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# 3 Evaluating the Accuracy of Emergency Department Triage Nurses in Predicting Patient

## 4 Admissions: retrospective, large-sample evidence from a community ED

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# 10 Abstract:

11 Objective: Emergency department (ED) flow could be improved with quicker disposition decisions. One

12 possible way to expedite decisions is for triage nurses to make predictions about whether patients require

13 admission to hospital. The information contained in these predictions could be useful for disposition

14 planning and for physician decision making. Previous studies make use of prospective designs that

introduce Hawthorne effects and have demonstrated mixed evidence on whether triage nurse predictions
 are accurate. We examined the accuracy of triage nurse predictions for patient admission in a southeastern

17 Ontario ED site.

18 Methods: We examined a retrospective sample of 134,891 visits to an ED in Ontario from March 2019 to

19 July 2024. Triage nurses made predictions about admission to hospital for these visits, from which we

20 estimated measures of specificity, sensitivity, positive predictive value, negative predictive value,

21 accuracy, and  $F_1$  scores.

22 Results: Of 134,891 visits, 13.7% resulted in hospital admission. We found the accuracy of the nurses in

predicting admission to be 85.8% (95CI: 85.7, 86.1), while overall sensitivity was 36.6% (95CI: 35.9,

24 37.3) and specificity was 93.7% (95CI: 93.5, 93.8). The positive predictive value of admission was 47.9%

 $25 \qquad (95CI: 47.1, 48.7) \ \text{and the negative predictive value of admission was } 90.3\% \ (95CI: 90.1, 90.5). \ F_1 \ \text{scores}$ 

were 0.415. These results were relatively stable over time, though there was notable variation in

27 prediction ability between nurses. We also report that some presenting conditions have relatively higher

28 prediction accuracy than others and that as overall case severity increases, sensitivity increases and

- 29 specificity decreases.
- 30 Conclusions: These results suggest that although nursing staff predictions are insufficient to streamline

31 disposition decisions completely, they could be useful in expediting certain decisions related to hospital

32 admission and resource requirement, improving flow in EDs.

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#### 34 Introduction

- 35 Emergency departments (EDs) face prolonged patient wait times and crowding due to limited resources.
- 36 Despite goals of reducing wait times, patients in Ontario waited an average of 30 minutes longer in
- 37 2022/2023 than in 2013/14 up to an average of 118 minutes to see an ED physician.<sup>1</sup> In the United States,
- only a minority of hospitals consistently achieve recommended wait times for all patients,<sup>2</sup> although this
   has improved over time.<sup>3</sup> Extended ED wait times lead to patient dissatisfaction,<sup>4</sup> patients leaving without
- 40 seeing a physician,<sup>1</sup> poorer outcomes, and higher resource use per admission to hospital.<sup>5</sup> ED crowding has
- 41 also been linked to increased patient mortality.<sup>6–8</sup>
- 42 A key challenge to improving ED wait times and crowding is flow: how can providers make quick, yet 43 accurate, decisions about disposition of patients to hospital or discharge? Quicker disposition means freeing 44 up resources such as beds and monitoring staff for other ED patients.<sup>9</sup> However, disposition decisions 45 require the ED physician's time, which is one of the most scarce resources in an ED. One possible solution 46 is to leverage the skill of triage nurses in identifying patients who require more involved care.<sup>10</sup> Using 47 triage nurses to predict whether patients require admission could streamline resources towards high-risk 48 patients, alert specialist physicians to patients who might require hospital care, and provide ED physicians
- 40 patients, alert specialist physicials to patients who high require hospital care, and provide ED p
- 49 quick information to make quicker disposition decisions.
- 50 The success of this solution depends on ED nurses' ability to make accurate predictions about patient 51 disposition. Previous literature highlights notable variability in the accuracy of nursing predictions. Several studies report an accuracy rate of 70% or higher for predicting patient disposition or outcome, with nearly 52 53 90% accuracy for predicting patient discharge.<sup>11–13</sup> Other research contradicts these findings, with one study 54 demonstrating inappropriate patient triaging in over 40% of patient presentations.<sup>14</sup> There is also variability 55 regarding the factors that influence nurses' prediction accuracy. Some studies demonstrate a positive correlation between nurse experience and predictive capability,<sup>15</sup> while others do not.<sup>11,16</sup> Certain patient 56 57 characteristics, including age and severity of presentation, have been correlated with high predictive 58 accuracy, though other literature has failed to replicate these findings.<sup>12,13</sup>
- 59 Most existing studies on nurse prediction rely on prospective designs, which limit sample size and make predictions prone to Hawthorne effects where subjects of studies change their behavior because they are 60 61 being observed.<sup>17</sup> In contrast, we examine an ED operations change that required triage nurses to predict 62 whether a patient required admission to facilitate earlier involvement of allied health. Our study makes two 63 key contributions to the literature. First, unlike prospective research, our results better reflect real-world 64 conditions, providing evidence on how triage nurses predict "in the wild" when they do not think they are 65 being studied. Second, by leveraging a large set of high-quality administrative data, we are able to explore the nuances of triage nurse predictions. This gives us power to examine heterogeneity in prediction accuracy 66 67 by patient type and other important characteristics. Our study adds to a small body of literature on nurses' 68 predictive capabilities, and to a smaller literature examining the heterogeneity in prediction by nurse and 69 patient type.
- 70

### 71 Materials and Methods

72 Study Design

This is a retrospective cohort study that uses administrative health data collected during March 2019 to July2024.

75 Setting

The study was conducted using data from a community ED within the Niagara Health system located in
southeastern Ontario. This site sees 80-100 visits per day and 30,000-40,000 visits per year. The ED has
approximately 20-30 regular nurses who are able to triage.

79 As part of a quality improvement initiative, triage nurses were asked to indicate within the electronic medical record (EMR) system if they believed a patient would require hospital admission. Predictions began 80 81 as a quality improvement initiative to reduce potential admission time. Triage nurses flagged patients who 82 they thought would be admitted so that allied healthcare like occupational therapy and discharge planning 83 would quickly see patients who likely needed their services. Triage nurses received no specific training. 84 For each triaged patient an additional question was added to the triaging screen after the nurse recorded the 85 patient's past medical history which asked "predicted admission y/n". Prediction could not be routinely 86 bypassed except for rapidly evolving emergencies or when the EMR was down for maintenance. There 87 were also exceptions for agency nurses who had not been hired full-time. For these situations nurses could

triage by paper and a prediction was not entered into the EMR.

89 This administrative data allows us to measure admission outcomes and define surrogates for admissions to 90 test how accurate nurses are at predicting. Specifically, in our primary outcome, we include the following

- 91 as an admission:
- 92 1. Any admission to the hospital at the time of the index ED visit,
- 93 2. Transfers to alternate hospitals, and
- 94 3. Deaths in the ED.

We also consider patients who return to the ED for any reason within 30 days and subsequently require admission (or meet one of the above criteria) as "admissions" for the purpose of evaluating prediction accuracy. This surrogate attempts to measure inappropriate discharges (i.e. patients that should have been admitted but were not) by the physician at the index visit. Our rationale for this broad 30-day window is that even if the return visit is for a seemingly unrelated issue, the need for admission indicates a potential clinical necessity that might not have been fully recognized at the initial presentation.

- 101
- 102 *Outcome Measures*

Our main measure of interest is the accuracy of a nurse predicting admission to hospital. We measure this
 by estimating sensitivity (1) and specificity (2) of admissions predictions.<sup>18</sup> These are defined as

105 
$$Sensitivity (TPR) = \frac{TP}{TP + FN}$$
(1)

106 and

107 
$$Specificity (TNR) = \frac{TN}{TN + FP}$$
 (2)

108 We also provide estimates for (3) positive predictive value and (4) negative predictive value defined as

109

110 Positive Predictive Value (PPV) = 
$$\frac{TP}{TP+FP}$$
 (3)

111 and

112 Negative Predictive Value (NPV) = 
$$\frac{TN}{TN+FN}$$
 (4)

113

114 We treat the ED physician's decision to admit as the reference standard, supplemented by the admission 115 surrogates noted above. The components of these measures are:

116 • True positives (TP): Patients predicted to need admission who are admitted, transferred, die in the 117 ED, or return to the ED within 30 days (for any reason) and meet one of these criteria. 118 119 • False negatives (FN): Patients predicted not to need admission but who are admitted, transferred, die in the ED, or return to the ED within 30 days (for any reason) and meet one of these criteria. 120 121 122 True negatives (TN): Patients predicted not to need admission and who do not meet any of the 123 above criteria at the index visit or within 30 days. 124 125 False positives (FP): Patients predicted to need admission but do not meet any of the above criteria 126 and do not return within 30 days requiring admission.

127

128 We also evaluate overall accuracy, defined as:

129 
$$Accuracy (ACC) = \frac{TP + TN}{TP + TN + FP + FN}$$
(5)

Finally, because substantially more patients are discharged than admitted, we also calculate the  $F_1$ -score, which balances sensitivity (recall) and positive predictive value (precision). This is commonly used in machine learning and is useful in settings with imbalanced outcomes,<sup>19</sup> such as ED visits where admissions are less common. The  $F_1$ -score is given by:

$$F_I = \frac{TP}{TP + \frac{l}{2}(FP + FN)} \tag{6}$$

136  $F_1$  scores below 0.5 are considered poor and scores between 0.5 and 0.8 are considered average.

#### 137 Additional Analyses

138 We also estimate a prediction compliance rate as the number of predictions that are recorded over the total number of patients. We provide several extensions of our headline measurements of compliance, 139 140 specificity, sensitivity, PPV, NPV, accuracy, and F<sub>1</sub> score. First, we examine how stable these outcomes 141 have been over the period of observation, to see whether predictions vary with familiarity. Second, we 142 examine the inter-nurse variation in predictions to check whether some nurses predict better than others. 143 Finally, we examine whether prediction outcomes vary by a patient's assigned triage acuity score and patient 144 complaint. The former variable, CTAS, is a computer-calculated measurement of the patient's requirement 145 for acute resources and corresponds to sickness of the patient.<sup>20</sup> CTAS categories correspond to a scale of

146 1 to 5, namely: resuscitation (1), emergent (2), urgent (3), less urgent (4), and non-urgent (5) visits.

147

Finally, To examine how our definition of "admission" (which includes 30-day readmissions for any reason) impacts our results, we also perform a sensitivity analysis that alters the outcome so that it only 1)

150 includes seven-day readmissions, 2) one day readmissions and 3) excludes these return admissions entirely

151 (ie only includes the index visit). Comparing our metrics (sensitivity, specificity, PPV, NPV, accuracy, F<sub>1</sub>-

- 152 score) across these four definitions allows us to identify whether this definition substantially alters our 153 conclusions.
- 154
- 155 Inclusion and Exclusion Criteria

We make two data restrictions when examining prediction heterogeneity to avoid small sample sizes. For inter-nurse prediction, we only include nurses who registered 50 or more predictions over the study period.

158 Our examination of nurse heterogeneity is also restricted to the period of January 2020 to July 2024, as we

- 159 do not have information on which nurses made predictions prior to this. For examination of presenting
- 160 complaints, we only include predictions for complaints that have appeared at least 100 times throughout
- 161 the study period.

#### 162 Data analysis

Analysis was performed with Stata 18. For our overall parameters of sensitivity, specificity, positive
 predictive value and negative predictive value we provide a 95% confidence interval that is based on a two sided test.

- 166 Ethics Approval
- 167 Ethics was obtained through the Hamilton Integrated Research Ethics Board under project number 17330.

# 168 Results

169

170 During the study period of March 2019 to July 2024, 162,392 visits occurred at the ED in this study. Triage 171 nurses provided disposition predictions for 134,891 visits for an overall compliance rate of 83%. Of these 172 visits, 16,022 resulted in admission to the hospital. Nurses correctly predicted 6,764 admissions (TPs) but 173 missed 11,700 admissions (FNs), resulting in an overall sensitivity of 36.6% (95CI: 35.9, 37.3). 174 Additionally, triage nurses accurately predicted that 109,067 visits would not result in an admission (TNs), 175 while 7,360 visits that they predicted as admissions did not result in hospitalization (FPs), yielding a 176 specificity of 93.7% (95CI: 93.5, 93.8). These findings correspond to positive and negative predictive 177 values of 47.9% (95CI: 47.1, 48.7) and 90.3% (95CI: 90.1, 90.5), respectively. The nurses' overall accuracy during the period of observation was 85.8% (95CI: 85.7, 86.1). The F<sub>1</sub> score of predictions was 0.415. Our 178 179 checks on whether our outcomes of interest change appreciably by altering outcome definition are also 180 contained in this table. We find little evidence that they are affected by changes to inclusion of bouncebacks 181 to ED.



Outcome	Sensitivity	Specificity	PPV	NPV	Accuracy	F <sub>1</sub> Score
Admission with 30-day bouncebacks (Primary Measure)	0.3665	0.9368	0.4791	0.9031	0.8587	0.4153
Admission with 7-day bouncebacks	0.3755	0.9353	0.4618	0.9102	0.8632	0.4142
Admission with 1-day bouncebacks	0.3888	0.9337	0.4424	0.9186	0.8688	0.4139
Admission at index visit	0.3892	0.9336	0.4415	0.919	0.869	0.4137

Table 1: Estimates of outcomes of interest by primary outcome and by changes to outcome by changes to
bounceback inclusions.

185

186 Figure 1 illustrates the stability of each of these outcomes over time. Compliance varies from a minimum 187 monthly average of 63% in September 2023 to a peak of 94% in September 2021. Sensitivity also varies 188 from a minimum of 28% in December 2021 to a maximum of 53% in April 2019. Relatively low PPV is 189 observed across the period with an exception where it spiked to 71% in late 2022. There is however 190 consistently high NPV observed over time. Specificity and accuracy are more stable over time, showing 191 less variation in contrast to compliance or sensitivity. This stability is reflective of the high prevalence of 192 patients who are not admitted to hospital. The relatively modest F<sub>1</sub> score we estimate also reflects this and 193 reflects poor specificity of nurse predictions. The exception to this pattern is that sensitivity is relatively 194 high in the first month of prediction before it stabilizes at a much lower baseline value in subsequent 195 months.



197

198 *Figure 1. Time series of outcomes of interest over the period of observation.* 

200 In line with our observations across time, compliance and specificity are similar across nurses (Figure 2). 201 The lowest non-outlier compliance rates are around 90%, indicating that non-compliance is concentrated 202 in a minority of outlier nurses. Specificity also remains consistently high across the majority of nurses in 203 our sample with the lowest prediction specificity for a nurse being 84%. However, there is considerable 204 variation in the sensitivities of nurse predictions which range from 0 to 100%. This results in the majority 205 of nurses having prediction accuracies between 77 and 97%. Negative predictive values have a limited 206 range between 82% and 100% whereas positive predictive values range between 18 and 91%. Nurse F<sub>1</sub> 207 scores range from 0 to 0.77.



208

209 Figure 2. Variation in outcomes of interest across nurses. The center white line represents the median

210 value, the edges of the box represent the 25th and 75th percentiles, and the whiskers indicate the upper

and lower adjacent values. Estimates exclude values that are outside these adjacent values.

212

213 We find that predictive abilities also vary by patient type (Figure 3). We first examine nurses' prediction 214 accuracy by patient triage score. Nurses have a reduced compliance of 52% in making predictions for very 215 sick patients, classified as CTAS 1, likely because some of these patients were paper triaged and predictions 216 were not entered into the administrative data. For those patients who do not have resuscitation level presentations, which includes CTAS 2-4, nurses predict admission probability for around 80% of all visits. 217 218 Among those patients that received a prediction, we find a positive correlation between triage score severity 219 and sensitivity, and a negative correlation between triage score severity and specificity. Higher triage 220 severity and need for emergency resources means higher sensitivity and lower specificity. This results in a 221 positive correlation between triage score and prediction accuracy and a negative correlation between triage 222 score and F<sub>1</sub> score.



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Figure 3. Outcomes of interest by triage scores. CTAS ranges from 1 to 5 which are resuscitation (1),
emergent (2), urgent (3), less urgent (4), and non-urgent (5) visits.

227 228

229 We find that most conditions have high prediction specificity and corresponding low sensitivities 230 (Supplemental Table 1). However, some conditions have comparatively high sensitivities as compared to 231 other complaints. This includes a cluster of complaints that relate to altered levels of consciousness, 232 confusion, bizarre behaviour, and social and patient welfare concerns. Prediction accuracy is relatively high 233 in a set of conditions that correspond to low overall probability of hospital admission, such as bites and 234 foreign bodies to the eye (Table 2). However,  $F_1$  scores are consistently poor with only the top 13 complaints 235 demonstrating scores that could be considered average in terms of prediction. All remaining patient 236 complaints have F<sub>1</sub> scores that would be considered poor (Table 2).

Bottom	ttom 20 complaints by accuracy				Top 20 complaints by accuracy				
Rank	Complaint	Accuracy	Ν	Rank	Complaint	Accuracy	Ν		
1	Confusion	0.5964	721	59	Facial trauma	0.9340	485		
2	Altered LOC	0.6207	1181	60	Neck swelling/pain	0.9340	849		
3	General weakness	0.6611	4642	61	Isolated chest trauma – blunt	0.9369	317		
4	Hyperglycemia	0.6829	360	62	URTI complaints	0.9386	277		
5	Hypoglycemia	0.6832	123	63	Minor complaints NOS	0.9386	880		
6	Shortness of breath	0.6832	6475	64	Sensory loss/paresthesia	0.9437	231		
7	Concern for welfare	0.6842	209	65	Epistaxis	0.9453	585		
8	Social problem	0.6887	106	66	Cough/congestion	0.9460	3018		
9	Bizarre behaviour	0.6994	316	67	Eye trauma	0.9506	263		
10	Substance withdrawal	0.7132	258	68	Visual disturbance	0.9544	592		
11	Abdominal mass/distension	0.7258	434	69	Upper extremity pain	0.9620	2396		
12	Direct referral for consultation	0.7317	1092	70	Upper extremity injury	0.9659	5779		
13	Overdose ingestion	0.7408	1065	71	Allergic reaction	0.9701	1204		
14	Extremity	0.7445	1139	72	Rash	0.9738	1296		
	weakness/symptoms of CVA								
15	Blood in stool/melena	0.7484	1077	73	Prescription/medication request	0.9763	760		
16	Depression/suicidal/deliberat e delf-harm	0.7517	584	74	Recheck eye	0.9771	218		
17	Vomiting blood	0.7556	266	75	Burn	0.9805	257		
18	Seizure	0.7556	1320	76	Eye pain	0.9867	602		
19	Palpitations/irregular heartbeat	0.7712	1914	77	Dental/gum problem	0.9868	836		
20	Edema, generalized	0.7739	115	78	Laceration/puncture	0.9885	3315		
Bottom	20 complaints by F1 score	•		Top 20	complaints by F1 score				
Rank									
i turin	Complaint	F <sub>1</sub>	Ν	Rank	Complaint	F <sub>1</sub>	N		
1	Allergic reaction	<b>F</b> <sub>1</sub> 0.0526	<b>N</b> 1204	Rank 59	Complaint Palpitations/irregular heartbeat	<b>F</b> <sub>1</sub> 0.3559	<b>N</b> 1914		
1 2	Allergic reaction Epistaxis	<b>F</b> <sub>1</sub> 0.0526 0.0588	N 1204 585	<b>Rank</b> 59 60	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results	<b>F</b> <sub>1</sub> 0.3559 0.3616	N 1914 2838		
1 2 3	Allergic reaction Epistaxis Neck trauma	<b>F</b> <sub>1</sub> 0.0526 0.0588 0.0909	N 1204 585 251	Rank           59           60           61	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope	<b>F</b> <sub>1</sub> 0.3559 0.3616 0.3788	N 1914 2838 2305		
1 2 3 4	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis	F1           0.0526           0.0588           0.0909           0.0938	N 1204 585 251 691	Rank           59           60           61           62	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour	F1           0.3559           0.3616           0.3788           0.3791	N 1914 2838 2305 316		
1 2 3 4 5	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture	F1           0.0526           0.0588           0.0909           0.0938           0.0952	N 1204 585 251 691 3315	Rank           59           60           61           62           63	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA	F1           0.3559           0.3616           0.3788           0.3791           0.4680	N 1914 2838 2305 316 1139		
1 2 3 4 5 6	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000	N 1204 585 251 691 3315 610	Rank           59           60           61           62           63           64	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800	N 1914 2838 2305 316 1139 115		
1 2 3 4 5 6 7	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081	N 1204 585 251 691 3315 610 346	Rank           59           60           61           62           63           64           65	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized Hypoglycemia	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935	N 1914 2838 2305 316 1139 115 123		
1 2 3 4 5 6 7 8	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111	N           1204           585           251           691           3315           610           346           485	Rank           59           60           61           62           63           64           65           66	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized Hypoglycemia Blood in stool/melena	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028	N 1914 2838 2305 316 1139 115 123 1077		
1 2 3 4 5 6 7 8 9	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176	N 1204 585 251 691 3315 610 346 485 322	Rank           59           60           61           62           63           64           65           66           67	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized Hypoglycemia Blood in stool/melena Lower extremity injury	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102	N 1914 2838 2305 316 1139 115 123 1077 6270		
1         2           3         4           5         6           7         8           9         10	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212	N           1204           585           251           691           3315           610           346           485           322           584	Rank           59           60           61           62           63           64           65           66           67           68	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized Hypoglycemia Blood in stool/melena Lower extremity injury Shortness of breath	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155	N           1914           2838           2305           316           1139           115           123           1077           6270           6475		
1         2           3         4           5         6           7         8           9         10           11         11	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288	N           1204           585           251           691           3315           610           346           485           322           584           2517	Rank           59           60           61           62           63           64           65           66           67           68           69	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized Hypoglycemia Blood in stool/melena Lower extremity injury Shortness of breath Hyperglycemia	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5379	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360		
1         2           3         4           5         6           7         8           9         10           11         12	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288           0.1429	N           1204           585           251           691           3315           610           346           485           322           584           2517           641	Rank           59           60           61           62           63           64           65           66           67           68           69           70	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized Hypoglycemia Blood in stool/melena Lower extremity injury Shortness of breath Hyperglycemia General weakness	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5379           0.5527	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642		
1         2           3         4           5         6           7         8           9         10           11         12           13         13	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention         Other skin conditions	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288           0.1429           0.1481	N           1204           585           251           691           3315           610           346           485           322           584           2517           641           294	Rank           59           60           61           62           63           64           65           66           67           68           69           70           71	Complaint         Palpitations/irregular heartbeat         Abnormal lab/imaging results         Syncope/pre-syncope         Bizarre behaviour         Extremity weakness/symptoms of CVA         Edema, generalized         Hypoglycemia         Blood in stool/melena         Lower extremity injury         Shortness of breath         Hyperglycemia         General weakness         Confusion	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5379           0.5527           0.5813	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642           721		
1           2           3           4           5           6           7           8           9           10           11           12           13           14	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention         Other skin conditions         Headache	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288           0.1429           0.1481           0.1493	N           1204           585           251           691           3315           610           346           485           322           584           2517           641           294           2426	Rank           59           60           61           62           63           64           65           66           67           68           69           70           71           72	Complaint Palpitations/irregular heartbeat Abnormal lab/imaging results Syncope/pre-syncope Bizarre behaviour Extremity weakness/symptoms of CVA Edema, generalized Hypoglycemia Blood in stool/melena Lower extremity injury Shortness of breath Hyperglycemia General weakness Confusion Fever	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5527           0.5836	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642           721           3151		
1           2           3           4           5           6           7           8           9           10           11           12           13           14           15	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention         Other skin conditions         Headache         Dental/gum problem	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288           0.1481           0.1481           0.1483           0.1538	N           1204           585           251           691           3315           610           346           485           322           584           2517           641           294           2426           836	Rank           59           60           61           62           63           64           65           66           67           68           69           70           71           72           73	Complaint         Palpitations/irregular heartbeat         Abnormal lab/imaging results         Syncope/pre-syncope         Bizarre behaviour         Extremity weakness/symptoms of CVA         Edema, generalized         Hypoglycemia         Blood in stool/melena         Lower extremity injury         Shortness of breath         Hyperglycemia         General weakness         Confusion         Fever         URTI complaints	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5379           0.5527           0.5813           0.5836	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642           721           3151           277		
1           2           3           4           5           6           7           8           9           10           11           12           13           14           15           16	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention         Other skin conditions         Headache         Dental/gum problem         Constipation	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288           0.1481           0.1483           0.1538           0.1777	N           1204           585           251           691           3315           610           346           485           322           584           2517           641           294           2426           836           591	Rank           59           60           61           62           63           64           65           66           67           68           69           70           71           72           73           74	Complaint         Palpitations/irregular heartbeat         Abnormal lab/imaging results         Syncope/pre-syncope         Bizarre behaviour         Extremity weakness/symptoms of CVA         Edema, generalized         Hypoglycemia         Blood in stool/melena         Lower extremity injury         Shortness of breath         Hyperglycemia         General weakness         Confusion         Fever         URTI complaints         Vomiting blood	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5379           0.5527           0.5813           0.5836           0.5854           0.6012	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642           721           3151           277           266		
1           2           3           4           5           6           7           8           9           10           11           12           13           14           15           16           17	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention         Other skin conditions         Headache         Dental/gum problem         Constipation         Medical device problem	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288           0.1481           0.1483           0.1483           0.1538           0.1777           0.1785	N           1204           585           251           691           3315           610           346           485           322           584           2517           641           294           2426           836           591           864	Rank           59           60           61           62           63           64           65           66           67           68           69           70           71           72           73           74           75	Complaint         Palpitations/irregular heartbeat         Abnormal lab/imaging results         Syncope/pre-syncope         Bizarre behaviour         Extremity weakness/symptoms of CVA         Edema, generalized         Hypoglycemia         Blood in stool/melena         Lower extremity injury         Shortness of breath         Hyperglycemia         General weakness         Confusion         Fever         URTI complaints         Vomiting blood         Social problem	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5379           0.5527           0.5813           0.5854           0.6012           0.6292	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642           721           3151           277           266           106		
1         2           3         4           5         6           7         8           9         10           11         12           13         14           15         16           17         18	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention         Other skin conditions         Headache         Dental/gum problem         Constipation         Medical device problem         Prescription/medication         request	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1176           0.1212           0.1288           0.1481           0.1483           0.1538           0.1777           0.1785           0.1818	N           1204           585           251           691           3315           610           346           485           322           584           2517           641           294           2426           836           591           864           760	Rank           59           60           61           62           63           64           65           66           67           68           69           70           71           72           73           74           75           76	Complaint         Palpitations/irregular heartbeat         Abnormal lab/imaging results         Syncope/pre-syncope         Bizarre behaviour         Extremity weakness/symptoms of CVA         Edema, generalized         Hypoglycemia         Blood in stool/melena         Lower extremity injury         Shortness of breath         Hyperglycemia         General weakness         Confusion         Fever         URTI complaints         Vomiting blood         Social problem         Direct referral for consultation	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5527           0.5813           0.5836           0.5854           0.6012           0.6292           0.6387	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642           721           3151           277           266           106           1092		
1         2           3         4           5         6           7         8           9         10           11         12           13         14           15         16           17         18           19         19	Complaint         Allergic reaction         Epistaxis         Neck trauma         Anxiety/situational crisis         Laceration/puncture         Vaginal bleed         Rectal/perineal pain         Facial trauma         Groin/pain mass         Depression/suicidal/deliberat         e self-harm         Flank-pain         Urinary retention         Other skin conditions         Headache         Dental/gum problem         Constipation         Medical device problem         Prescription/medication         request	F1           0.0526           0.0588           0.0909           0.0938           0.0952           0.1000           0.1081           0.1111           0.1116           0.1212           0.1288           0.1481           0.1483           0.1483           0.1538           0.1777           0.1785           0.1818	N           1204           585           251           691           3315           610           346           485           322           584           2517           641           294           2426           836           591           864           760           592	Rank           59           60           61           62           63           64           65           66           67           68           69           70           71           72           73           74           75           76           77	Complaint         Palpitations/irregular heartbeat         Abnormal lab/imaging results         Syncope/pre-syncope         Bizarre behaviour         Extremity weakness/symptoms of CVA         Edema, generalized         Hypoglycemia         Blood in stool/melena         Lower extremity injury         Shortness of breath         Hyperglycemia         General weakness         Confusion         Fever         URTI complaints         Vomiting blood         Social problem         Direct referral for consultation         Altered LOC	F1           0.3559           0.3616           0.3788           0.3791           0.4680           0.4800           0.4935           0.5028           0.5102           0.5155           0.5527           0.5813           0.5836           0.5854           0.6012           0.6387           0.6601	N           1914           2838           2305           316           1139           115           123           1077           6270           6475           360           4642           721           3151           277           266           106           1092           1181		

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*Table 2. Top and bottom 20 patient presentations by prediction accuracy and*  $F_1$  *score.* 

## 242 Discussion

We estimate the sensitivity, specificity, positive predictive value, negative predictive value, accuracy and the  $F_1$  score of triage nurses at an ED in Ontario, Canada, to assess how effectively they predict patient admission to hospital. Our contribution is twofold: first, these estimates are not contaminated by Hawthorne effects, which are characteristic of previous prospective studies. Second, we use a much larger sample of data than previous studies. This allows us to provide evidence on temporal, nurse, and patient heterogeneity in predictions.

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We observe that this sample of nurses achieves reasonably high prediction accuracy for hospital admissions. Prediction accuracy is 85.8% and is relatively stable over the entire period that we examine. However, the estimated F<sub>1</sub>-score was 0.415 which is poor, and is due to the relatively low sensitivity and positive predictive value of predictions. Thus, the high accuracy is predicated on a relatively high specificity among a group of patients that are more likely to be discharged from hospital. This high specificity is also possibly grounded in the relatively large numbers of non-emergent presentations (i.e. CTAS 5-3). Performance in predicting admissions to hospital is more modest, with sensitivities in the range of 30-40%.

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259 There are several explanations for this modest sensitivity. Triage nurses, as the point of first contact, have 260 much less information to base predictions upon relative to other health care providers in the ED. Prediction 261 accuracy might improve if made by bedside nurses, who are able to use initial investigations and conduct a 262 more involved physical exam. Another possibility is unfamiliarity with predictions. However, our accuracy 263 results are stable over time, suggesting that nurses did not learn to improve their predictions with increased 264 prediction practice. Feedback, training and stakes may also be important to improve prediction sensitivity 265 and were absent in our setting. On this last point, predictions had no immediate impact on care within the 266 ED and were largely supposed to improve inpatient care. Similarly, incentivization, also absent in our setting, has been demonstrated to improve performance in similar tasks.<sup>22</sup> However, poor sensitivity may 267 268 be more of a general issue in ED care than one specific to triage nurses. Even highly trained physicians 269 only predict patient outcomes with equivocal,<sup>16</sup> or only slightly greater ability.<sup>2</sup>

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271 Our results demonstrating that nurses have low sensitivity/high specificity and high negative predictive 272 value/low positive predictive value have implications for ED operations. High specificity and low positive 273 predictive value suggest the potential for overtriage or where nurses suggest admission for patients who do 274 not require admission. Where there is relatively low prevalence in need for admission as in our setting, ED 275 physicians cannot necessarily trust a positive admission prediction from the nurse. Low sensitivity and 276 high negative predictive value suggest a simultaneous but opposite issue. Nurses are under-triaging and 277 suggesting discharge for patients who should actually be admitted. In ED settings where admission is 278 relatively rare this may be useful in that most of the people the nurse identifies as not needing admission 279 are probably safe for discharge. However, our results suggest that it is not reliably safe to trust the triage 280 nurse discharge decision either.

281

Despite this paradoxical issue of simultaneous over and under triage and a poor F<sub>1</sub> score for overall need for admission, our exploration of prediction heterogeneity suggests that ED physicians should pay attention to certain predictions. Triage nurses are accurate at predicting admission for presentations related to mental health concerns, altered levels of consciousness, confusion, bizarre behaviour, and social and patient welfare concerns. These have relatively higher sensitivities and could be used to accelerate admission planning. The inter-nurse variation we observe in our outcomes also suggests that particular nurses may be able to provide more accurate information to a physician about a patient's discharge disposition, and so predictions from these nurses should be paid particular attention. Both of these findings are novel and suggest nuance in understanding when to trust nursing admission predictions. It may be reasonable to delegate admission decisions for certain complaints and certain nurses under narrow circumstances.

292 Our findings are consistent with previous literature that indicates nurses are not able to predict patient admission with sufficient sensitivity,<sup>10,14,23–26</sup> and from an operations perspective suggests against the direct 293 294 streamlining of patients to admission based on triage nurse predictions. This is contrary to some literature 295 that suggests triage nurses may be able to achieve satisfactory levels of sensitivity to implement triage prediction programs.<sup>11-13,15,27-29</sup> It is unclear what drives this difference between our results and this 296 literature, but it is likely multifactorial. Site specific circumstances and the nursing staff's experience may 297 298 play a role. We also highlight that most of the previous literature is prospective, and nurses know they are 299 being monitored. Monitoring may alter prediction behaviour and improve sensitivity and rule-in 300 performance, possibly accounting for some of the superior sensitivities in contrasting literature.<sup>17</sup> In support 301 of this, we find some suggestive evidence of these Hawthorne effects. Sensitivity was much higher in our 302 first month of observation when nurses were being told to produce predictions, and the system was novel 303 to them than in subsequent months.

304 Although triage nurses were unable to accurately predict patient admissions at our site, they had high 305 negative predictive value. This finding is consistent with previous literature which demonstrates that triage nurses are better at predicting discharge.<sup>11–13,23,26,28,29</sup> This suggests that triage nurses may be useful in 306 307 identifying patients who are *likely* to be discharged quickly. Healthcare providers can then take a second, 308 more involved examination and admit those patients that triage nurses may have undertriaged. This is 309 already done through the use of ED 'see-and-treat' areas where patients deemed to require lower levels of 310 care are streamed. Such streaming could help to reduce congestion and improve workflow in acute care 311 sections where most patients have been deemed as requiring admission. A version of this concept was 312 demonstrated by Derlet et al. (1995) who were able to successfully divert 18% of adult ambulatory visits 313 over a five-year period. This led to reductions in ED waiting times, the number of patients who left without 314 care, and complications resulting from delayed care.<sup>27</sup> This also reduced costs without any deaths within 315 72 hours of patients being triaged.<sup>27</sup>

316 Finally, we find evidence that triage nurses predict well at the extremes of the triage distribution, having 317 higher sensitivities in patients with low triage scores and who are more likely to be admitted, and higher 318 specificities in patients with high triage scores and who are more likely to be discharged. This is consistent 319 with previous literature which suggests that prediction accuracy increases at the extremes of case severity.<sup>12,13,23,25,28</sup> While high and low admission rates for resuscitation and non-urgent triage scores 320 321 respectively may make predicting dispositions easier, these categories only account for 5-9% of total ED 322 visits.<sup>30,31</sup> Of total visits, 45-60% are categorized as the middle category, or urgent, which are considerably 323 less predictable with admission rates of 28.2-49.4%.<sup>20,30,31</sup> Our results on prediction accuracy by patient 324 complaint reinforces this: triage nurses are most likely to accurately predict disposition among patients with 325 complaints that are less likely to require admission to hospital. This result suggests that triage nurses may 326 be most effective at making predictions when uncertainty is minimized.

#### 327 Limitations

We note several limitations of this study. First, this is a single site study and findings may not be 328 329 generalizable to other settings. Second, due to the retrospective design of this study, information such as 330 prediction confidence ratings were not collected, which we note impacted the accuracy of predictions in 331 previous literature. Third, we did not have data explaining the 20% rate of non-compliance that was 332 observed. It is possible that nurses selectively made predictions for cases in which they felt more confident, 333 artificially inflating our reported sensitivity and specificity. Fourth, admission prediction is not included in 334 current triage training, and consequently, formal implementation may be required to acquire the most 335 accurate measurements. Fifth, while using bounceback presentations with admission allows us to account 336 for incorrect discharge by the physician, it may result in underestimation of specificity and overestimation 337 of sensitivity if the subsequent admission is for a reason unrelated to the index presentation. We provide 338 evidence on this in our sensitivity checks. Lastly, although a retrospective trial limits influence of the 339 Hawthorne effect, the absence of consequences or incentives for incorrect or accurate predictions 340 respectively may have reduced the intentionality of predictions made by triage nurses, and in turn, accuracy.

#### 341 Conclusion

We find generally high accuracy but low F<sub>1</sub> scores when triage nurses make admission predictions about
 patients at our site of interest in Ontario, Canada. High accuracy stems from high specificities with modest
 sensitivities. We find notable variation in nurse accuracy and variation based on patient characteristics.
 These results suggest that nursing staff predictions could be useful in expediting some resource allocation
 decisions and improving flow in EDs.

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Author Contributions: S Strobel, CA, MD, GS, DKE, AEG contributed to conception of the project. S
 Strobel conducted the data analysis. CM was responsible for research coordination. CA, DKE, MD, and S
 Strobel drafted the manuscript. All authors contributed significantly to its revision.

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**Data Sharing Statement:** We are unable to share the data for this project as Niagara Health considers it sensitive and subject to patient anonymity concerns. We are able to provide the underlying Stata code that replicates the project.

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