sensation (85% and 96%, respectively) and any pinprick sensation remained high (75% and 83%, respectively). However, the NPV for no pinprick sensation in either the left and right lateral heels was markedly lower for the lumbar SCI validation subset: only 44% in comparison with 85% in the cervicothoracic SCI validation subset. While we are unsure of the exact reasons underlying this finding, we hypothesize that some of these participants with lumbar SCIs may be classified with lower motor

neuron injuries where function in key lower extremity muscles (ie, quadriceps) may have remained at least partially intact. These individuals may be able to walk independently using ankle-foot orthoses and/or other assistive devices. Taken together, these data suggest a good prognosis for those with lumbar neurologic level SCIs who have normal bilateral pinprick at the lateral heels, but our CPR does not rule out future independent walking if pinprick at the lateral heels is limited in this subgroup.

Study limitations

Our intention was to create a simple CPR for those in the middle of the SCI severity spectrum but admittedly, our CPR is less accurate in the AIS B and C subgroup than the established van Middendorp and Hicks CPRs.[3,4] For their CPRs, overall accuracy is ≈74%,12 vs our overall accuracy of 67% for our AIS B and C validation subgroup. When considering which CPR to use, simplicity and ease of clinical application without reliance on motor scores should be considered for our CPR, but this comes as a trade-off of reduced accuracy compared with the van Middendorp and Hicks CPRs. Next, the use of self-reported outcome measures for the walking outcome may not reflect actual walking performance, although past research found good accuracy with self-reporting in a cohort of individuals with SCI compared with physiatrist criterion standard.34

Strengths

We believe that a major strength of our CPR lies in its simplicity. Our CPR only requires pinprick information at the right and left lateral heels (ie, S1 dermatomes) to predict walking 1 year after SCI. The lack of reliance on motor scores is a strength of our CPR. Another strength is our definition of independent walking, where each person had to endorse the ability to both walk indoors as well as outdoors at least 1 street block. A third strength of our study is the use of a multi-site dataset (12 sites) with a large and geographically diverse sample. The large sample size allowed us to independently derive (N=623) and validate (N=3056) the CPR, and the diversity in the sample likely improves the generalizability of the CPR to the United States SCI population.35

Future directions

A remaining research question is how to further improve the predictive value for the AIS B and C subpopulation. Adding other clinical variables, such as MRI-based measures of SCI,[20,21,31,36] might bolster the prediction of walking in this subgroup. Also, future research should consider external validation of our CPR in other cohorts and/or outside the United States.

Conclusions

In this large, multi-site retrospective study, we derived and validated a simple and accurate CPR that predicts future independent walking ability after SCI that does not rely on motor scores and works for those in the middle of the recovery spectrum. With pinprick sensory testing in a single dermatome, S1 at the lateral heels, clinicians can use our CPR to predict —within 31 days after SCI—who is likely to recover independent walking 1 year after traumatic SCI.

Disclosures:

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List of abbreviations:

AIS	American Spinal Injury Association Impairment Scale
CI	confidence interval
CPR	clinical prediction rule
ISNCSCI	International Standards for Neurological Classification of Spinal Cord Injury
NPV	negative predictive value
PPV	positive predictive value
SCI	spinal cord injury
SCIMS	Spinal Cord Injury Model Systems

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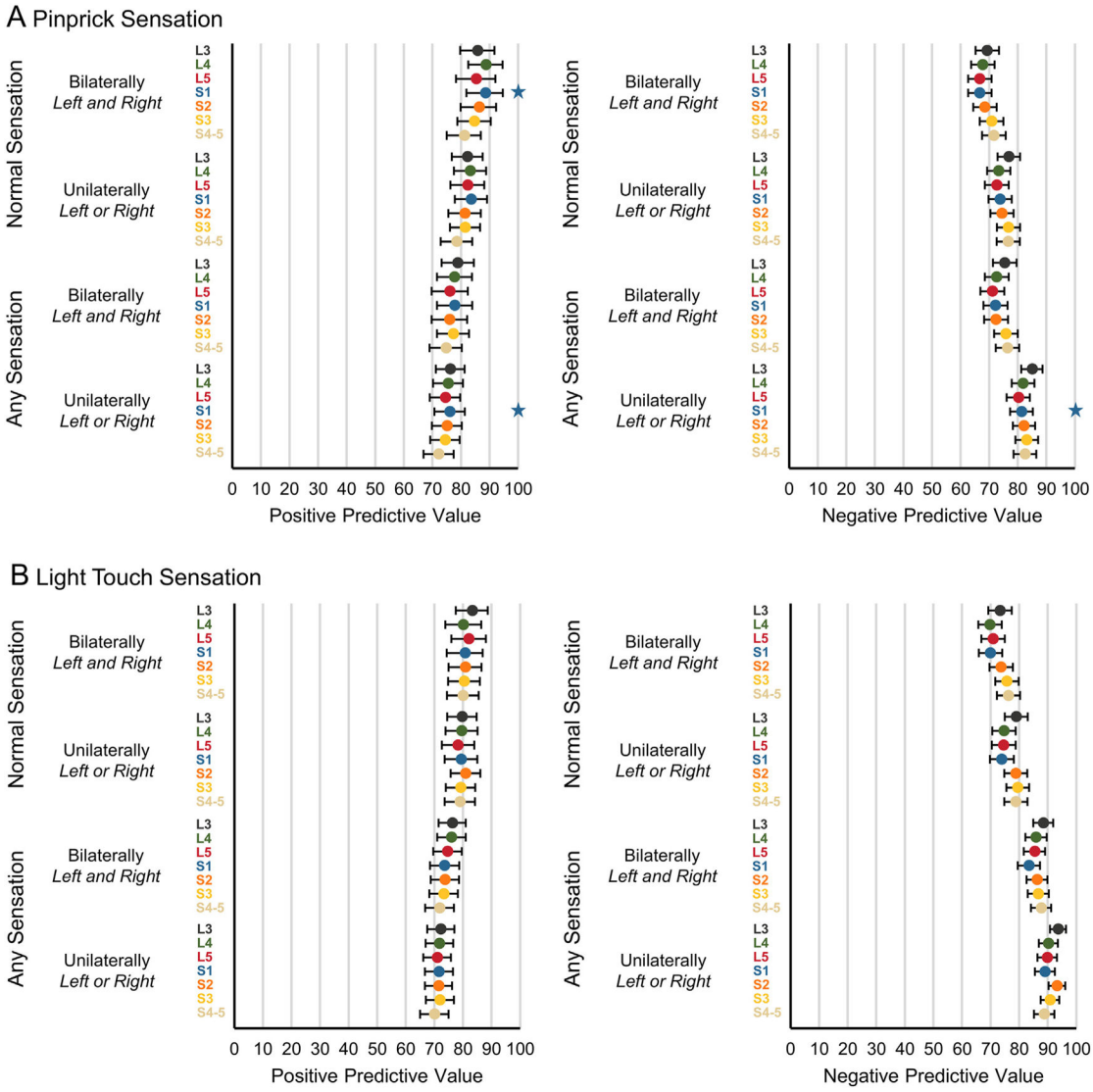

Fig 1.

Positive and negative predictive values of the candidate CPR variables derived from the pinprick (A) and light touch sensory scores (B) in the derivation dataset (n=623). For each dermatome and the pinprick and light touch sensory scores, we derived binary variables that indicated normal sensation bilaterally (both left and right), normal sensation unilaterally (left or right), any sensation (normal or altered) bilaterally (left and right), and any sensation (normal or altered) unilaterally (left or right). Mean PPVs and NPVs are shown for each candidate variable (●). Error bars=bootstrapped 95% CIs. ★=Used in CPR.

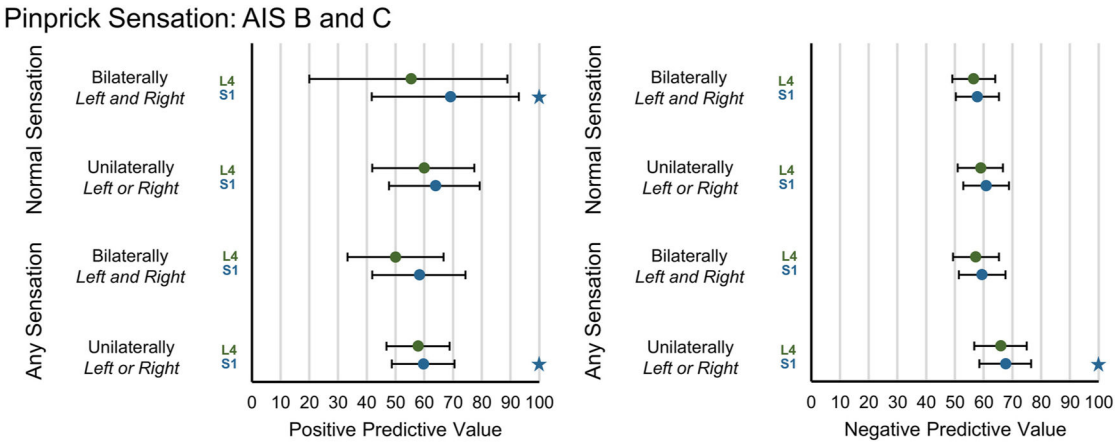

Fig 2.

Positive and negative predictive values of the candidate CPR variables derived from the pinprick sensory scores at the L4 and S1 dermatomes in the AIS B and C derivation dataset subset (n=179). In the whole derivation dataset, pinprick at the L4 and S1 dermatomes had similar predictive value (fig 1). When considering the AIS B and C subset of the derivation dataset, pinprick at the S1 dermatome yielded the optimal PPV (primary measure) and NPV (secondary measure) for predicting independent walking, so pinprick sensation at S1 was used to derive the CPR. Mean PPVs and NPVs are shown for each candidate variable (●). Error bars=bootstrapped 95% CIs. ★=Used in CPR.

Fig 3.
The S1 lateral heel pinprick clinical prediction rule.

Table 1

Demographic information

Dataset	N	Age (Years)	% Men	Independent Walkers	Non-Independent Walkers	Initial AIS A	Initial AIS B	Initial AIS C	Initial AIS D
Derivation (Full)	623	42.8±18.0 (1)	79.8	261	362	248	61	118	196
Derivation (AIS B&C)	179	43.7±17.4 (0)	79.9	79	100	0	61	118	0
Validation (Full)	3056	42.8±17.9 (22)	79.1	1191	1865	1161	398	636	861
Validation (AIS B&C)	1034	44.0±17.5 (7)	78.4	375	659	0	398	636	0
Validation (Cervicothoracic) *	2826	43.3±18.0 (21)	79.0	1045	1781	1090	350	587	799
Validation (Lumbar) *	185	36.4±16.1 (1)	81.1	129	56	48	43	46	48

NOTE. Age displayed as mean ± 1 standard deviation with (#) indicating number of participants with missing data.

* In the validation dataset, 45 participants had missing neurologic injury level data and were excluded from the cervicothoracic and lumbar neurologic injury level analysis.

Table 2

Clinical prediction rule prediction results

Dataset	N	Predictor	True Negative	False Positive	False Negative	True Positive	Sensitivity	Specificity	Accuracy	PPV	NPV
Derivation (Full)	623	Normal left and right S1 pinprick sensation	351	11	175	86	32.9 (27.4, 38.8)	97.0 (95.1, 98.6)	70.1 (66.5, 73.7)	88.7 (81.9, 94.6)	66.7 (62.6,70.8)
Derivation (Full)	623	Any S1 pinprick sensation left or right	302	60	69	192	73.6 (68.2,78.7)	83.4 (79.5,87.1)	79.3 (76.1,82.5)	76.2 (70.7, 81.3)	81.4 (77.3, 85.3)
Derivation (AIS B and C)	179	Normal left and right S1 pinprick sensation	96	4	70	9	11.3 (4.9, 18.8)	96.0 (91.7, 99.1)	58.7 (51.4,65.9)	69.2 (41.7, 92.9)	57.8 (50.3, 65.3)
Derivation (AIS B and C)	179	Any S1 pinprick sensation left or right	69	31	33	46	58.2 (47.4,69.0)	69.0 (59.8,77.9)	64.3 (57.5,70.9)	59.7 (48.7, 70.5)	67.7 (58.5, 76.5)
Validation (Full)	3056	Normal left and right S1 pinprick sensation	1813	52	879	312	26.2 (23.7,28.7)	97.2 (96.4,97.9)	69.5 (67.9,71.2)	85.7 (82.0, 89.2)	67.3 (65.6, 69.1)
Validation (Full)	3056	Any S1 pinprick sensation left or right	1595	270	323	868	72.9 (70.3,75.4)	85.5 (84,87.1)	80.6 (79.2,82)	76.3 (73.8, 78.8)	83.2 (81.5, 84.8)
Validation (AIS B and C)	1034	Normal left and right S1 pinprick sensation	636	23	329	46	12.3 (9.0,15.7)	96.5 (95.0,97.9)	66.0 (63.1,68.9)	66.7 (55.4, 77.6)	65.9 (62.9, 68.9)
Validation (AIS B and C)	1034	Any S1 pinprick sensation left or right	479	180	160	215	57.3 (52.2,62.3)	72.7 (69.3,76.1)	67.1 (64.2,70)	54.4 (49.5, 59.3)	75.0 (71.5, 78.3)
Validation (AIS B and C under 50 years old)	575	Normal left and right S1 pinprick sensation	343	6	201	25	11.1 (7.2,15.2)	98.3 (96.8,99.4)	64.0 (60.0, 68.0)	80.7 (65.6,93.8)	63.1 (59.0,67.1)
Validation (AIS B and C under 50 years old)	575	Any S1 pinprick sensation left or right	271	78	96	130	57.5 (50.9,64)	77.7 (73.2,82.0)	69.7 (65.9,73.4)	62.5 (55.8,69.0)	73.8 (69.2,78.3)
Validation (AIS B and C, 50 years and older)	452	Normal left and right S1 pinprick sensation	288	17	127	20	13.6 (8.2,19.3)	94.4 (91.7,96.9)	68.1 (63.7,72.3)	53.9 (37.5,70.3)	69.4 (64.9,73.7)
Validation (AIS B and C, 50 years and older)	452	Any S1 pinprick sensation left or right	204	101	64	83	56.4 (48.3,64.4)	66.9 (61.5,72.2)	63.5 (59.1,67.9)	45.1 (37.8,52.4)	76.1 (71.0.81.2)
Validation (Cervicothoracic) *	2826	Normal left and right S1 pinprick sensation	1730	51	764	281	26.9 (24.3,29.6)	97.1 (96.3,97.9)	71.2 (69.5,72.8)	84.6 (80.6, 88.4)	69.4 (67.6, 71.2)
Validation (Cervicothoracic) *	2826	Any S1 pinprick sensation left or right	1527	254	266	779	74.6 (71.9,77.1)	85.7 (84.1,87.3)	81.6 (80.2,83.0)	75.4 (72.8, 77.9)	85.2 (83.5, 86.8)
Validation (Lumbar) *	185	Normal left and right S1 pinprick sensation	55	1	102	27	20.9 (14.1,28.1)	98.2 (94.1,100)	44.3 (37.3,51.4)	96.4 (88.0, 100.0)	35.1 (27.7, 42.8)
Validation (Lumbar) *	185	Any S1 pinprick sensation left or right	41	15	53	76	58.9 (50.4,67.4)	73.1 (61.0,84.4)	63.2 (56.2,70.3)	83.4 (75.5, 90.7)	43.6 (33.7, 53.8)

NOTE. Data for Sensitivity, Specificity, Accuracy, PPV, and NPV are displayed as mean (95% confidence intervals).

* In the validation dataset, 45 participants had missing neurologic injury level data and were excluded from the cervicothoracic and lumbar neurologic injury level analysis.

Table 3

Clinical prediction rule results by time window of pinprick test

Dataset	N	Predictor	True Negative	False Positive	False Negative	True Positive	Sensitivity	Specificity	Accuracy	PPV	NPV
Validation: pinprick assessed within 0-3 days of SCI	49	Normal left and right S1 pinprick sensation	13	2	21	13	38.2 (22.2, 54.5)	86.7 (68.4, 100)	53.1 (38.8, 67.3)	86.7 (66.7, 100)	38.2 (22.2, 55)
Validation: pinprick assessed within 0-3 days of SCI	49	Any S1 pinprick sensation left or right	13	2	9	25	73.5 (57.9, 87.9)	86.7 (68.4, 100)	77.6 (65.3, 87.8)	92.6 (81.0, 100)	59.1 (38.1, 79.2)
Validation: pinprick assessed within 4-7 days of SCI	599	Normal left and right S1 pinprick sensation	249	8	237	105	30.7 (25.9, 35.7)	96.9 (94.6, 98.8)	59.1 (55.1, 62.9)	92.9 (87.9, 97.3)	51.2 (46.7, 55.6)
Validation: pinprick assessed within 4-7 days of SCI	599	Any S1 pinprick sensation left or right	219	38	85	257	75.1 (70.5, 79.7)	85.2 (80.8, 89.5)	79.5 (76.3, 82.6)	87.1 (83.2, 90.9)	72.0 (67.0, 77.0)
Validation: pinprick assessed within 8-31 days of SCI	2408	Normal left and right S1 pinprick sensation	1551	42	621	194	23.8 (20.9, 26.7)	97.4 (96.5, 98.1)	72.5 (70.7, 74.3)	82.2 (77.1, 87)	71.4 (69.6, 73.3)
Validation: pinprick assessed within 8-31 days of SCI	2408	Any S1 pinprick sensation left or right	1363	230	229	586	71.9 (68.9, 75.0)	85.6 (83.8, 87.3)	80.9 (79.4, 82.5)	71.8 (68.7, 74.9)	85.6 (83.9, 87.3)

NOTE. Data for sensitivity, specificity, accuracy, PPV, and NPV are displayed as mean (95% CI).