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Identifying Pressure Ulcer Risk Factors in Persons With Spinal Cord Injury Over Time to Inform Clinical Evaluations

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Abstract

Introduction: Persons with spinal cord injury (SCI) or disease are at high risk of developing pressure ulcers (PrUs) throughout their lives. Seating evaluations typically involve interviews that seek to understand wheelchair use, activities, and factors that might indicate higher levels of PrU risk. The objective was to identify risk factors as a function of time since injury to help clinicians focus questions during their evaluations. The results of this study can be used to inform clinicians to ask about specific risk factors at various timeframes since injury.

Methods: The study used the SCI Model Systems database, which collects a robust dataset on persons with SCI starting one year after injury and then at five-year timeframes thereafter (Follow-up Year).

The dataset included 13,990 individuals who answered the item about PrUs. Fourteen possible risk factors were identified based on a review of literature and clinician interviews. Variables were dichotomized for inclusion in the modeling to foster a more clinically usable model. Cut points for continuous variables were determined through an optimized machine learning approach. Separate logistic binary regressions were run for the full dataset and each Follow-up Year group.

Results: PrU occurrence incrementally increased in each Follow-up Year group, rising from 26% in Year 1 to 34% in the Year30+ group. All variables were significant in the regression using the full dataset, but some fell out of the timeframe-based models. Having a previous PrU was a top risk factor from YR5 onward. Three risk factors appeared in all five timeframes: 1) having a urinary tract infection (UTI) in the past year, 2) having a bowel incontinence episode at least once a month, and 3) being a power wheelchair user.

Conclusion: The results found that asking about UTIs, bowel incontinence, and prior occurrences of PrUs should be a part of interviews regardless of time since injury. The use of powered wheelchairs was also a top risk factor over all timeframes.

Categories: Physical Medicine & Rehabilitation
Keywords: clinical evaluation, pressure ulcer, spinal cord injury, wheelchair, wheelchair seating

Introduction

Persons with spinal cord injury or disease (SCI/D) are at high risk of developing pressure ulcers (PrUs) throughout their lives. PrUs are a critical problem with negative consequences for the health, activities of daily living, employment, and quality of life for wheelchair users [1,2]. Individuals with a PrU experience reduced mobility, activity, and participation [2], and are at increased risk for future PrU development [3] and premature death [4].

Over the years, researchers have identified an extensive list of demographic and clinical risk factors associated with PrU development in persons with SCI/D. These clinical variables include demographic factors (e.g., age [5,6], gender [7,8], race [9,10]), behavioral factors (e.g., smoking [8,10,11] and alcohol use [8], level of spinal cord injury (SCI) [8,9], time since injury [8,11], spasticity [6], nutrition [6,9,11], low-normal body weight [12], mobility [5], and continence [13]. These clinical factors have been used to develop PrU risk assessment tools and to inform clinicians when assessing their clients. Conceptually, these risk factors can be distinguished as nonmodifiable (e.g., gender, race) and modifiable factors (e.g., behavioral factors, continence). The type of risk factor is used slightly differently by clinicians when evaluating risk and interventions. While well described overall, PrU risk factors have not been examined in the context of how they might change over time since onset of SCI/D.

Seating evaluations typically involve interviews that seek to understand wheelchair use, activities, and factors that might indicate higher levels of PrU risk. As persons with SCI/D return for evaluations over time,

clinicians routinely tailor their interviews accordingly and recognize that risk factors can change over time.

The objective of this project was to identify risk factors as a function of time since injury to help clinicians focus questions during their evaluations. This objective was exploratory, as this cohort has never been analyzed using a large dataset. As such, no specific hypotheses were defined. Consistent with this objective was the intent to define a pragmatic yet valid list of risk factors and markers associated with PrU occurrence in persons with SCI/D. While the analysis considered both modifiable and nonmodifiable risk factors, interpretation emphasized modifiable risk factors consistent with the objective to provide clinically useful information. The results of this study can then be used to inform clinicians to ask about specific risk factors at various timeframes since injury.

This project was previously presented orally at the 39th International Seating Symposium on March 21, 2025.

Materials And Methods

The SCI Model Systems (SCIMS) dataset is the world's largest and longest active database of information on individuals with traumatic SCI. Since its establishment in 1973, it has prospectively collected detailed data from a network of federally funded SCI Model System Centers across the United States. The database collects a robust dataset on persons with SCI over multiple time points, starting one year after injury and then at five-year timeframes thereafter (termed Follow-up Year). The SCIMS dataset started asking about PrUs in 2011. This project used the publicly available 2016-2021 dataset [14].

Data management and analysis were performed using Python 3 (Python Software Foundation, Wilmington, DE) within the Jupyter Notebook environment (Project Jupyter, NumFOCUS, United States). The cohort used for analysis was created by merging Form 1 (completed around discharge from rehabilitation) and Form 2 data (taken in subsequent Follow-up Years), then eliminating persons who were injured before age 18 and eliminating persons who did not answer the PrU item at least once since its introduction. The PrU item asked, “Since discharge/In the last 12 months, have you had a pressure sore with open or broken skin? That is, there was an opening in the skin, not just a red patch.” The final cohort was then assigned to an age group and classified by severity of injury using the SCI Core Data Set [15] as documented in Form 1. Additionally, several new parameters were added to aid in analysis, including body mass index, follow-up year, and a report of a previous PrU. Demographics, such as age group, injury severity, and PrU occurrence for the final cohort, were tabulated.

To identify risk factors of interest, a list of SCIMS variables was created that either had been linked to PrU risk in prior studies or might be of interest to clinicians. We interviewed four clinicians who regularly work with SCI/D patients to gain insights about variables that they either currently considered or would be interested in asking. Clinicians were presented with the SCIMS variables and asked to comment about clinical usefulness. Their feedback was combined with information from prior studies to define the 14 potential risk factors included in the analysis.

Cut points for continuous variables were determined using outcome-driven thresholds derived through an optimized machine learning approach utilizing single-node decision trees executed using Python routines (Decision Tree Classifier with max depth = 1). The methodology employed recursive binary splitting to identify optimal thresholds that maximized the separation between PrU outcomes. For each continuous predictor variable, a decision tree algorithm evaluated all possible splitting points within the variable's range to identify the threshold that maximizes information gain based on Gini impurity, a metric of grouping effectiveness [16]. For items with ordinal responses, an analogous approach was used by evaluating cut points at each ordinal level. This approach identifies the cutpoint that best separates participants into groups with differing probabilities of PrU occurrence within the study cohort. This method derives cutpoints specifically associated with the outcome of interest, does not assume a linear relationship between the predictor and outcome, and yields clinically interpretable binary risk groups suitable as clinical screening markers, not as causal thresholds. Following threshold determination, variables were dichotomized using the identified cut points, creating binary predictors for subsequent logistic regression analysis. The resulting binary variables were used to calculate adjusted odds ratios, with statistical significance determined at $p < 0.05$, to quantify the association between each dichotomized predictor and PrU occurrence (Table *1*). Separate logistic binary regressions were run for the full dataset and each follow-up year group using the variables with significant odds ratios (ORs). Because some individuals contributed more than one observation, observations within participants were not necessarily independent. To account for within-participant correlation, cluster-robust standard errors were used for all logistic regression models, with clustering by participant identifier. This approach retains the logistic regression coefficient and OR estimates while adjusting standard errors and associated statistical inference for within-participant clustering. We chose logistic modeling for its pragmatism, as we believed clinicians would find ORs based on cut points a more accessible description of risk.

Variable	Description	Cutpoint
UTI	UTI with antibiotic, last 12 months	At least 1 UTI in the past year
Previous_PU	Previous self-reported ulcer	Cutpoint at least 1 previous PU
WC_type	Type of wheelchair used most often	PWC vs. any other type WC
Bwl_Incont	In the last 4 weeks, on average, how often have you had bowel incontinence?	At least once per month incontinence
Rate_Health	Compared to 1 year ago, rate your health now	"Somewhat worse now than one year ago"
Sex	The primary source is from the medical chart	Male vs. all others
Race	What race are you?	Black vs. all others
Tob_Use	In the past 3 months, how often have you used tobacco products?	Tobacco use at least once per month
Bld_Incont	On average, in the past 4 weeks, did you experience incontinence daily, weekly, or monthly?	Daily incontinence
Num_Rehosp	Number of rehospitalizations during last 12 months	Cutpoint at 1 hospitalization during last 12 months
Diabetes	Diabetes, current	Binary
BMI	Body mass index	26.6
Alc_Rate	Alcohol rate: how often have you had a drink in the past year?	At least 2-5 drinks per month - protective
HyperTen	Hypertension, current	Binary

TABLE 1: Variables and their cutpoints to create binary predictors

UTI: urinary tract infection; BMI: body mass index; PWC: power wheelchair; PU: pressure ulcer; WC: wheelchair

Results

To define the final study cohort, individuals injured before 18 years of age were excluded. Participants were eligible if they had at least one postrehabilitation follow-up assessment (Form II) that included the PrU outcome measure. The PrU question was introduced into the SCIMS Form II questionnaire in 2011; therefore, follow-up assessments completed before 2011 did not contain the study outcome and were not eligible for analysis. This process resulted in 13,990 individuals being entered into the analysis who contributed 21,399 entries (Figure *1*). Follow-up years were grouped into five categories, YR1, YR5, YR10&15, YR20&25, YR30+. Combining some follow-up years was done to increase the size of the cohort within each epoch and to create a more clinically friendly interpretation.

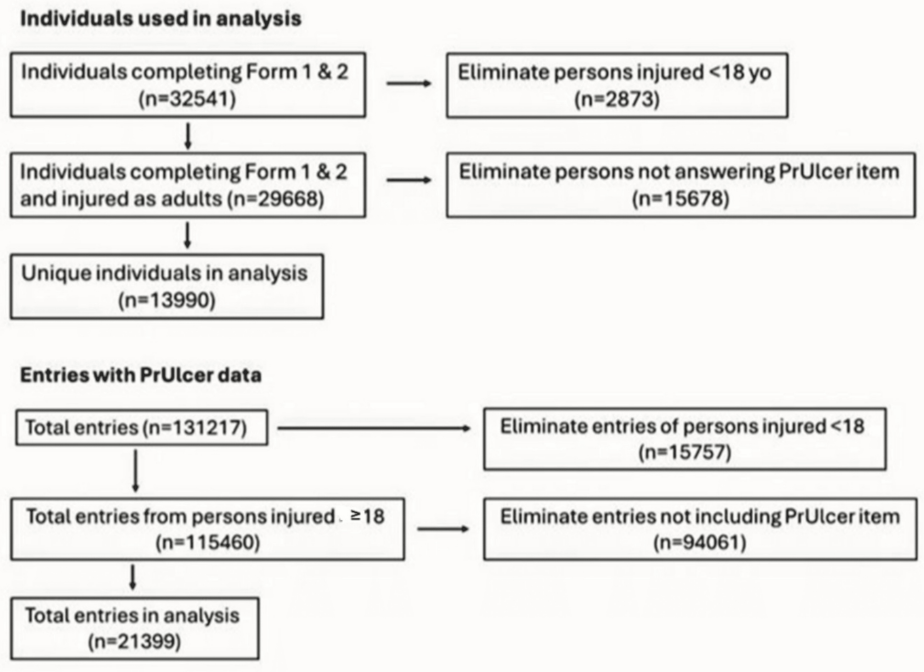


FIGURE 1: Enrollment flowchart for unique individuals and entries

The cohort was dominated by men (n = 11,801) (79%) and skewed to younger age groups, with 45% being between 18-29 (n= 6,308) years old at the time of injury, with a subsequent decrease in proportion through the 75+ age group (Table *2*). Persons self-identifying as White (n = 9,819) formed the largest Race category (70%), followed by Black race (n= 2,954) (21%). Injury severity was somewhat balanced, with 28% having a cervical injury (n = 4,057), 34% classified as having paraplegia (n = 4,782), and 27% with an American Spinal Injury Association Impairment Scale/Frankel category of D or E (n = 3,736). PrU occurrence by Follow-up year increased incrementally from 26% (YR1) to 34% (Year 30+) (Table *3*) [17].

Age group	Number (%)
18-29	6,308 (45%)
30-44	3,582 (26%)
45-59	2,549 (18%)
60-74	1,320 (9%)
75+	231 (2%)
Race	
White	9,819 (70%)
Black	2,954 (21%)
American Indian	104 (1%)
Asian, Pacific Islander	274 (2%)
Other, Multiracial	413 (3%)
Declined	22 (<1%)
Unknown	404 (3%)
Neurologic category	
C1-4 AIS/Frankel ABC	1,825 (13%)
C5-8 AIS/Frankel ABC	2,232 (16%)
T1-S3 AIS/Frankel ABC	4,782 (34%)
AIS/Frankel DE	3,736 (27%)
Other-N/A	1,415 (10%)

TABLE 2: Demographics of unique individuals used in analysis (n = 13,990)

AIS/Frankel DE: Association Impairment Scale/Frankel category of D or E; N/A: not available

Follow-up year	No PrU	PrU	12-month occurrence
YR1	4,061	1,440	0.26
YR5	2,870	1,052	0.27
YR10&15	3,690	1,483	0.29
YR20&25	2,128	1,034	0.33
YR30+	2,390	1,251	0.34
Total	15,139	6,260	0.29

TABLE 3: PrU occurrence by follow-up year

YR: year; NoPrU: no pressure ulcer; PrU: pressure ulcer

The reported occurrence of PrU within calendar years ranged from 26% (n = 55 out of 215) (2011) to 31% (n = 676 out of 2,199) (2017), with no trend being evident (Figure *2*). Of note is that the 2011 data set was an order of magnitude smaller than the other years since 2011 was the introduction of the PrU item.

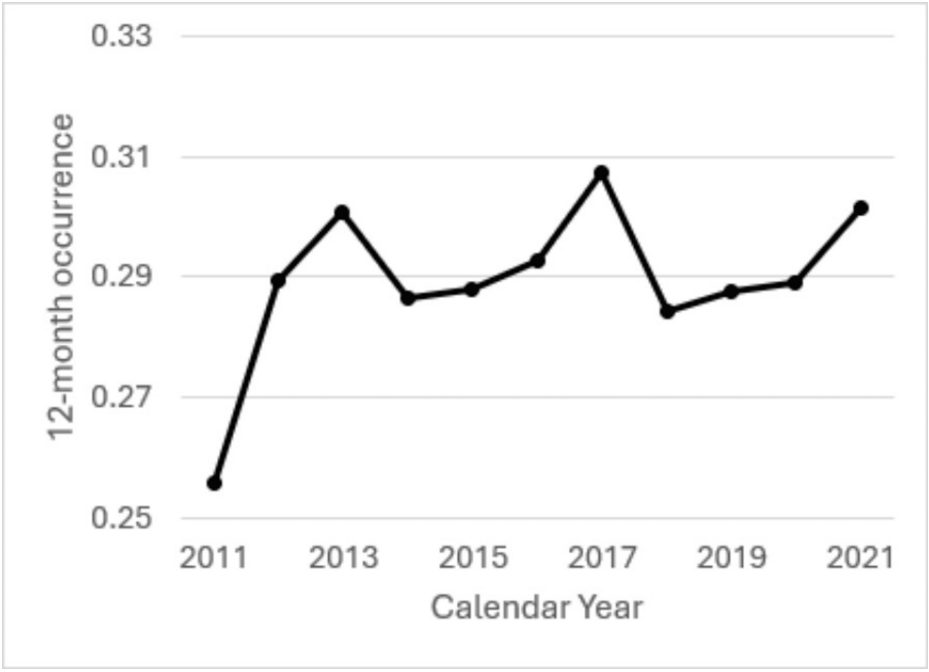


FIGURE 2: Line graph of PrU occurrence by calendar year

PrU: pressure ulcer

All 14 variables reported significant odds ratios using the calculated cutpoints and were entered into a logistic binary regression, with separate regressions run for each Follow-up Year category. All variables were significant in the regression using the full dataset, but some fell out of the timeframe-based models.

Consistent with the overall objective of informing clinical interventions, the top five predictors were considered, based on OR. The results indicate that from Year 10 to Year 30+, all top predictors were the same, although with slightly different ORs (Table *4*). Three risk factors appeared in all five timeframes: 1) having a urinary tract infection (UTI) in the past year, 2) having a bowel incontinence episode at least once a month, and 3) being a power wheelchair (PWC) user. Having a previous PrU was a top risk factor from YR5 onward. Having hypertension was a significant protective parameter at all time points except YR5. Being of Black race was a top risk factor in YR1 only, and hospitalization in the past year was a top predictor in YR5 only. Based on the results, health factors are consistently the most impactful risk factors, with being a PWC user being the only consistent demographic risk factor over all timeframes.

Years	Predictor	aOR
All years	UTI	1.5
	Previous-PU	1.47
	HyperTen	0.70 (1.44)
	WC-Type-PWC	1.33
	Bwl_Incontin	1.3
Year 5	Previous-PU	1.51
	UTI	1.47
	Bwl_Incontin	1.33
	WC-Type-PWC	1.32
	Recent_Hospital	1.3
Years 20-25	Previous-PU	1.59
	UTI	1.44
	HyperTen	0.75 (1.34)
	WC-Type-PWC	1.29
	Bwl_Incontin	1.21
Year 1	UTI	1.75
	HyperTen	0.56 (1.8)
	WC-Type-PWC	1.46
	Bwl_Incontin	1.35
	Black_race	1.25
Years 10-15	Previous-PU	1.64
	UTI	1.49
	HyperTen	0.70 (1.43)
	Bwl_Incontin	1.34
	WC-Type-PWC	1.32
Years 30+	Previous-PU	1.58
	UTI	1.36
	HyperTen	0.78 (1.28)
	WC-Type-PWC	1.22
	Bwl_Incontin	1.2

TABLE 4: Top 5 predictors at each follow-up time period

All reported aORs were significant at $p < 0.05$. Inverse odds for hypertension are shown in parentheses

aOR: adjusted odds ratio; UTI: urinary tract infection; PWC: power wheelchair; PU: pressure ulcer; WC: wheelchair

Discussion

The use of the SCIMS dataset proved valuable in being able to meet the objective of the analysis. Despite the PrU item being included for only 10 years, a robust cohort of nearly 14,000 participants was entered into the analysis. This will certainly grow over time, offering the opportunity for more powerful analyses.

The cohort entered into the analysis exhibited similar characteristics as described by Chen et al. [18], who evaluated the entire SCIMS dataset. The percentage of men (79%) was the same, with a slightly greater percentage of persons identifying as white (70% vs. 62.5%) and nearly the same percentages of those identifying as Black (22% vs. 21%). Injury severity of the cohort was quite similar to Chen et al., with 11% having a high cervical injury vs. 12%, 16% having a lower cervical injury vs. 20%, and 34% with a classification of paraplegia vs. 35%.

PrU occurrence within both a calendar year and follow-up year group was fairly stable. Discounting 2011 when the PrU item was added, the yearly occurrence rate varied only a few percentage points, with an average of 29.2% of respondents reporting a PrU in the previous 12 months. This value is consistent with a meta-analysis reporting a combined incidence of 28.8% [19]. PrU occurrence incrementally increased in each Follow-up year group, rising from 26% in Year 1 to 34% in the Year30+ group. These values were consistent with those in [8], which also used SCIMS in the analysis. Both results reflect an opportunity to devise more effective preventive measures. The stable annual occurrence suggests that the overall burden of PrUs has not substantially declined over time, highlighting the continued need for improved prevention strategies.

The results are able to inform clinicians during seating and mobility evaluations over time. Three risk factors spanned all timeframes: 1) having a UTI in the past year, 2) having a bowel incontinence episode at least once a month, and 3) being a PWC user. Clinicians should ask their patients about UTIs and bowel incontinence during evaluations at all time points after injury. These factors indicate greater odds of developing a PrU and also indicate an opportunity for medical intervention to address these issues. A PrU within the past 12 months was a significant predictor from Year 5 onward and was also a top predictor across all years. Therefore, a 12-month look-back on skin health is another question that should be raised regularly by clinicians. Krause and Broderick advocated for differentiating between PrUs occurring during inpatient stays vs. those occurring after discharge from rehabilitation [11]. This analysis appears to support that categorization since the SCIMS uses a 12-month look-back when querying skin health.

Hypertension was identified as a top associated variable across all timeframes and every Follow-up Year except for Year 5. This is the third analysis that found hypertension to be consistently associated with lower odds of PrU occurrence. The other two analyses involved different cohorts, including acute care [20] and persons with mobility disability [21]. This underscores a need to investigate hypertension more closely with respect to preventing tissue damage using methods able to address potential physiological mechanisms and causation.

To our knowledge, an association between PWC use and PrU occurrence has not been previously reported. A study found that higher levels of SCI were at greater risk [22], but dichotomized levels as cervical-thoracic vs. lumbar-sacral, which does not address the levels that overlap between using manual and powered mobility. One can deduce many possible reasons for differences between PWC and manual wheelchair users, including differences in postural stability, performing weight shifts, and sitting duration, to name a few. Regardless, this finding offers a simple clinical marker for PrU risk for clinicians.

A few limitations exist that should be considered when evaluating the results and their applicability. The SCIMS dataset is based on data collected from specific centers, so its representativeness of the US population is not well defined. The occurrence of PrUs was based on self-report, so the data are beholden to the accuracy of recall by the SCIMS respondents. Although the SCIMS database contains repeated observations on many participants, the analyses were designed to identify clinically useful, time-specific associations rather than model within-person changes over time. Consequently, these findings should not be interpreted as describing individual risk trajectories or the longitudinal predictive effects of earlier risk factors. The empirically derived cutpoints are not intended to represent universal clinical decision thresholds. Rather, they identify values that best discriminate participants with and without PrU occurrence within this cohort and may serve as practical clinical markers during patient evaluation. Over time, and specifically after the release of the 2021-2026 SCIMS data, a more robust longitudinal dataset will be available.

Conclusions

This analysis was performed with the objective of identifying PrU risk factors across years since injury that can inform clinicians during seating and mobility evaluations. Even though persons with SCI are at high risk for PrUs, clinicians are naturally focused on extracting any information that might assist during the selection of seating and mobility equipment. The results found that asking about UTIs, bowel incontinence, and prior occurrences of PrUs after rehabilitation should be a part of interviews regardless of time since injury. The use of powered wheelchairs was also a clinical marker associated with PrU occurrence over all timeframes.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Stephen Sprigle

Acquisition, analysis, or interpretation of data: Stephen Sprigle, Troy Allen, Christine Olds

Drafting of the manuscript: Stephen Sprigle, Troy Allen, Christine Olds

Critical review of the manuscript for important intellectual content: Stephen Sprigle, Troy Allen, Christine Olds

Supervision: Stephen Sprigle

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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