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Predicting Mortality from Burn Injuries: The need for age-group specific models

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Abstract

Traditional burn mortality models are derived using all age groups. We hypothesized that age variably impacts mortality after burn and that age-specific models for children, adults, and seniors will more accurately predict mortality than an all-ages model. We audited data from the American Burn Association (ABA) National Burn Repository (NBR) from 2000-2009 and used mixed effect logistic regression models to assess the influence of age, total body surface area (TBSA) burn, and inhalation injury on mortality. Mortality models were constructed for all ages and age-specific models: children (<18 years), adults (18-60 years), and seniors (>60 years). Model performance was assessed by area under the receiver operating curve (AUC). Main effect and two-way interactions were used to construct age-group specific mortality models. Each age-specific model was compared to the All Ages model. Of 286,293 records 100,051 had complete data. Overall mortality was 4% but varied by age (17% seniors, <1% children). Age, TBSA, and inhalation injury were significant mortality predictors for all models (p<0.05). Differences in predicted mortality between the All Ages model and the age-specific models occurred in children and seniors. In the age-specific pediatric model, predicted mortality decreased with age; inhalation injury had greater effect on mortality than in the All Ages model. In the senior model mortality increased with age. Seniors had greater increase in mortality per 1% increment in burn size and 1 year increase in age than other ages. The predicted mortality in seniors using the senior-specific model was higher than in the All Ages model. "One size fits all" models for predicting burn outcomes do not accurately reflect the outcomes for seniors and children. Age-specific models for children and seniors may be advisable.

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Keywords

burns; mortality; model

Introduction

Burn mortality has decreased markedly in the past 100 years, and multiple burn mortality prediction models have been developed over time in response to that decline. Mortality prediction models are important for quality control and assessment, planning treatment, providing families with prognosis, performing research power analysis, and comparing the efficacy of therapeutic interventions. To be valuable, however, mortality models need to accurately reflect survival for all patient populations.

The first burn mortality models developed in Copenhagen and Toronto set the stage for the landmark studies by Bull and Fisher as well as Pruitt. [1-4] One of the most frequently used mortality prediction models is the Baux Index, which was developed as a thesis by a non-burn academic. [5] These were followed by the Abbreviated Burn Severity Index and the Clark mortality prediction model. [6-7] The modern era has marked the development of a plethora of burn mortality models from multiple different countries, including China, the United States, Africa, Australia, Belgium, and Canada. [8-13] The sheer number of different models suggests that none accurately predicts outcomes in every population.

Virtually all of these burn mortality models have included three variables: age, total body surface area (TBSA) burn, and inhalation injury in their analysis of burn outcomes. Typically the entire spectrum of age and TBSA are included in one model. In addition, many models were developed from data sets of <10,000 patients, often from a limited number of centers. These characteristics limit the generalizability and utility of these models. We hypothesized that age variably impacts outcomes in burns and that age-specific models for children, adults, and seniors will more accurately predict mortality than a single model for all ages. The purpose of our study was to develop four burn outcomes models: All Ages, Children (<18 years), Adults (18-60 years), and Seniors (>60 years) and compare both outcomes and accuracy of the four models.

Data

The American Burn Association (ABA) National Burn Repository (NBR) contains outcomes, patient and injury characteristics for patients admitted to burn centers for treatment of burns and related medical conditions. We obtained the ABA's 2009 release of the NBR containing of 286,293 admission records. To focus on recent burn care and outcomes, we restricted our analysis to admissions in 2000 or later (210,683). We eliminated records missing information on survival to discharge (12,226), age (5,441), burn size (42,545), or inhalation injury (12,861). We also removed 3,218 records identified as probable duplicates, 6,529 records with unreliable information (e.g., total burn surface area greater than 100, records from facilities with questionable ages or mortality rates), 23,084 records associated with readmissions, and 3,690 records of patients with non-burn injuries. [14] This validation left 100,051 records of initial hospital visits (admissions and outpatient visits) with the minimum information for necessary analysis (i.e., patient age, a burn or inhalation injury, and hospital discharge status). We used mixed effect logistic regression models to evaluate the effect of patient age, TBSA burn and the presence of inhalation injury on mortality. Facility was included as a random effect to account for correlation among patients treated at the same facility. Proc GLIMMIX in SAS software version 9.2 was used to fit these regressions.

We first developed and evaluated mortality models by separating the data set into equally–sized training and test sets via computerized randomization. Model parameters were estimated using the training set and applied to the test set. We constructed models using all ages (All Ages model) and then separately modeled children (<18 years old), adults (18-60 years old), and seniors (≥ 60 years old). Model performance was assessed via the area under the receiver operating curve (AUC) and by comparing observed and predicted mortality of the test set. We first fit a main effects only model (age, TBSA burn, and inhalation injury) and then fit a more robust model that also included all two-way interactions between age, TBSA burn, and inhalation injury. We compared performance of the All Ages model to the age group-specific models for the three age groups. Finally, based on these results, we used all the data to construct age-group specific mortality models.

Results

The NBR yielded 100,051 unique records of initial hospital admissions or first outpatient visits with valid data on the patient's age, TBSA burn, inhalation injury, and survival to discharge. These record were randomly divided utilizing computer-based algorithm into a training (N=50,025) and test set (N=50,026). Children and seniors comprised a relatively small percentage of the records (Table 1). In both the training and test sets, overall mortality was about 4% but varied among the age groups with relatively high mortality among seniors (˜17%) and extremely low mortality (<1%) for children (Table 1). The occurrence of inhalation injury also varied substantially among the age groups with a much higher proportion of seniors suffering inhalation injury than children (Table 1).

Based on regression results with the training set, mortality was significantly ($p < 0.05$) related to TBSA burn and the presence of inhalation injury in all models. Increases in burn size had a similar increasing impact on mortality in children and adults but had a larger effect in seniors (Table 2). The presence of inhalation injury increased mortality in all models. However, its effect was considerably larger in children than in adults or seniors (Table 2). Increasing age was a significant factor for seniors and adults but not for children ($F_{1,16701} = 0.86$, $p = 0.355$). For seniors and adults, mortality increased with age with a greater impact in seniors than adults (Table 2).

We tested the validity of the model by applying the models developed with the training set (Table 2) to the independent test set. Models developed with the training set had high discriminatory ability of mortality for patients in the test set. The area under the receiver operating curves (AUC) exceeded 0.89 in all cases and was greater than 0.93 except for seniors (Table 3). Across all ages, the AUC for the All Age model was 0.947. With this model however, the AUC decreased when adults, and most notably, seniors were considered separately. Including all two-way interactions in the models yielded only small improvements in AUC values (Table 3).

Across all records, the All Ages training model showed very good calibration with the test set (Figure 1A), but when separated by age group, this model tended to underestimate mortality among seniors (Figure 1D) and slightly overestimate adult mortality (Figure 1C). For children, agreement between observed and predicted mortality was poorer than for the other age groups (Figure 1B). This apparent poor agreement likely results from the small number of deaths among children. For many risk deciles fewer than 10 children died (Table 4). As a result, misclassifying just one child could change the estimated mortality by 10% or more. Directly comparing the observed number of deaths to the predicted number of deaths by risk deciles clearly showed that the All Ages model underestimated the total number of deaths among children particularly those with a low mortality risk (Table 4). The All Ages model also underestimated the total number of deaths among seniors but overestimated deaths in the lowest risk group (Table 5).

Discriminatory ability for mortality among children improved with the child-specific model (AUC = 0.969 vs. 0.952 with the All Ages model) but age-specific models increased AUC values only slightly for adults and seniors. The child-specific model yielded total deaths among children much closer to the observed value and with a more similar distribution than the All Ages model (Table 4). Similarly, for seniors, predicted deaths with the senior-specific model were closer to the observed values. Including interaction terms generally improved predictions for all age groups although AUC values did not improve substantially beyond the main effects only model (Table 3).

Age-Specific Mortality Prediction Models

The above results revealed the benefit of separately considering children and seniors in predicting mortality from burns and showed models with main effects of age, TBSA, and the presence of inhalation injury to capture much of the variation in mortality. Therefore, we developed predictive models for each age group using the full data set.

Age, TBSA and inhalation injury were significant ($p < 0.05$) mortality predictors for all models developed using the full data set. Unlike the models for seniors, adults and those using all ages, predicted mortality for children decreased with age, highlighting the importance of using age-specific models (Table 6). Inhalation injury was also estimated to have a larger effect in children than in other age groups. For seniors, the age-specific modeling revealed a greater increase in mortality risk for every 1% increase in burn size and 1 year increase in age than among adults (Table 6).

The greatest differences in predicted mortality between the All Ages model and the age-specific model occurred for children and seniors. The most substantial difference is that the child-specific model predicts lower mortality in older children than in younger children while the opposite is predicted by the All Ages models (Figure 2). Secondly, the child-specific model predicts considerably higher mortality among children suffering inhalation injury than does the All Ages model (Figure 2B). For seniors, predicted mortality is higher with the age-specific model when inhalation injury is absent (Figure 2B) but is similar between the All Ages and senior-specific model for seniors suffering inhalation injury.

Discussion

Traditional mortality models have served the burn community well. However, as our study demonstrates, they are less accurate in predicting outcomes in children and seniors. Children have decreased mortality as they get older, most likely due to organ and immune system development. In contrast, the elderly have increased mortality as they age, and each percent burn and year in age change impact their outcomes more than predicted by an all ages model. The inaccuracies in an all ages model are likely due to the large number of patients in the 18-60 year old group, which dwarfs the contribution of the smaller pediatric and senior groups.

Why should we care about these differences? First, children have the greatest number of life-years after injury, so an over or underestimation of mortality in any single patient will have a greater impact sytem-wide. Second, the senior population is growing rapidly, and the number of burn injuries in the elderly is likely to parallel that increase. Indeed, this is already reflected in the NBR, which has seen a steady increase in the number of senior burn injuries reported in the last 10 years. (Figure 3)

We are not the first in the modern era to use the NBR to develop burn mortality prediction models. Osler, et al used the NBR and logistic regression analysis to modify the classical Baux score and estimate mortality after burn injury. [15] Our mortality model had a smaller age effect and smaller effect of inhalation injury on mortality. This is likely due to the data used to develop the model. Osler utilized records from initial admission patients in the NBR from 2000-2007 but eliminated patients from centers that submitted less than 300 patients. As a result, they analyzed 1/3 the patient volume (about 40,000 records) and utilized data from only 40 different burn centers in the analysis. We included all centers to increase generalizibility of the data set, and included patients from 2000-2010 in our model. Our data set was 2.5 larger, consisting of over 100,000 records. With this larger data set, we had larger numbers of seniors and children than were available in Osler's data set which allowed us to better estimate mortality for these age groups. In addition, Osler combined the extremes of ages in his model and acknowledged that the revised Baux model was less accurate for children or seniors because it was based on the “majority” of burn injuries, which occurs in ages 20-80 years. The fundamental purpose of Osler's work was to create a single simple to use score for all patients, which he accomplished, but at the cost of accuracy for children and seniors.

Using data bases for development of mortality models has pitfalls that must be acknowledged. First, the accuracy of burn size and inhalation injury diagnosis was not standardized among centers and cannot be confirmed objectively. This could lead to individual center variability in diagnosis. We compensated for this by including center as a random effect; however, this may not fully account for data variability. Second, using the model for prognostication in any individual patient is not necessarily appropriate, as survival rates represent averages over patients for a given age, burn size and inhalation injury. For example, for patients predicted to have a 90% mortality probability, 10% are predicted to survive on average. Perhaps the most reasonable approach is to provide the family with the percentages as a perspective regarding chances for survival. Third, other factors, such as comorbidities, are not accounted for in the model and may indeed explain the variability in AUC for seniors and children. The impact of comorbidities and other variables is likely to be most pronounced in the senior population, and as such the model fit is not as robust as for other groups. Our study suggests that the classical triad used to predict mortality after burn injury (inhalation injury, age, and TBSA burn) may need to be expanded to include other factors for extremes of ages. Finally, children as a group have an extremely low mortality; as such, predicting survival in a child will be accurate in the majority of cases. Further examination of data sets including larger numbers of children and more refined information on injury characteristics may be needed to further refine mortality predictions.

In conclusion, traditional burn mortality models have concentrated efforts on development of a “one size fits all” model to make estimation of burn mortality easier for the clinician. However, this methodology is less accurate at the extremes of ages-both seniors and children. Specific modeling for these groups is necessary to allow for a more accurate representation of mortality for quality control, research, and comparison of different treatments. Ideally a fully audited prospective data collection effort could provide accurate data that could be used to model mortality for all groups in the future.

Acknowledgments

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Appendix A: Assessment of linear relationships between log odds mortality and TBSA and age

An implicit assumption of the models we developed for predicting mortality as a function of patient age, total burn surface area (TBSA) and inhalation injury is that the log odds of mortality is linearly related to TBSA and age. Using the NBR, we investigated the functional nature of the relationships between the log odds of mortality and TBSA and age and assessed the appropriateness of using only linear terms for these factors in the modeling.

Total Body Surface Area Burned

With the large number of records available in the NBR, we were able to directly calculate the log odds mortality for every 1% TBSA. All patients were used for the calculations irrespective of age or inhalation status. A plot of the log odds mortality versus TBSA revealed a mild non-linear relationship (Figure A1). Adjusted r^2 values from a simple linear regression indicated slightly improved fit with inclusion of a quadratic TBSA term (Linear regression adjusted $r^2 = 0.956$; Quadratic regression adjusted $r^2 = 0.944$).

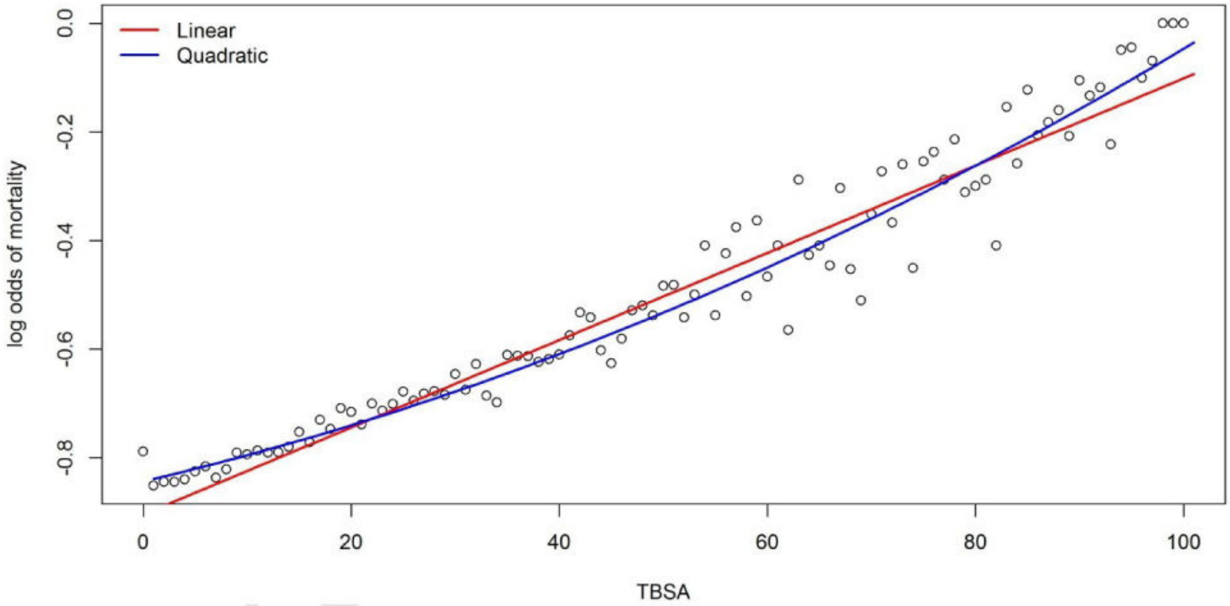

Figure A1.

Log odds of mortality calculated for each 1% of total burn surface area using the training set consisting of 50,025 records. The red line shows a regression fit with a linear term for TBSA and the blue line shows the regression fit with a linear and quadratic term for TBSA.

We then compared predicted mortality for the training and test sets using age-specific models developed with the training set with 1) only a linear TBSA term and 2) with a linear and quadratic terms for TBSA. For children and adults, predicted mortality was nearly identical for the two models (Figure A2). For seniors, the two models still showed considerable agreement but did deviate more than for the other age groups (Figure A2).

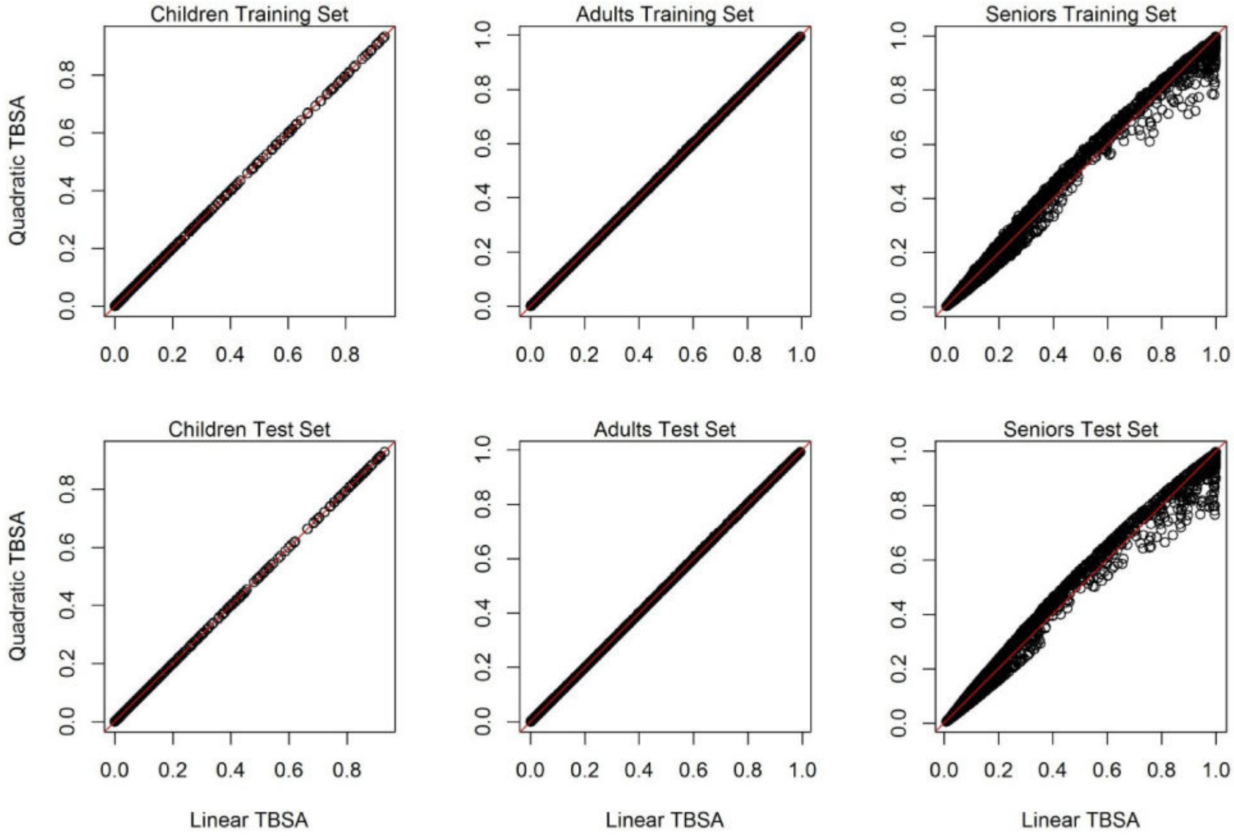

Figure A2.

Comparison of predicted for mortality for the training and test sets for age-specific models with only a linear term of TBSA (Linear TBSA) or linear plus quadratic terms for TBSA (Quadratic TBSA).

Finally, we compared the observed and predicted number of deaths predicted for the test set using the age-specific models with only a linear TBSA term or linear plus quadratic terms for TBSA. Consistent with Figure A2, predicted number of deaths were identical for children and nearly identical for adults but differed for seniors (Table A1). For seniors, the quadratic model provided a slightly better fit particularly for the smallest and largest risk deciles.

Table A1

Comparisons of observed (Obs) and predicted (Pred) mortality from age-specific models applied to the test set by risk decile. Risk deciles were defined based on predicted mortality probability for each model. Linear models included only a linear term for TBSA while quadratic models included linear and quadratic terms for TBSA.

	Children				**Adults**				**Seniors**			
	Linear		**Quadratic**		**Linear**		**Quadratic**		**Linear**		**Quadratic**	
Decile	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred

	Children				**Adults**				**Seniors**			
	Linear		**Quadratic**		**Linear**		**Quadratic**		**Linear**		**Quadratic**	
0-10	54	45	54	45	296	264	296	264	129	136	128	129
10-20	20	11	20	11	82	72	82	72	125	124	110	108
20-30	8	8	8	8	67	63	67	63	78	67	84	68
30-40	5	8	5	8	58	54	59	53	72	64	56	62
40-50	7	8	7	8	43	46	41	45	61	52	61	55
50-60	3	8	3	8	51	59	52	59	50	54	58	61
60-70	3	6	3	6	51	58	51	57	47	51	59	61
70-80	9	14	9	14	61	68	60	68	59	61	76	83
80-90	19	23	19	23	83	94	83	94	70	74	96	98
90-100	7	10	7	10	161	169	162	171	267	274	230	230
Total	135	141	135	141	953	947	953	946	958	957	958	955

Age

As for TBSA, because of the large number of records available in the NBR, we were able to directly calculate the log odds mortality for every one year of age. All patients were used for the calculations irrespective of TBSA or inhalation status. Over the full range of ages, the log odds of mortality had a nonlinear relationship with age (Figure A3). However, within the age groups that we used in developing our models, the relationships can reasonably be represented linearly (Figure A3).

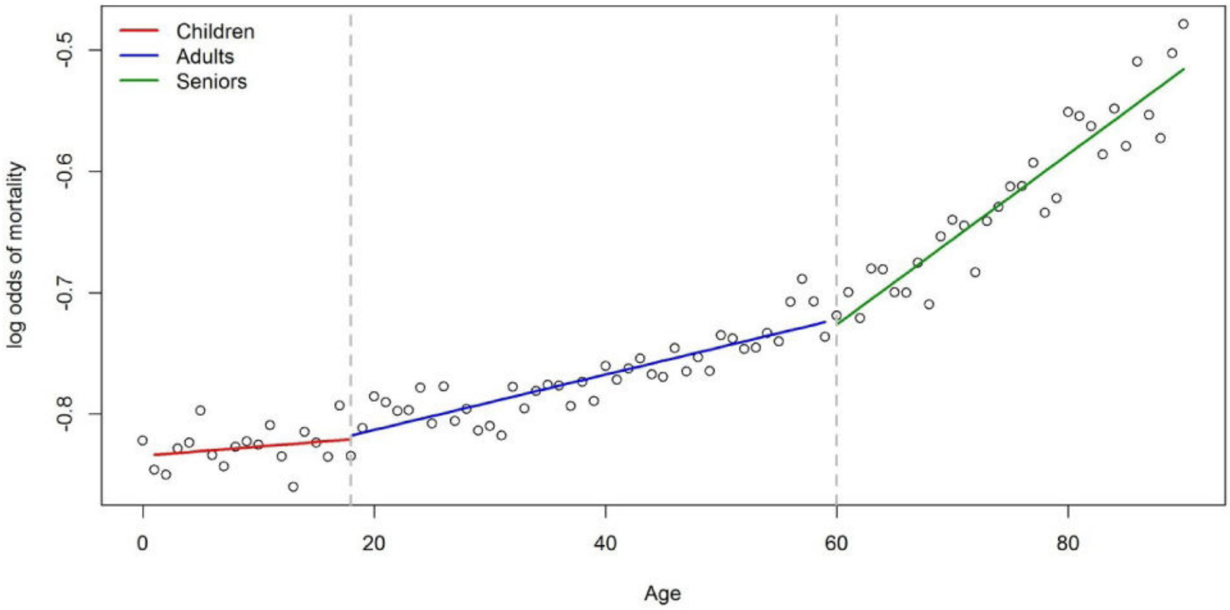

Figure A3.

Log odds of mortality calculated for each 1 year of age using the training set consisting of 50,025 records. Solid lines show linear regression fitted values determined separately for children (red), adults (blue) and seniors (green).

This finding emphasized the value of the age-specific models we developed but also suggested that age could be modeled with non-linear terms without creating age specific models. We further investigated this possibility by developing a model using all records of the training set that included linear, quadratic and cubic terms for age. We considered a cubic polynomial based on based on Moreau et al (2005). We also developed age-specific models with cubic age terms. Models developed with the training set were applied to the test set and AUC values computed.

The cubic polynomial All Ages had higher AUC values than the All Ages linear model for all age groups which is expected given the non-linear relationship between age and the log odds of mortality (Table A2). However, the age-specific linear models remained superior to the All Ages cubic polynomial model. Interestingly, the age-specific cubic polynomial models were no better than the linear age-specific models.

Table A2

Area under the curve values (AUC) for models containing only a linear term for age and cubic polynomials for age. Model parameters were estimated with the training set and applied to an independent test set. AUC values were calculated for the All Ages Model applied to all test set records, children (0-18 years old) only, adults (18-60 years old) only and seniors (≥ 60 years old) only and compared to results for models developed using training set records for the specific age groups.

Model	Linear Age Effect	Cubic Polynomial Age
All Ages Linear Model		
All Ages	0.947	0.951
Children only	0.952	0.963
Adults only	0.933	0.935
Seniors only	0.896	0.894
Children-specific Model	0.969	0.967
Adult-specific Model	0.935	0.933
Senior-specific Model	0.896	0.895

Summary and Conclusions

These results showed that the log odds of mortality is not linearly related to age over the full range of ages. However, a linear relationship is a reasonable assumption for the three age groups we used – children (0-18 years), adults (18-60 years) and seniors (≥ 60 years). The log odds of mortality showed a slightly non-linear relationship with TBSA. However at the practical level of predicting the probability of mortality, incorporating this non-linearity into the modeling resulted in almost no differences for children and adults. For seniors, predictions using models with linear and quadratic terms for TBSA differed more than for the other age groups, although were still substantially similar.

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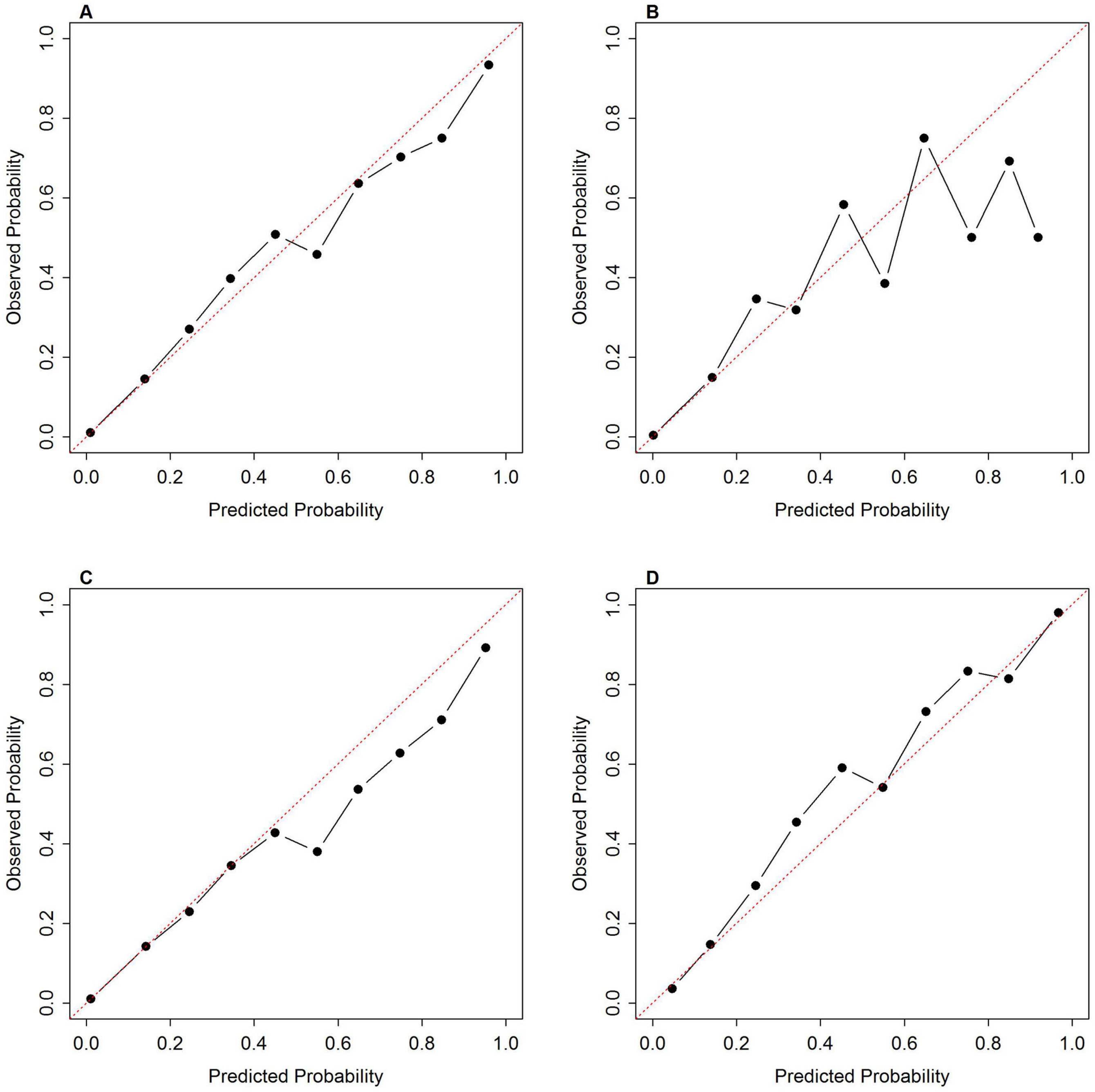

Figure 1.

Calibration curves for All Ages model applied to test set separated by age groups, A) all ages, B) children, C) adults, and D) seniors.

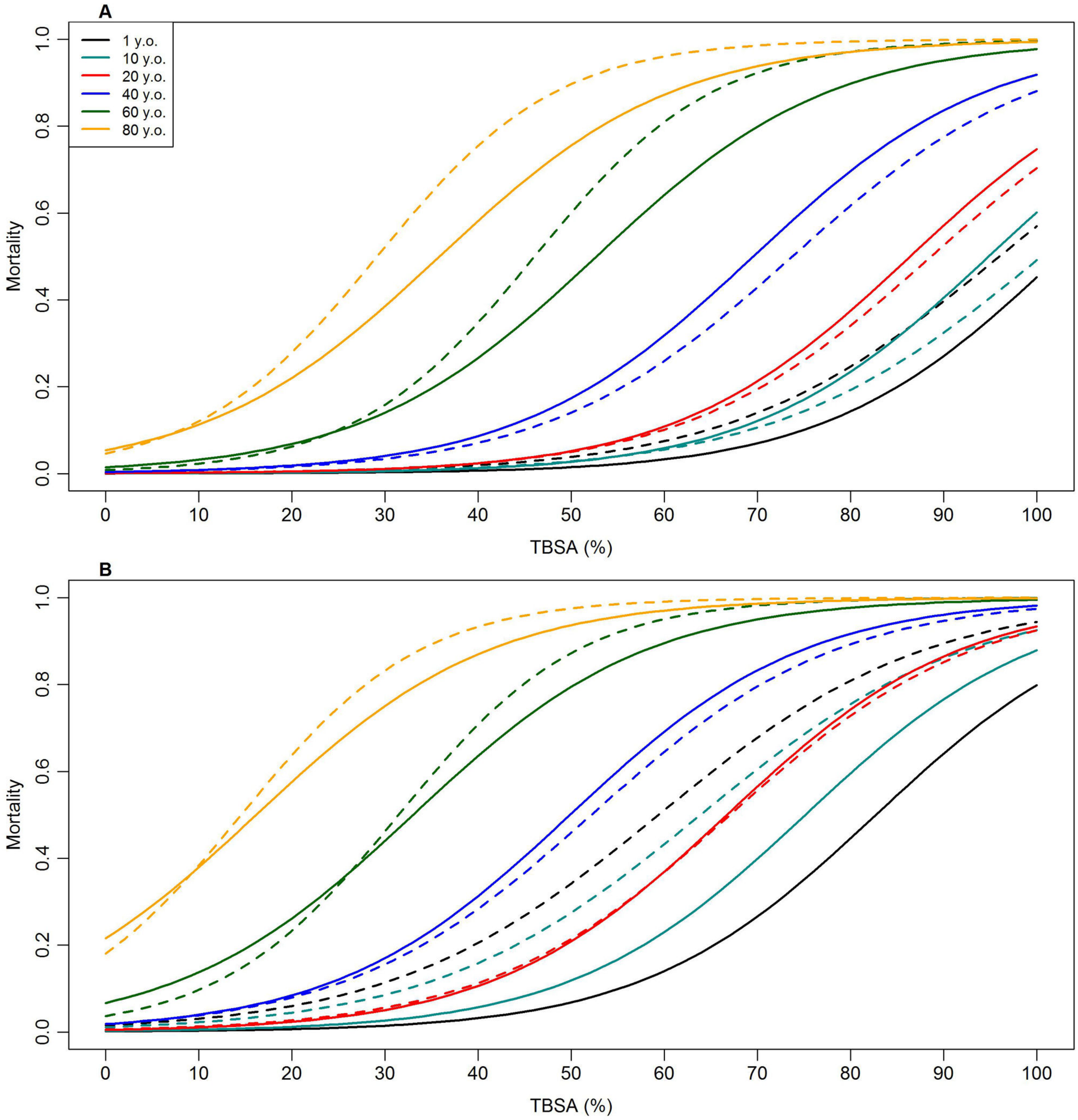

Figure 2.

Predicted mortality for different ages (1, 10, 20, 40, 60, and 80 years old) as a function of total burn surface area (%) without inhalation injury (A) and with inhalation injury (B). Solid lines are prediction from model developed using all ages. Dashed lines show predictions from age-specific models.

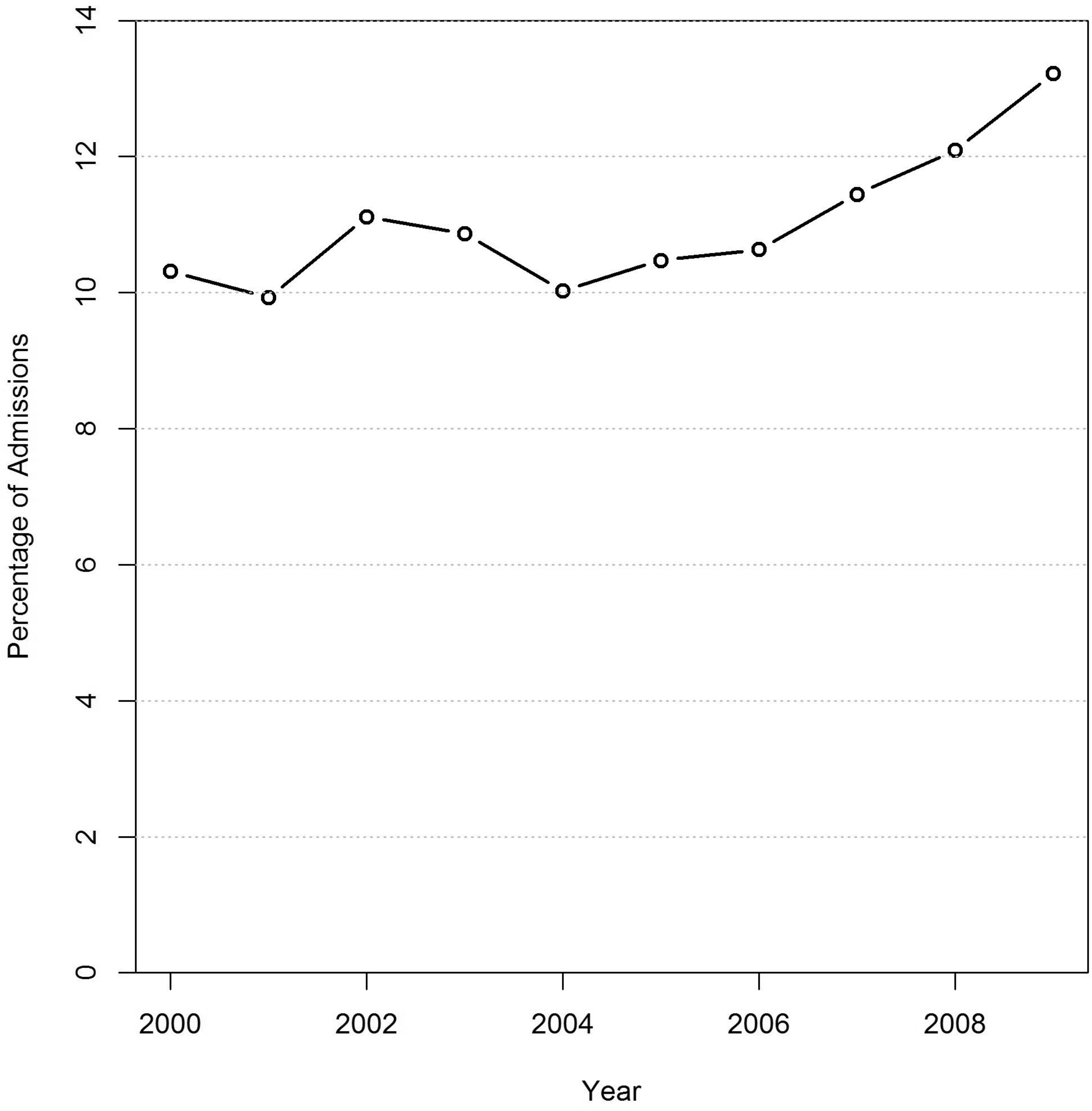

Figure 3.

Percentage of senior (> 60 years old) burn admissions reported in the National Burn Repository (NBR) 2000-2009.

Table 1

Total number of records, number with inhalation injury (%) and number (%) of deaths in each age group evaluated for the training and test sets.

	Training Set			Test Set		
Group	**Records**	**With Inhalation Injury**	**Deaths**	**Records**	**With Inhalation Injury**	**Deaths**
All Ages	50,025	4,460 (8.9%)	2,082 (4.2%)	50,026	4,408 (8.8%)	2,046 (4.1%)
Children	16,783	554 (3.3%)	122 (0.7%)	16,685	543 (3.3%)	135 (0.8%)
Adults	29,194	2,953 (10.7%)	992 (3.6%)	27,671	2,865 (10.3%)	953 (3.4%)
Seniors	5,487	953 (17.2%)	968 (17.4%)	5,571	1,000 (18.2%)	958 (17.5%)

Table 2

Parameter estimates (± SE) for the intercept, total burn surface area, age and presence of inhalation injury (1: present, 0: absent) with developed with the training set using records for all ages, children (0-18 years old) only, adults (18-60 years old) only and seniors (≥ 60 years old) only. Except where noted all estimated parameters are significantly different from 0 ($p < 0.05$).

Models	Intercept	TBSA	Age	Inhalation Injury
All Ages	-8.36±0.136	0.082±0.001	0.069±0.002	1.527±0.067
Children-specific	-6.853±0.270	0.071±0.004	-0.019±0.021[a]	2.432±0.254
Adult-specific	-8.075±0.219	0.079±0.002	0.061±0.004	1.562±0.093
Senior-specific	-10.065±0.453	0.104±0.004	0.088±0.006	1.527±0.110

[a] Not significantly different from 0 ($F_{1,16701} = 0.86$, $p = 0.355$)

Table 3

Area under the curve values (AUC) for models containing only main effects (TBSA, age and inhalation injury) and models with these main effects plus all two-way interactions. Model parameters were estimated with the training set and applied to an independent test set. AUC values were calculated for the All Ages Model applied to all test set records, children (0-18 years old) only, adults (18-60 years old) only and seniors (≥ 60 years old) only and compared to results for models developed using training set records for the specific age groups.

Model	Main Effects Model	Main Effects + 2-way Interactions Model
All Ages Model		
All Ages	0.947	0.954
Children only	0.952	0.960
Adults only	0.933	0.942
Seniors only	0.896	0.897
Children-specific Model	0.969	0.970
Adult-specific Model	0.935	0.943
Senior-specific Model	0.896	0.898

Table 4

Comparisons of observed and predicted mortality in children for the All Ages model children-specific model with main effects and with interactions. Risk deciles were defined based on predicted mortality probability for each model.

	All Ages Model		Child Specific Main Effects Model		Child Specific Interactions Model	
Risk Deciles	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
0-10%	72	25	54	44	50	41
10-20%	7	7	20	11	16	16
20-30%	9	6	8	8	9	12
30-40%	7	8	5	8	12	10
40-50%	7	5	7	8	6	9
50-60%	5	7	3	8	5	11
60-70%	12	10	3	6	21	23
70-80%	6	9	9	14	16	17
80-90%	9	11	19	23	-	-
90-100%	1	2	7	10	-	-
Total	135	90	135	141	135	139

Table 5

Comparisons of observed and predicted mortality in seniors for the All Ages model senior-specific model with main effects and with interactions. Risk deciles were defined based on predicted mortality probability for each model.

	All Ages Model		**Senior-Specific Main Effects Model**		**Senior-Specific Interactions Model**	
Risk Deciles	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
0-10%	120	156	129	136	126	135
10-20%	148	139	125	124	122	114
20-30%	100	83	78	67	89	75
30-40%	84	63	72	64	57	59
40-50%	65	50	61	52	66	54
50-60%	52	53	50	54	55	60
60-70%	60	53	47	51	54	55
70-80%	60	54	59	61	44	48
80-90%	70	73	70	74	79	82
90-100%	199	196	267	274	266	269
Total	958	920	958	957	958	951

Table 6

Parameter estimates (± SE) for the intercept, total burn surface area, age and presence of inhalation injury (1: present, 0: absent) with developed using all records for children (0-18 years old) only, adults (18-60 years old) only and seniors (≥ 60 years old) only. All estimated parameters are significantly different from 0 ($p < 0.05$).

Models	Intercept	TBSA	Age	Inhalation Injury
All Ages	-8.232±0.105	0.080±0.001	0.067±0.001	1.570±0.047
Children-specific	-6.671±0.200	0.070±0.003	-0.035±0.015	2.559±0.177
Adult-specific	-7.888±0.160	0.076±0.001	0.057±0.0034	1.645±0.066
Senior-specific	-10.046±0.325	0.104±0.003	0.088±0.004	1.515±0.079