Comparison of Age and Modified Frailty Index-5 as Predictors of In-Hospital Mortality in Complete Traumatic Cervical Spinal Cord Injury

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Abstract

Frailty, as measured by the modified frailty index-5 (mFI-5), and older age are associated with increased mortality in the setting of spinal cord injury (SCI). However, a comparison of the predictive power of each measure has not been completed. We conducted a retrospective cohort study to evaluate in-hospital mortality among adult complete cervical SCI patients at participating centers of the Trauma Quality Improvement Program from 2010 to 2018. Logistic regression was used to predict in-hospital mortality, and the area under the Receiver Operating Characteristic curve (AUROC) of regression models with age, mFI-5, or age with mFI-5 was used to compare predictive power. 4,733 patients were eligible. We found significant effect of age > 75 years (OR 9.77 95% CI [7.21 13.29]) and mFI-5 ≥ 2 (OR 3.09 95% CI [1.85 4.99]) on in-hospital mortality. The AUROC of a model including age and mFI-5 (0.81 95%CI [0.79 0.84] AUROC) was comparable to a model with age alone (0.81 95%CI [0.79 0.83] AUROC). Both models were superior to a model with mFI-5 alone (0.75 95% CI [0.72 0.77] AUROC)). Our findings suggest that age provides more predictive power than mFI-5 in the prediction of in-hospital mortality for complete cervical SCI.

Introduction

Complete traumatic spinal cord injury (SCI) confers significant in-hospital mortality risk to patients. Mortality after such an injury has been estimated as high as 17% [1–3]. Several studies have sought to identify factors contributing to this high rate, and unsurprisingly, patient age often emerges as a strong predictor of mortality [4–9]. However, in recent years there has been growing interest in the concept of clinical frailty as a counterpart to patient age in predicting patient morbidity and mortality [10].

Clinical frailty refers to a state of decreased physiologic reserve and vulnerability to stressors due to a decline in the normal functioning of multiple organ systems [11]. Numerous scales have been described to quantify the degree of frailty in a patient [12–14]. In the setting of trauma, the 5-item modified frailty index (mFI-5) has been described as a facile tool to determine a given patient’s frailty [13]. The mFI-5 is calculated based on the presence of diabetes, hypertension, congestive heart failure, chronic obstructive pulmonary disease, and dependent functional status. In cases of traumatic SCI, the mFI-5 has been shown to be a predictor of in-hospital mortality [5].

A state of high frailty is generally associated with older age, and vice versa, but there are always exceptions to the rule. There are invariably cases of high functioning elderly patients with minimal chronic disease, and by contrast, middle aged individuals with poor nutrition, mobility, and numerous comorbidities. As such, there is not necessarily a one-to-one correlation of a given patient's age and frailty. In the setting of degenerative cervical myelopathy, age and frailty have differential predictive power of adverse events. However, no study has compared the predictive power of age and frailty in the context of SCI. In this study we aim to address this knowledge gap, by assessing age and mFI-5 as predictors of in-hospital mortality using a large multi-center database.

Methods

Data Source

All data in this study was derived from the 2010–2018 American College of Surgeons (ACS) Trauma Quality Improvement Program (TQIP) [15, 16]. More than 450 ACS- and state-verified level I and II trauma centers across North America contribute to TQIP. It includes all patients from verified centers with at least one severe injury (Abbreviated Injury Scale [AIS] ≥ 3 in at least one body region). Data reliability and quality is maintained through training of data abstractors and inter-rater reliability audits of contributing centers.

Research Ethics Board Approval

This study number 20–247 was approved by the Unity Health Toronto Research Ethics Board (Toronto, Ontario, Canada) in January of 2021. Study procedures were followed in accordance with the ethical standards of the institutional committee on human experimentation and with the Helsinki Declaration of 1975. This study used only de-identified retrospective patient data, and individual participant informed consent was waived by the Unity Health Toronto Research Ethics Board.

Study Eligibility

Adult patients (≥ 16 years) with a diagnosis of acute complete (ASIA A) traumatic cervical SCI due to blunt trauma that were treated at level I or II trauma centers were included based on AIS codes (Supplementary Table S1). The International Classification of Diseases 9th and 10th revision Procedure Classification System (ICD-9-PCS and ICD-10-PCS) codes were used to identify procedure codes for decompression and fusion (see Supplementary Table S2). Patients with missing data on whether they underwent spinal surgery were excluded. In addition, patients with missing data on in-hospital mortality were also excluded as this was our primary outcome of interest. Finally, patients with any AIS body score of 6 were also excluded, as these are non-survivable injuries [17].

Patient, Injury, Treatment, And Hospital Characteristics

Several patient and hospital covariates were selected from the TQIP database according to their clinical relevance. Patient demographic data included age, mFI-5, sex, ethnicity, and insurance type. For our analysis we categorized age as 16–60 years, 60–75 years, and > 75 years. The mFI-5 is a frailty index that has been used in trauma and is scored with one point given based on the presence of each of the following: congestive heart failure, diabetes, hypertension, congestive heart failure, chronic obstructive pulmonary disease, and dependent functional status [18]. For our analysis we dichotomized patients into categories of low frailty (mFI < 2) and high frailty (mFI ≥ 2). This type of dichotomy in the mFI-5 has been found to be relevant in prior studies [5]. Sex was dichotomized into male and female, and race was grouped into categories of African American, Caucasian, and other. Insurance was categorized as private, public, and other. Data on the characteristics of the injury were also collected. This included mechanism of injury, presenting Glasgow Coma Scale (GCS), presence of shock (defined as emergency department blood pressure < 90 mmHg), and year of injury. The patient's GCS was categorized as GCS15, GCS13-14, GCS 9–12, and GCS 3–8, consistent with categories corresponding to severity of traumatic brain injury [19]. Mechanisms of injury were categorized as motor vehicle traumas, falls, and other. The primary treatment characteristic extracted from TQIP was whether the patient underwent a spinal operation. We used ICD-9 and − 10-PCS codes as described above to identify which patients underwent a spinal operation. Surgery was therefore classified as a binary variable. Hospital characteristics including the ACS verification level, teaching status, and hospital size were also extracted from TQIP. Hospital teaching status was categorized as university hospital, community hospital, and non-teaching hospital. Hospital size was categorized as < 200 beds, 200–400 beds, and > 400 beds.

Outcomes

The primary outcome was mortality, which was defined as the presence of an in-hospital mortality during the trauma admission. We computed counts and proportions of mortality across our various age and frailty categories. Using R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria), we computed a heat map of the mortality counts using the *lattice* package [20].

Statistical Analyses

All statistical analyses were performed using R version 4.2.1 with an a priori specified significance level of P = 0.05 (two-tailed). Descriptive statistics were reported as mean and standard deviation (SD) for continuous variables and count and percentage for categorical variables.

Predictive Model And Effect Modification

Logistic regression was used to formulate a predictive model of mortality. Patient age, mFI-5, sex, ethnicity, insurance type, mechanism of injury, presenting GCS, presence of shock, whether they underwent surgery, hospital ACS verification level, teaching status, hospital size, and year of injury were used as covariates for adjustment. To test effect modification of mFI-5 on age, we followed the method described by Wilson et al. and Baron & Kenny [21, 22]. We categorized variables as outlined above, included a final interaction term of age and mFI-5 in the regression model, and considered a moderating effect to exist if the interaction term explained a statistically significant amount of the variance of the outcome variable. To visualize the results of our regression model and the effect modification we used *visreg* package within R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria) [23].

Predictive Model Analysis

Three separate logistic regression models were compared using receiver operating characteristic (ROC) analysis to compare the predictive power of age and mFI-5. We composed a base model of patient, injury, treatment, and hospital covariates described above, and included either age, mFI-5, or age with mFI-5 as covariates in the model. We then computed true and false positive rates of predicted mortality from the regression model to generate an ROC curve. The area under the ROC curve (AUROC) was used to compare a model of age, mFI-5, and age with mFI-5. ROC analysis was conducted using Stata version 17 (Stata Corp, College Station, TX, USA) with an a priori specified significance level of $P = 0.05$ (two-tailed). We completed pairwise comparisons of the AUROC of the different regression models using a χ^2-statistic.

Sensitivity Analyses

We performed sensitivity analyses by computing ROC curves in two patient subgroups. Subgroup 1 was formed by restricting the cohort to patients with age above 60 years. Subgroup 2 was formed by restricting the cohort to patients with age above 60 years, and those who underwent surgery.

Results

Overview of Cohort

Within the 2010–2018 TQIP database, we identified 4,733 patients that sustained complete cervical SCI due to blunt trauma with survivable injuries with data on in-hospital mortality (Fig. 1). Baseline characteristics of the cohort are summarized in Table 1. Mean age was 49 years (20.2 years SD), and there were 3,803 (80.4%) males. Within the cohort 3,126 (66%) patients underwent a decompression and/or a fusion procedure. With respect to frailty, 2,990 (63.2%) patients had an mFI-5 of 0, 1,062 (22.5%) had an mFI-5 of 1, 557 (11.8%) had an mFI-5 of 2, and 121 had an mFI-5 ≥ 3. With respect to frailty categories, this corresponded to 4,052 (85.7%) patients with lower frailty (mFI-5 < 2), and 678 (14.3%) with high frailty (mFI-5 ≥ 2).

Table 1

Baseline characteristics of study cohort. Abbreviations: SD, standard deviation; n, categorical variable count; GCS, Glasgow Coma Scale; ED, emergency department; SBP, systolic blood pressure.

Patient Characteristics	
Age (years) – mean ± SD	49 ± 20.2
Age Category – n (%)	
16–59 years	3085 (65.7)
60–75 years	820 (17.5)
> 75 years	790 (16.8)
Modified Frailty Index-5 (mFI) Category – n (%)	
Low Frailty (mFI < 2)	4052 (85.7)
High Frailty (mFI ≥ 2)	678 (14.3)
Sex – n (%)	
Female	929 (19.6)
Male	3803 (80.4)
Ethnicity– n (%)	
African American	992 (21.2)
Caucasian	3038 (65.1)
Other	639 (13.7)
Insurance– n (%)	
Government	2016 (43.5)
Private	2125 (45.9)
Other	493 (10.6)
Injury/Presentation Characteristics	
Mechanism of injury– n (%)	
Fall	2205 (46.8)
Motor Vehicle Trauma	1790 (38)
Other	717 (15.2)
GCS– n (%)	

Patient Characteristics	
15	2865 (61.2)
13–14	654 (14.0)
9–12	424 (9.1)
3–8	740 (15.8)
Hypotension in ED (SBP < 90) – n (%)	789 (16.9)
Year – n (%)	
2010	204 (4.3)
2011	270 (5.7)
2012	276 (5.8)
2013	288 (6.1)
2014	333 (7.0)
2015	391 (8.3)
2016	453 (9.6)
2017	1311 (27.7)
2018	1207 (25.5)
Treatment Characteristics	
Surgery – n (%)	3843 (81.2%)
Hospital Characteristics	
Level I trauma center – n (%)	2927 (71.3)
Number of beds – n (%)	
> 400	906 (19.1)
200–400	1576 (33.3)
≤ 200	2250 (47.5)
Teaching status – n (%)	
Community	155 (32.9)
Non-teaching	471 (10.0)
University	2691 (57.1)

Mortality Increases Proportionate To Frailty And Age

Within our cohort there were 730 (15.9%) patients who suffered an in-hospital mortality. We identified the number and proportion of patients that died within each age and frailty category (Table 2). There was a total of 2,903 patients in our cohort that were 16–59 years with low frailty (mFI < 2). Among these patients 216 (7.44%) had an in-hospital mortality. As a comparison there were 269 patients in our cohort that were > 75 years with high frailty (mFI ≥ 2). Among these patients 119 died (44.24%). Table 2 demonstrates that the mortality for a given age group is larger in the high frailty group. Alternatively, mortality within a specific frailty category is larger in the older age groups (Fig. 2a).

Table 2
In-hospital mortality events given in counts (rate %) by age and frailty categories. Abbreviations: mFI, Modified Frailty Index-5.

Complete Cohort		**730 (15.9%)**
	mFI < 2	mFI ≥ 2
16–59 years	216 (7.44%)	29 (16.11%)
60–75 years	119 (19.7%)	42 (19.44%)
> 75 years	205 (39.42%)	119 (44.24%)

Results for the logistic regression model for mortality in the cohort are summarized in Table 3 and Fig. 2b. Patient characteristics significantly associated with in-hospital mortality included age > 75 years (OR 9.77 95% CI [7.21 13.29], p < 0.001), age 60–75 years (OR 3.49 95%CI [2.58 4.71], p < 0.001), and high frailty (OR 3.09 95% CI [1.85 4.99], p < 0.001). In addition, Caucasian ethnicity (OR 1.51 95% CI [1.15 2.02], p = 0.004) and having non-governmental and non-private insurance (OR 1.51 95% CI [1.06 2.14], p = 0.022) were significantly associated with in-hospital mortality. Injury characteristics associated with in-hospital mortality included GCS 3–8 (OR 1.24 95% CI [2.4 4.1], p < 0.001). In contrast, patients who underwent surgery were associated with significantly less in-hospital mortality (OR 0.34 95% CI [0.26 0.43]). We did not find any significant effect from sex, year of injury, or hospital characteristics on rates of in-hospital mortality from complete cervical SCI.

Table 3
Association of patient, injury/presentation, treatment, and hospital characteristics with in-hospital mortality for complete cervical spinal cord injury. Abbreviations: OR, odds ratio; CI, confidence interval; GCS, Glasgow Coma Scale; ED, emergency department; SBP, systolic blood pressure.

	OR	*95% CI*	*P Value*
Patient Characteristics			
Age Category			
16–59 years	Reference		
60–75 years	3.49	2.58 to 4.71	< 0.001***
> 75 years	9.77	7.21 to 13.29	< 0.001***
Modified Frailty Index-5 (mFI) Category			
Low Frailty (mFI < 2)	Reference		
High Frailty (mFI ≥ 2)	3.09	1.85 to 4.99	< 0.001***
Sex			
Female	Reference		
Male	1.26	0.97 to 1.64	0.086
Ethnicity			
African American	Reference		
Caucasian	1.51	1.15 to 2.02	0.004**
Other	1.15	0.78 to 1.68	0.487
Insurance			
Government	Reference		
Private	0.96	0.76 to 1.22	0.748
Other	1.51	1.06 to 2.14	0.022*
Injury/Presentation Characteristics			
Mechanism of injury			
Fall	Reference		
Motor Vehicle Trauma	1.17	0.92 to 1.49	0.187
Other	0.86	0.6 to 1.2	0.379
GCS			

	OR	95% CI	P Value
15	Reference		
13–14	1.07	0.78 to 1.45	0.672
9–12	1.1	0.76 to 1.58	0.599
3–8	2.73	2.08 to 3.59	< 0.001***
Hypotension in ED (SBP < 90) – n (%)	1.22	0.93 to 1.58	0.140
Year			
2010	Reference		
2011	1.02	0.53 to 1.97	0.962
2012	1	0.52 to 1.95	0.997
2013	0.78	0.4 to 1.54	0.468
2014	0.82	0.44 to 1.58	0.542
2015	0.9	0.49 to 1.7	0.745
2016	0.87	0.48 to 1.63	0.663
2017	1.17	0.68 to 2.08	0.587
2018	1.25	0.74 to 2.23	0.420
Treatment Characteristics			
Surgery	0.34	0.26 to 0.43	< 0.001*
Hospital Characteristics			
Level I trauma center	0.86	0.64 to 1.16	0.325
Number of beds			
> 400	Reference		
200–400	0.87	0.64 to 1.20	0.396
≤ 200	0.89	0.65 to 1.22	0.476
Teaching status			
Community	Reference		
Non-teaching	1.25	0.85 to 1.83	0.250
University	1.32	1.01 to 1.72	0.042
Interaction (Age x Frailty)			

	OR	95% CI	P Value
Low Frailty-16-59 yrs vs. High Frailty-16-59 yrs	Reference		
Low Frailty-60-75 yrs vs. High Frailty-60-75 yrs	0.43	0.22 to 0.85	0.014*
Low Frailty->75 yrs vs. High Frailty->75 yrs	0.44	0.24 to 0.82	0.008**

Figure 3 demonstrates the effect size of each covariate on in-hospital mortality. Among all covariates that were adjusted, age > 75 years had the largest effect on in-hospital mortality (OR 9.77 95% CI [7.21 13.29], $p < 0.001$). Conversely, surgery was associated with the greatest reduction of in-hospital mortality (OR 0.34 95% CI [0.26 0.43]).

Age Is Associated With Superior In-hospital Mortality Prediction Compared To Frailty

Table 3 represents the results of covariate adjustment in a regression model for in-hospital mortality. Including an interaction term of age-mFI in the regression model demonstrates a significant moderating effect of high frailty (mFI ≥ 2) on patients aged 60–75 years ($p = 0.014$), and patients > 75 years ($p = 0.008$).

Age Provides Superior Predictive Power Of In-hospital Mortality Compared To Frailty

Figure 4 and Table 4 illustrate the results of ROC analysis from three regression models comparing age and mFI-5. We found the AUROC for a model with age alone (0.81 95% CI [0.79 0.83]) to be superior ($p < 0.001$, χ^2) to a model with mFI-5 alone (0.75 AUROC 95% CI [0.72 0.79]). Additionally, we found the AUROC for a model with age with mFI-5 (0.81 AUROC 95%CI [0.79 0.84] AUROC) to be comparable ($p = 0.57$, χ^2) to a model with age alone (0.81 AUROC 95%CI [0.79 0.83] AUROC). Sensitivity analysis within subgroup 1 (Age > 60 years) also demonstrated that age (0.74 AUROC 95% CI [0.71 0.77]) was superior ($p < 0.001$, χ^2) to mFI-5 (0.72 95% CI [0.69 0.74]) in a prediction model for in-hospital mortality. As well, age alone remained comparable ($p = 0.24$, χ^2) to a model including age with frailty (0.75 AUROC 95% CI [0.72 0.77]). Moreover, the superiority of age to mFI-5 also remained true after restricting to patients who underwent surgery (subgroup 2) (Table 4).

Table 4
Area under the Receiver Operating Characteristic curve in regression models of in-hospital mortality in patients with complete cervical spinal cord injury. P-Values from comparison (χ^2) between regression model including age alone, with mFI-5 alone, or age with mFI-5. Abbreviations: AUROC, Area under the Receiver Operating Characteristic; CI, confidence interval; mFI-5, Modified Frailty Index-5.

	AUROC	*95% CI*	*Comparison with Age Alone P Value, χ^2*
Complete Cohort			
Age	0.81	0.79 to 0.83	Reference
mFI-5	0.75	0.72 to 0.79	< 0.001***
Age with mFI-5	0.81	0.79 to 0.84	0.570
Subgroup 1: Age ≥ 60 years			
Age	0.74	0.71 to 0.77	Reference
mFI-5	0.72	0.69 to 0.74	< 0.001***
Age with mFI-5	0.75	0.72 to 0.77	0.24
Subgroup 2: Age ≥ 60 years and Underwent Surgery			
Age	0.71	0.68 to 0.75	Reference
mFI-5	0.68	0.64 to 0.71	< 0.001***
Age with mFI-5	0.71	0.68 to 0.75	0.39

Discussion

In-hospital mortality for patients suffering from traumatic SCI has been estimated between 4–17% [2]. In our study we noted an overall in-hospital mortality of 15.9% across all patient and frailty categories, consistent with what has been reported in the literature. After investigating the characteristics of patients, we noted higher rates of mortality in older patients, and patients with increased frailty as measured by mFI-5 (Fig. 2). A retrospective study conducted by Blex et al. looked at specific disease predictors of in-hospital mortality in the setting of SCI [24]. Their study consisted of 321 patients from a single level 1 trauma center spanning 2011 to 2017. They noted an overall mortality of 6.2% within older age patients. Moreover, a higher Carlson Comorbidity Index was noted among patients who died. Our results build upon these findings, as a multi-center observational study spanning 2010 to 2018, including 4,733 patients and calculating adjusted mortality across various age and frailty categories. The mFI-5 has been shown to be a relevant comorbidity and frailty index within the trauma population, as well as an important mortality predictor [25].

The association of clinical frailty with outcomes in the spine patient population has been frequently studied [26–29]. However, most of these studies pertain to degenerative spine disease, with more limited evidence in the setting of acute SCI. One retrospective multi-center cohort study conducted by Elsamadicy et al. in 2021 assessed the impact of frailty as an independent predictor of mortality in patients with cervical SCI [5]. Their study consisted of 8,986 patients from 2017 that sustained cervical SCI and noted significant effect of an mFI ≥ 2 in a logistic regression model for patient mortality (OR 1.45 95% CI [1.14 1.83]). Our study findings are consistent with this result, although we show a stronger effect size for mFI ≥ 2 (OR 3.09 [1.85 4.99]). However, in addition to investigating frailty as a predictor of mortality, we compare it to other patient characteristics, most notably, age. We show that in a base mortality prediction model, adding patient frailty as a covariate produces a smaller AUROC for the model when compared to the addition of age (Table 4). Moreover, once age is included in a prediction model, the addition of frailty does not seem to provide further improvement to the AUROC of the prediction model. This result was robust to sensitivity analyses within older age and surgical patient subgroups. These findings suggest that among patients with complete SCI, age contributes superior predictive value than frailty for in-hospital mortality prediction.

Age has been shown to be a predictor of mortality in the setting of acute traumatic SCI [30, 31]. A long-term survival study conducted by Frankel et al. investigated mortality rates of 3,179 patients who suffered acute SCI [31]. Their study spanned 50 years and provided long term survival data. Using Cox proportional hazards regression, they noted an increased risk of mortality with a higher age at the time of injury (risk ratio 1.07 95% CI [1.07 1.08]). A separate retrospective cohort study by Inglis et al. utilizing the Rick Hansen Spinal Cord Injury Registry used logistic regression to compute predicted in-hospital mortality among patients with traumatic SCI who underwent surgery [30]. They found older age (≥ 77 years) to be a significant predictor ($p < 0.001$) of in-hospital mortality among these patients (OR 6.76 95% CI [3.04 15.05]). Our results are consistent with these findings, whereby we noted that older age (≥ 75 years) was a significant predictor ($p < 0.001$) of in-hospital mortality (OR 9.77 95% CI [7.21 13.29]). In addition to contributing more evidence to the impact of age on mortality among patients with SCI, we further investigated the moderating effects of patient frailty on this relationship. Our analyses show that there is a significant interaction effect between age and frailty in a logistic regression model of in-hospital mortality. This indicates that patient frailty functions as an effect modifier to the relationship between age and mortality in patients with SCI. This can be visualized using a Direct Acyclic Graph (Fig. 5). Figure 5 represents a pictorial representation of our major findings. Specifically, in our study we found that age and mFI-5 are each individually associated with increased in-hospital mortality after covariate adjustment. However, the effect size of age > 75 years (OR 9.77 95% CI [7.21 to 13.29]) was found to be larger than that for high frailty (OR 3.09 95% CI [1.85 4.99]). Moreover, we noted significant effect modification from frailty on the relationship between age and mortality.

A strength of this study is the use high-quality audited data across various trauma centers within North America. Notably, we did not find a significant effect from ACS verification level, hospital size (number of beds), or teaching status in our regression model (Table 3). This finding improves the applicability of these results to various institutions. Moreover, the large size sample size of nearly 5,000 patients enabled adjustment of predicted in-hospital mortality to numerous patient and trauma characteristics. However, there are some notable limitations to our findings. Given the observational and retrospective study design, we cannot conclude any causal effects between regression model covariates and in-hospital mortality. Second, our study design meant that our assessment of mortality was limited to the in-hospital trauma admission. This was largely due to the data available within TQIP. There may be a larger proportion of patients within each age category that die within a short interval after hospital discharge or transfer. This highlights the need for short term follow-up studies in this patient population to determine interval mortality rates for each patient subgroup. Finally, our measurement of frailty was limited to the mFI-5. Although this index has been shown to be relevant in the context of mortality in trauma, it does not completely capture every dimension of reduced physiologic reserve encompassed in a clinically frail patient. Other measures of clinical frailty, such as the 9-point Clinical Frailty Scale, or the 11-point Modified Frailty Index, provide more granular descriptions of patient frailty [32, 33]. However, capturing this level of patient data remains a challenge in the setting of trauma, where patients are often unidentified [34].

Increasing age and frailty are associated with increased in-hospital mortality among patients suffering complete cervical SCI. In the current study we have shown that when comparing these two variables in a mortality prediction model, age appears superior in mortality prediction. However, frailty has a significant moderating effect on the relationship between age and mortality, and as such, these two variables should be considered together. The results of these studies will hopefully serve to assist in counselling of SCI patients and their families, and in the future may help direct the establishment of improved treatment and triaging protocols for spinal trauma.

Declarations

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Author contributions statement

H.S. worked on study design, data analysis, manuscript preparation and revisions. B.N.R.J. worked on data analysis, manuscript preparation and revisions. P.F.Z. and R.H.J. worked on data analysis. A.K.M. worked on data analysis and manuscript revision. E.H. worked on manuscript revision. J.R.W. worked on study design, data analysis, manuscript preparation and revisions. C.D.W. worked on study design, data analysis, manuscript preparation and revisions. All authors reviewed the manuscript.

Data availability statement

The data that support the findings of this study are available from American College of Surgeons (ACS) Trauma Quality Improvement Program (TQIP) but restrictions apply to the availability of these data, which were used under license for the current study. Data from this study is owned by the ACS and it is publicly available, but an online request has to be made to the ACS. The corresponding author of this paper can be contacted for guidance in requesting access to this data.

Additional information

Competing interests: The authors declare no competing interests.

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Figures

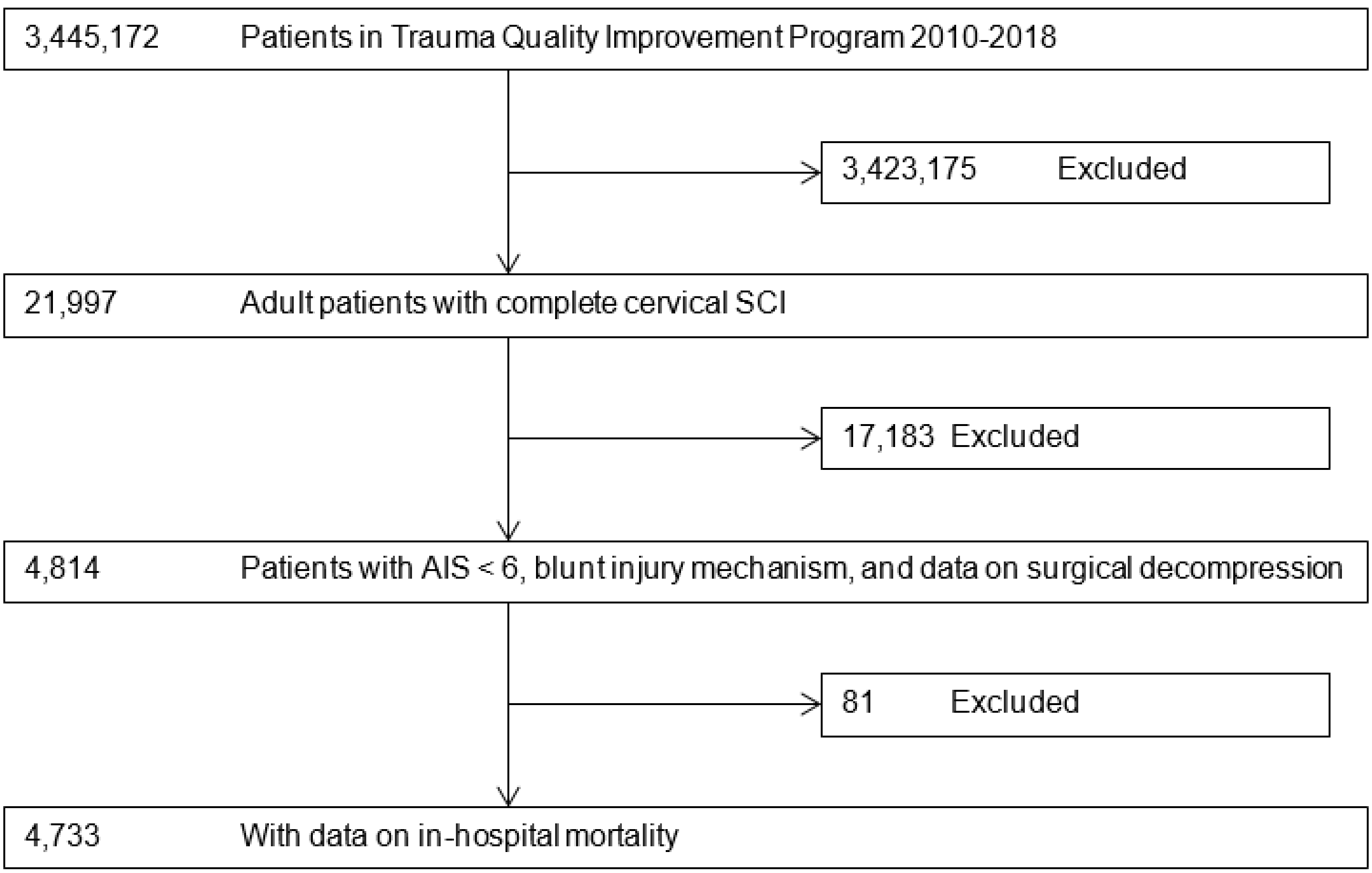

Figure 1

Flowchart of patient eligibility and enrollment

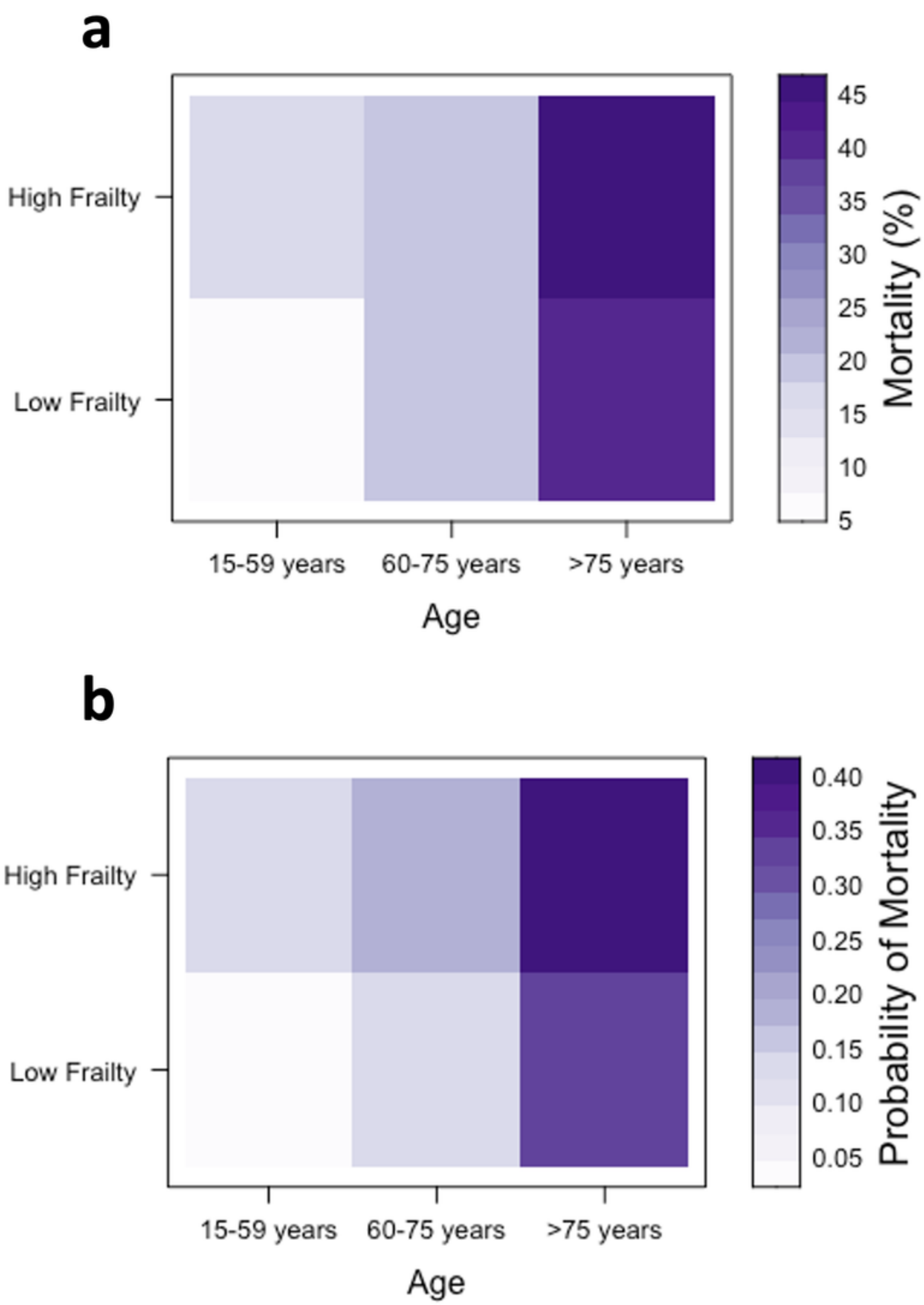

Figure 2

Mortality Increases Proportionate to Frailty and Age. (a) Heatmap of mortality proportions relative to age and Modified Frailty Index-5 (mFI) category (b) Probability of a mortality event based on the logistic regression model relative to age and mFI category. Young 16-59 years; Intermediate 60-75 years; Old > 75 years; Low frailty mFI < 2; High frailty mFI ≥ 2.

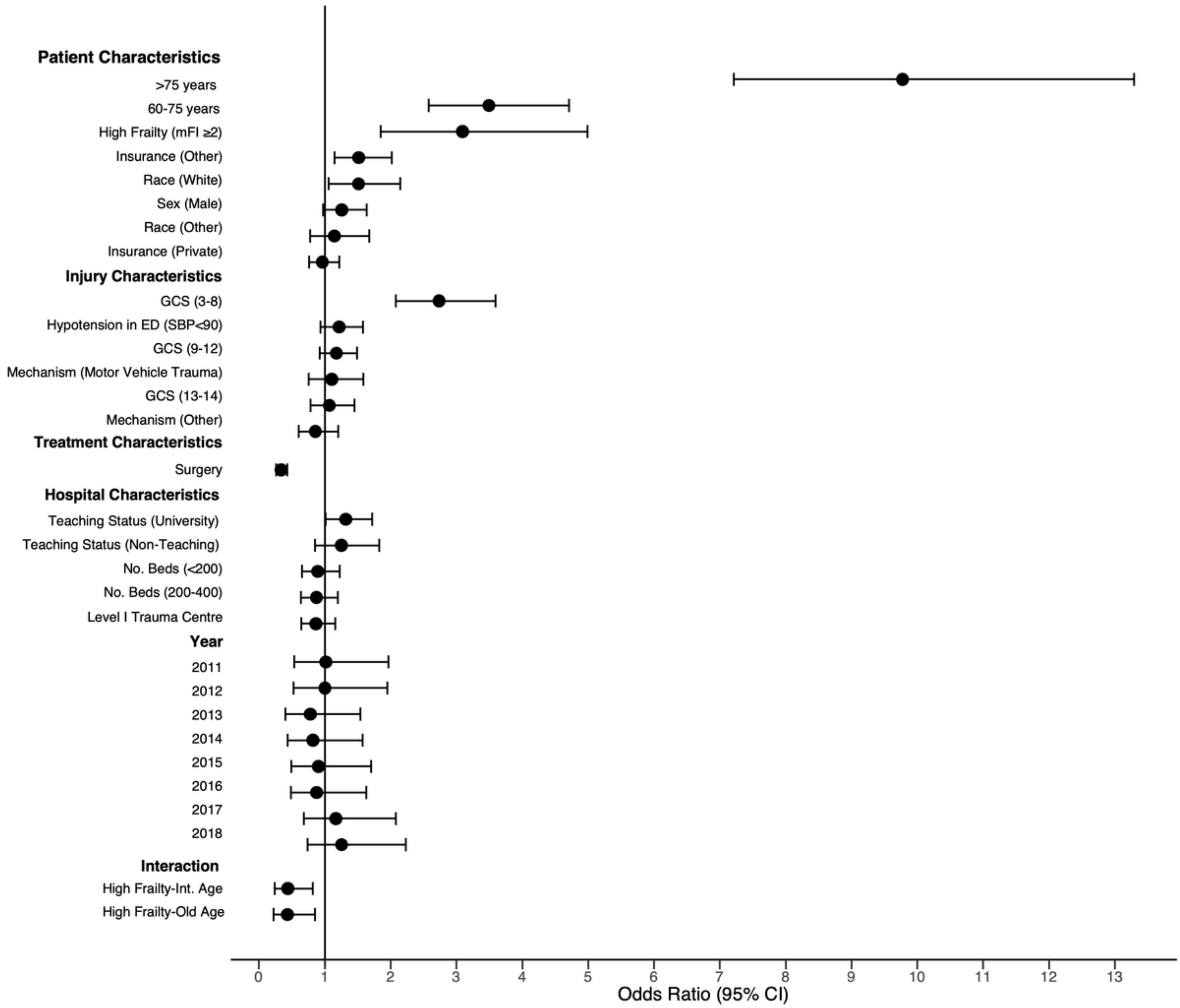

Figure 3

Forest plot of adjusted odds ratios and 95% confidence intervals for patient, injury, treatment, hospital, characteristics for mortality in complete cervical spinal cord injury. High Frailty mFI-5 ≥ 2; Low Frailty mFI < 2. Abbreviations: mFI, Modified Frailty Index- 5; GCS, Glasgow Coma Scale; ED, emergency department; SBP, systolic blood pressure.

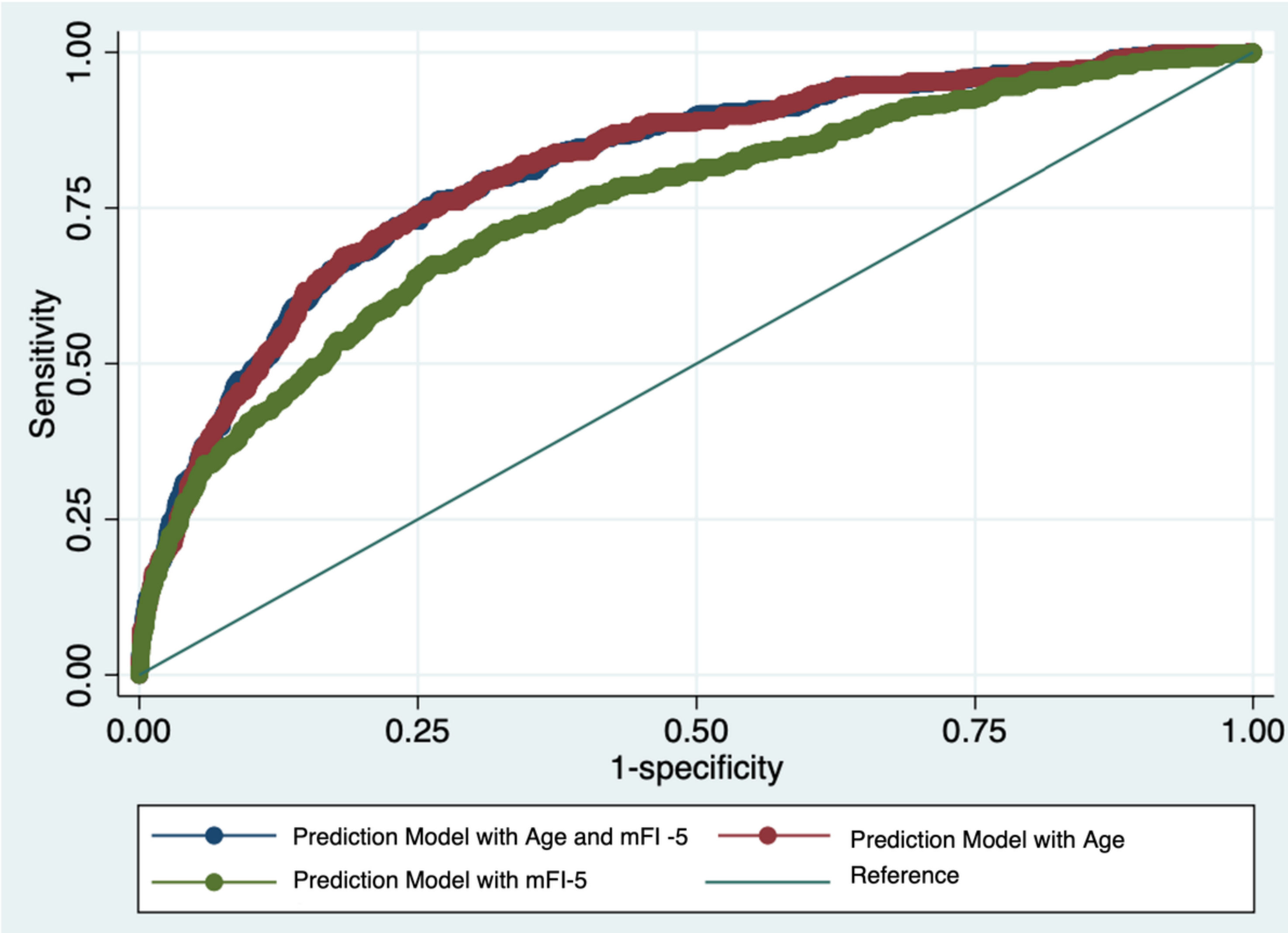

Figure 4

Receiver Operating Characteristic curve analysis for age, frailty, and age with frailty regression models of in-hospital mortality in complete cervical spinal cord injury. Abbreviations: mFI-5, Modified Frailty Index-5.

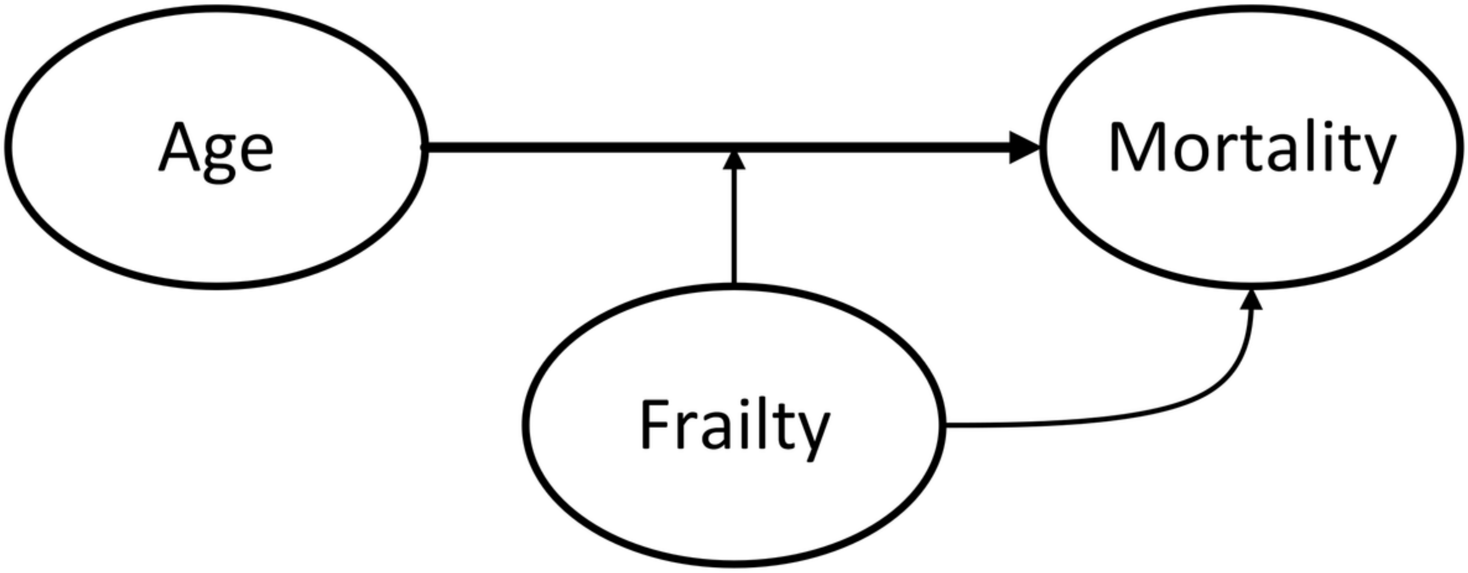

Figure 5

Directed Acyclic Graph demonstrating the proposed relationship between patient age, frailty, and mortality in complete cervical spinal cord injury. Arrows indicated a significant association in a logistic regression model. Interacting arrows indicate effect modification.

Supplementary Files

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- SupplementaryMaterial.pdf