Derivation and Validation of a Brief Emergency Department-Based Prediction Tool for Persistent Severe Pain After Motor Vehicle Collision Trauma Using Data From the AURORA Study

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Introduction

Chronic pain following traumatic stress is common in the US[1-6]. Although most individuals recover following traumatic stress exposure, a substantial proportion develop persistent severe pain. ***This project aimed to develop a simple-to-use and highly accurate tool to predict the development of severe pain after traumatic stress.*** Modern methods often use complex analytical techniques such as machine learning to make highly accurate predictions using many features[7,8]. These methods are difficult to implement quickly with limited computational resources and specialized training, hindering their use in fast-paced settings like the emergency department where people often report following traumatic experiences. Simpler models, such as regression, while unable to consider complex relationships between predictor and outcome variables, are easier to implement quickly.

Methods

Study Design and Setting – Data used in the current study (see **Table 1** for demographics) was a part of AURORA study **(Figure 1)**, a national multi-site prospective study based in 30 US emergency departments (EDs)[9]. The aim of the AURORA study is to gain insight into the development of adverse posttraumatic neuropsychiatric sequelae among trauma survivors, including pain.

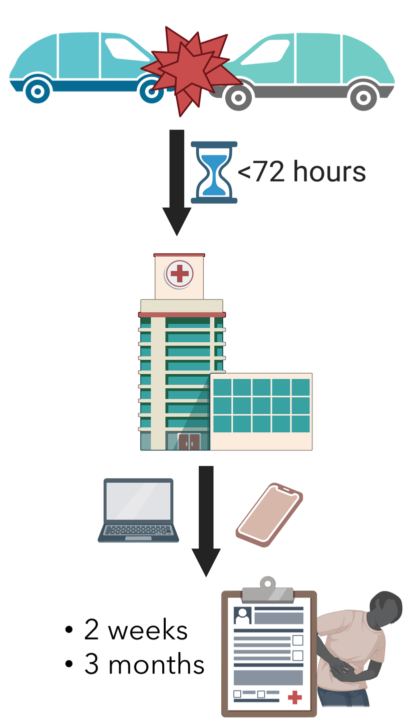

Figure 1 : Overview of the AURORA study.

Participants – AURORA participants were included in the study if they reported to the ED within 72 hours following a motor vehicle collision (MVC)-related traumatic event, were not admitted to the hospital, and completed both 2-week and 3-month assessments.

Measurements – Predictor measures included 265 variables spanning demographic, psychological and personality traits, past experiences/stressors, and physical health categories. The outcome measure was severe pain, defined as Pain Numeric Rating Scale (NRS) Scoring ≥ 7[10]. Pain NRS was scored on a 0-10 scale where 0 indicated "no pain or tenderness" and 10 represented "severe pain or tenderness".

Data Analysis – Ten lasso logistic regressions in randomly selected (bootstrapped) cohort subsamples were performed to determine the top 20 predictors (**Figure 2**) based on regression coefficient. Then, each predictor was converted into binary variables based on dichotomizing each level of response options (**Table 2**). The final Lasso logistic regression model was developed based on the selected number of binarized variables. Model performance (**Table 3**) was assessed considering both discrimination (i.e., area under the receiver operating characteristic curve [AUC]) and accuracy of predicted risk probabilities (i.e., Brier).

Original Self Report Predictor

	Response	1	2	3	4	5
1	How much do you experience repeated, disturbing memories, thoughts, of a stressful experience from the past?	not at all	a little bit	moderately	quite a bit	extremely

Binary Conversion of Original Predictor

	Response	1	2
1A	How much do you experience repeated, disturbing memories, thoughts, of a stressful experience from the past?	not at all	a little bit, moderately, quite a bit, or extremely
1B	"…"	not at all or a little bit	moderately, quite a bit, or extremely
1C	"…"	not at all, a little bit, or moderately,	quite a bit, or extremely
1D	"…"	Not at all, little bit, moderately, or quite a bit	extremely

Table 2: Example binary conversion of original predictor variables.

Results

Table 1: Baseline characteristics of primary analysis study participants (N=1,055) who reported to the ED after experiencing an MVC-related trauma. The prediction model was developed based on the derivation cohort (19 ED sites) and the model was tested in the validation cohort (9 ED sites). Both cohorts had similar levels of reported 3-month severe pain.

	Derivation Cohort (n = 872)	Validation Cohort (n = 183)
Female	548 (63%)	133 (72.6%)
Age (Years), Mean (SD)	33.8 (12.4)	33.5 (12.1)
Race		
Hispanic	82 (9.4%)	27 (14.8%)
Non-Hispanic White	317 (36.5%)	50 (27.1%)
Non-Hispanic Black	437 (50.3%)	100 (54.4%)
Non-Hispanic Other	33 (3.8%)	7 (3.7%)
Employment		
Employed	689 (79.0%)	154 (84.1%)
Total Family Income		
≤ $19K	249 (28.6%)	48 (26.2%)
$19K - $35K	279 (32.1%)	59 (32.4%)
$35K - $50K	131 (15.0%)	30 (16.3%)
$50K - $75K	82 (9.4%)	22 (11.8%)
$75K - $100K	69 (8.0%)	11 (6.1%)
> $100K	60 (6.9%)	13 (7.2%)
Marital Status		
Married or Cohabitating	345 (39.6%)	71 (38.8%)
3-Month Severe Pain	178 (20.5%)	31 (17.3%)

Emergency Department (ED), Motor Vehicle Collision (MVC), Standard Deviation (SD),
[2] Missing values were excluded when calculating percentages.

Table 3: Model performance was assessed by AUC and Brier score for 3-month severe pain with increasing number of binary features. The final derivation model (shaded row) was selected to maximize performance (i.e., increased AUC, lowered Brier Score), minimize the number of binary variables needed for accurate prediction, and maximize the ease of assessment. AUC are shown for both the derivation (n=872) and validation cohorts (n=183).

Number of Original Questions	Number of Binary Features [1]	Derivation Cohort AUC (Integer)	Derivation Cohort Brier Score (Integer)	Validation Cohort AUC (Integer)	Validation Cohort Brier Score (Integer)
4	4	0.643	0.152	0.669	0.138
5	5	0.607	0.154	0.685	0.137
5	6	0.680	0.148	0.694	0.136
6	7	0.705	0.144	0.726	0.133
7	8	0.722	0.143	0.720	0.134
8	9	0.745	0.140	0.718	0.133
9	10	0.742	0.139	0.726	0.133
9	11	0.741	0.141	0.717	0.138
9	12	0.742	0.141	0.719	0.137
9	13	0.742	0.142	0.717	0.140
10	14	0.741	0.141	0.717	0.140
11	15	0.748	0.140	0.728	0.133
13	20	0.742	0.142	0.722	0.142
14	30	0.728	0.146	0.704	0.139
15	40	0.715	0.145	0.709	0.140
16	50	0.714	0.145	0.715	0.144

Area Under the Receiver Operating Characteristic Curve (AUC), Motor Vehicle Collision (MVC)
[1] The final stage of model development utilized binary variables. These binary variables were developed by dividing ordinal survey questions with N response options into N-1 binary variables, in which each binary variable dichotomizes the ordinal survey question at each ordered response. For example, an ordinal question with 3 response options of mild, moderate, and severe was converted into 2 binary variables: mild vs. moderate/severe and mild/moderate vs. severe. This was done to determine influential cut-offs and assign scoring weights.

Table 4: Performance characteristics of the clinical decision support tool to identify individuals at high risk for severe pain (Pain NRS ≥ 7) 3 months after motor vehicle collision. Using higher score cutoffs exhibited the lowest prediction sensitivity, highest specificity, and highest positive predictive value.

Raw Score	Combined Derivation & Validation Cohorts: Sensitivity (95% CI)	Specificity (95% CI)	Positive Predictive Value	Proportion of False Positive Results (Negative Predictive Value)	N (%) of Total Trauma Survivors with Substantial Severe Pain Identified at Each Threshold
46	0.0 (0.0,0.02)	1.0 (1.0,1.0)	1.00	0	1 (0.48%)
40	0.01 (0.01,0.03)	1.0 (0.99,1.0)	0.67	0.33	3 (1.44%)
36	0.07 (0.05,0.1)	0.99 (0.98,0.99)	0.65	0.35	15 (7.18%)
32	0.18 (0.14,0.22)	0.97 (0.96,0.97)	0.57	0.43	37 (17.7%)
28	0.33 (0.29,0.38)	0.92 (0.91,0.94)	0.52	0.48	70 (33.49%)
24	0.48 (0.43,0.53)	0.85 (0.83,0.86)	0.44	0.56	100 (47.85%)
18	0.71 (0.67,0.76)	0.66 (0.64,0.69)	0.35	0.65	150 (71.43%)
10	0.92 (0.89,0.95)	0.37 (0.34,0.39)	0.27	0.73	193 (92.34%)

Figure 2. The top 20 important characteristics predicting three-month severe pain following motor vehicle collision (MVC) trauma exposure. Data were collected by patient self-report in the emergency department (ED) within 72 hours following trauma exposure. The variables are listed with the most predictive (highest absolute value of the mean regression coefficient) at the top and the least predictive at the bottom. Each characteristic was grouped by broad category: Personality (dark blue), past psychological distress (red), peritraumatic symptoms (grey), childhood trauma (yellow), demographics (green), insomnia (purple), and others (light blue).

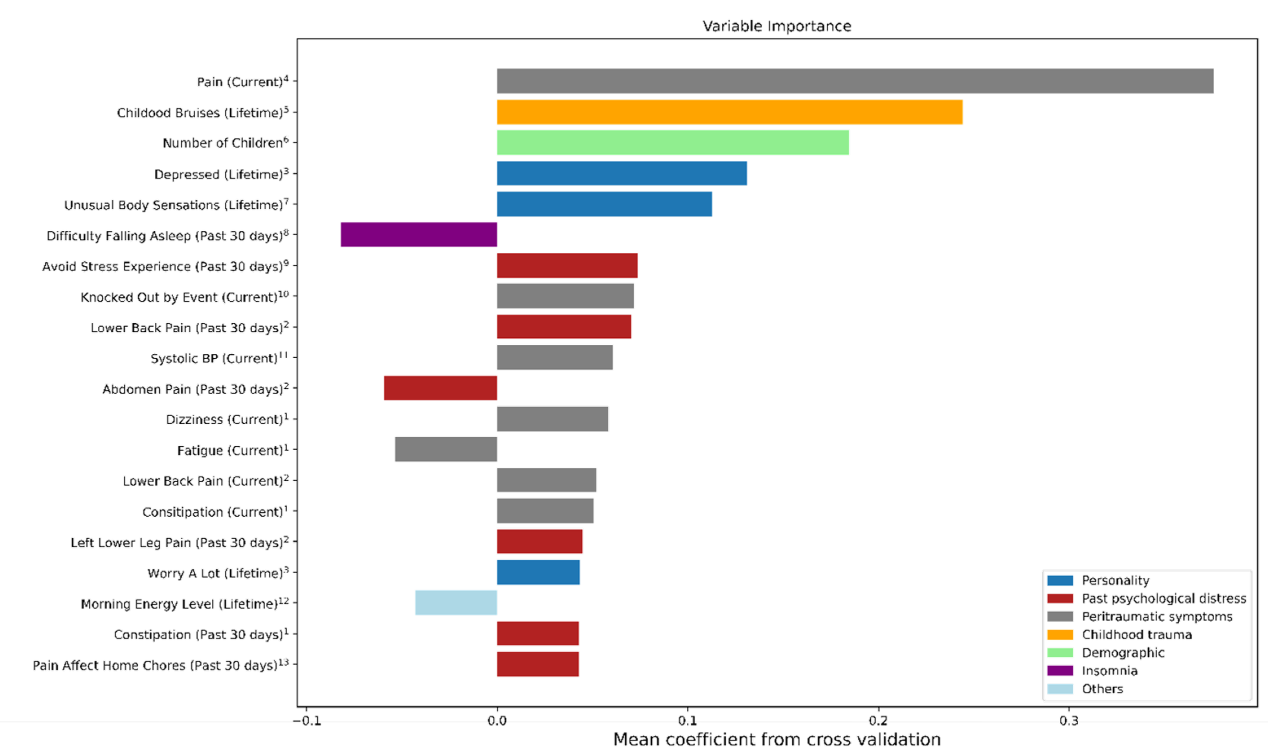

Figure 3. A nine-question, three-month severe pain prediction instrument including scores for each response is shown. In developing this clinical decision support tool 3 of the top 20 predictors were removed : number of children (seemingly clinically irrelevant/contextually awkward), systolic BP (not self-report), and childhood bruises (potentially re-traumatizing in this clinical setting). The scoring weights were assigned based on model development and the selected binary variables and they were designed to be integer based for easy calculation in the emergency department.

Instructions: Mark responses to each question. Add or subtract scores from each question as indicated within parentheses to calculate total score.

During the 30 days before the event, how often did you have difficulty falling asleep?
Never (0), Less than once a week (-5), 1-2 nights a week (-5), 3-4 nights a week (-5), Every or nearly every night (-5)

During the 30 days before the event, how severe was your pain or tenderness in the lower back?
None (0), Mild (+7), Moderate (+7), Severe (+7)

During the 30 days before the event that brought you to the ER today, how much were you bothered by avoiding memories, thoughts, or feelings related to a past highly stressful experience?
Not at all (0), A little (+4), Some (+4), A lot (+4), Extremely (+4)

Did your head injury cause you to lose consciousness or to be "knocked out"?
No (0), Yes (+5)

How much of a problem do you have with each of the following symptoms right now?

Dizziness
None (0), Mild (0), Moderate (+5), Severe (+5)

Pain or tenderness in lower back
None (0), Mild (0), Moderate (+5), Severe (+5)

Intensity of any physical pain
None (0), Mild (0), Moderate (+7), Severe (+12)

Here is a list of things people might say about themselves. How much do you disagree or agree with each as a description of you?

Unusual body sensations scare me
Disagree strongly (0), Disagree moderately (0), Disagree a little (+6), Neither disagree nor agree (+6), Agree a little (+6), Agree moderately (+6), Agree strongly (+6)

Worry a lot
Disagree strongly (0), Disagree moderately (0), Disagree a little (0), Neither disagree nor agree (0), Agree a little (0), Agree moderately (+7), Agree strongly (+7)

Total Score: ____________________

Total Score	10	18	24	28	32	36	40	46	54
Risk of Severe Pain	10%	20%	30%	40%	50%	60%	70%	80%	90%

Results Summary

- Baseline characteristics of participants are shown in **Table 1**. The rate of severe pain 3 months after trauma was 21% in the derivation cohort and 17% in the validation cohort. The cohorts were similar on other demographic factors.
- The strongest predictors of 3-month severe pain were current pain, childhood bruises, number of children, lifetime depression, and unusual body sensations (**Figure 2**).
- After developing and comparing Lasso logistic regression models for 4-50 binary items (**Table 3**), the optimal prediction model was a Lasso logistic regression model consisting of 10 binary questions.
- Within the derivation cohort, the AUC of the final tool was 0.74 with a Brier Score of 0.14, and in the validation cohort, the AUC was 0.73 with a Brier Score of 0.13 **(Table 2)**.
- The final risk prediction survey tool (**Figure 3**) was developed to have 9 questions with 10 weighted responses and integer-based scoring. Increased total score corresponds with increased risk of severe pain.
- The performance characteristics of the tool at different score cutoffs based on data from all participants can be seen in **Table 4 .** For example, a cutoff score of ≥ 18 identified over 70% of individuals with substantial severe pain 3 months following MVC-related trauma in the full cohort.

Conclusions

Here, we established a new tool based only on self-reported data that can predict the development of severe pain 3 months following traumatic stress such as motor vehicle collision. Tools likes this one that are quick and easy to use are highly necessary for better precision care in the immediate aftermath of trauma.

Further validation of this tool in other types of trauma cohorts is necessary to ensure its accuracy and generalizability before it can be implemented in a clinical trauma care setting.

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