https://doi.org/10.23873/2074-0506-2024-16-1-64-73

Comparing the Indices predictive of the thermal injury outcome

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Abstract

Introduction. *While developing the algorithms for diagnosis and treatment of patients with thermal injury, an injury outcome prediction index with the best predictive properties should be used.*

Aim. *To compare the predictive properties of the Revised Frank Index and other specialized indices.*

Material and methods. *A retrospective observational study included 307 patients with thermal injury, of whom 80 (26%) died. We compared the discriminatory ability, as well as sensitivity, specificity, positive predictive value and negative predictive value, the accuracy of the diagnostic test in relation to predicting a fatal outcome for 8 specialized prediction indices: RFI, FI, Baux, RBS, PBI, ABSI, BOBI, and Ryan.*

Results. *RFI showed the largest area under the ROC curve: 0.942 [0.913–0.971], other indices had a smaller area: FI 0.827 [0.768–0.886], Baux 0.860 [0.811–0.909], RBS 0.891 [0.848–0.933], PBI 0.893 [0.848–*

0.937], ABSI 0.838 [0.786–0.890], BOBI 0.865 [0.819–0.910], Ryan 0.816 [0.764–0.869]. The Ryan index had the highest sensitivity (95%), but its specificity (49%) was the lowest, and the proportion of false positive results was 60%. The RBS index had high sensitivity (84%) and specificity (80%), but the false positive rate was 40%. The RFI and PBI indices showed similar sensitivity (81%); however, the proportion of false positive results for RFI (23%) was lower than that of PBI (39%) and all other indices, and the RFI accuracy in predicting the outcome was the highest among the other indices, making 89%.

Conclusion. *The predictive properties of the Revised Frank Index are better than those of other specialized indices.*

Keywords: burns, inhalation injury, mortality prognosis, thermal injury outcome index, Revised Frank Index

Conflict of interests Authors declare no conflict of interest

Financing The study was performed without external funding

For citation: Zhirkova EA, Spiridonova TG, Sachkov AV, Medvedev AO, Eliseenkova EI, Borisov IG, et al. Comparing the Indices predictive of the thermal injury outcome. *Transplantologiya. The Russian Journal of Transplantation.* 2024;16(1):64–73. (In Russ.). https://doi.org/10.23873/2074-0506-2024-16-1-64-73

ABSI, Abbreviated Burn Severity Index
BOBI, Belgian Outcome in Burn Injury
CI, confidence interval
FET, Fisher's exact test
FI, Frank Index
FI_m, modified Frank index
NPV, negative predictive value
OR, odds ratio
PBI, Prognostic Burn Index
PC, “probability calculator”
PPV, positive predictive value
RBS, Revised Baux Score
RFI, Revised Frank Index
TBSA, total body surface area

Introduction

Scoring indices for predicting the outcome of injury in burn patients include predictors of unfavorable outcome. Despite the fact that the first scoring indices were developed as long ago as in the last century [1], there are still no index-based algorithms for diagnosing and treating burn patients. This is due to an insufficient discriminatory power of the indices and/or the lack of relevant index-based stratification of patients.

To predict the thermal injury outcome, several variants of the classic Frank Index (FI) [2, 3, 4], modified Frank Index (FI_m) [5], and Baux Score [3, 6] have been used in Russia; and in other countries the Baux Score, and Revised Baux Score (RBS) [7], Prognostic Burn Index (PBI) [8], Abbreviated Burn Severity Index (ABSI) [9], Belgian Outcome in Burn Injury (BOBI) [10], Ryan Score for burns [11] have been used.

Predictors of death in patients with thermal injury are considered to be: gender, age, the body surface area affected by the burn (total burn area, superficial/partial-thickness burn and deep (full thickness) burn areas) in % of the total body surface area (TBSA), and inhalation injury [1]. Components of the main prediction indices are presented in Table 1. Each of these indices has its scoring estimates for predictors. Most of them have been validated in different groups of burn patients [8, 12–15].

Table 1. Prediction indices and their predictors

Prediction Index, country, year of development	Predictors assessed					
	Gender	Age	Total burn area	Superficial/Partial thickness burns	Deep (full-thickness) burn	Inhalation injury
FI (RF, 1986)				+	+	
FI_m (RF, 2005)				+	+	+
Baux (France, 1961)		+	+			
RBS (USA, 2010)		+	+			+
PBI (Japan, 2015)		+		+	+	
ABSI (USA,	+	+	+		+	+

1982)						
BOBI (Belgium, 2009)		+	+			+
Ryan (USA, 1998)		+	+			+

We have improved the FI_m formula by adding the patient's age and 30 points for inhalation injury, and keeping unchanged the scoring for the area of superficial/partial-thickness burns (1 point per 1% of TBSA) and deep (full-thickness) burn (3 points per 1% of TBSA). The Revised Frank Index, which we calculate using the formula: $\sum = S_{\text{Superficial/Partial-thickness burns}}$ (% TBSA) + 3× $S_{\text{Deep(full-thickness) burns}}$ (% TBSA) + age (absolute number of years) + 30 (score for inhalation injury), showed better predictive ability than its predecessor [16].

This study was based on a comparison of the predictive abilities between the RFI and other burn outcome prediction indices.

The objective was to compare the predictive properties of the Revised Frank index and other specialized indices.

Material and methods

A retrospective observational study included 307 patients admitted at the Intensive Care Unit for Burn Patients at the N.V. Sklifosovsky Research Institute for Emergency Medicine in 2019–2021. The inclusion criteria were: thermal skin burns (flame, scald, contact burn), inhalation injury, age 18 years and older, admission at hospital in the first 24 hours after injury. The patient characteristics are presented in Table 2.

Table 2. Patient characteristics

Parameters		Values		
		n (%)	Me (Q1;Q3)	Min;max
Gender	Male	220 (72)	-	-
	Female	87 (28)	-	-
Age, years		307 (100)	51 (35;67)	18;93
Total burn area, % of TBSA		307 (100)	30 (20;40)	3;95
Superficial/Partial-thickness burn area, % of TBSA		298 (97)	20 (10;30)	1;86
Deep (full-thickness) burn area, % TBSA		185 (60)	10 (3;25)	1;95
Inhalation injury		98 (32)	-	-

The following indices were calculated for each patient: RFI, FI [3], Baux Score [6], RBS [7], PBI [8], ABSI [9], BOBI [10], Ryan [11]; and their predictive abilities for death were compared.

Statistical data processing was performed using the Statistica™, TIBCO® Software Inc., version 13.3, and IBM SPSS Statistics 23 software. Descriptive statistics are presented in absolute (n) and relative values (%), medians (Me), and interquartile ranges (Q1;Q3), minimum (min) and maximum (max) values. Discrete variables were compared using Fisher's exact test (FET). To assess the discriminatory ability of the indices, the Receiver Operating Characteristic (ROC) analysis was performed; the area under the ROC curve (AUC) was calculated, and the cut-off point was determined based on the maximum sum of sensitivity and specificity. We calculated odds ratios (OR), the predictive value of positive (PPV) and negative (NPV) results, and the diagnostic test accuracy (Accuracy). The confidence intervals [95% CI] for proportions were calculated using the Clopper–Pearson method. Probability calculator (PC) analysis was used to compare proportions. The threshold level of statistical significance was taken as $p<0.05$. A continuous sampling method was used. The analysis of the number of deaths required the inclusion of 307 patients in the study to detect statistically significant differences with a confidence level of 95% and a study power of 80% [17, 18].

Results

Of the 307 patients, 80 patients died (26%).

The ROC analysis showed that the largest AUC was demonstrated by RFI, and the smallest by Ryan (Figure, Table 3).

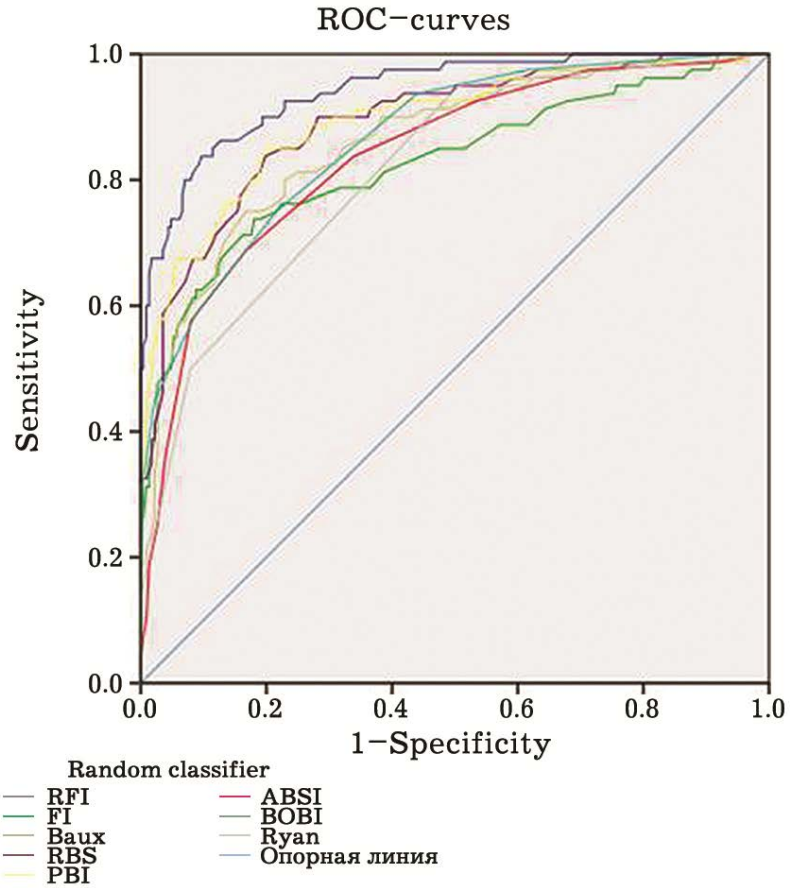

Fig. ROC curves for the indices used

Table 3. Areas under the ROC curves

Prediction Index	Area under the ROC curve and 95% CI
RFI	0.942 [0.913–0.971]
FI	0.827 [0.768–0.886]
Baux	0.860 [0.811–0.909]
RBS	0.891 [0.848–0.933]
PBI	0.893 [0.848–0.937]
ABSI	0.838 [0.786–0.890]
BOBI	0.865 [0.819–0.910]
Ryan	0.816 [0.764–0.869]

Cut-off points were determined for all indices. Taking deaths in the patients with a score above the cut-off point as a true positive result, we calculated the OR, sensitivity, specificity, PPV, and NPV.

All indices demonstrated a several-fold increase in the probability of death among patients with the scores above the cut-off points compared to the patients with the scores below them (Table 4). The OR value was the highest for RFI: an index value above 130 points increased the chance of an unfavorable outcome by 47 times.

Table 4. Comparing the number of outcomes relatively to the cut-off point

Prediction Index	Cut-off point, score	Number of outcomes								OR [95% CI]	p, FET
		Above the cut-off point				Below the cut-off point					
		died		alive		died		alive			
		n	%	n	%	n	%	n	%		
RFI	130	65	77	19	23	15	7	208	93	47 [23–99]	<0.001
FI	42	59	59	41	41	21	10	186	90	13 [7–23]	<0.001
Baux	96	60	61	38	39	20	10	189	90	15 [8–28]	<0.001
RBS	97	67	60	45	40	13	7	182	93	21 [11–41]	<0.001
PBI	82	65	61	42	39	15	8	185	92	19 [10–37]	<0.001
ABSI	9	55	59	38	41	25	12	189	88	11 [6–20]	<0.001
BOBI	4	60	55	49	45	20	10	178	90	11 [6–20]	<0.001
Ryan	1	76	40	115	60	4	3	112	97	19 [7–52]	<0.001

Note: FET, Fisher's exact test

Ryan index also had the highest sensitivity (95%), but its specificity (49%) and PPV (40%) were the lowest, since the proportion of surviving patients with scores above the cut-off point (false-positive results) was 60%. The RBS also had high sensitivity (84%) and a false positive rate of 40%. The RFI and PBI showed the same sensitivity (81%), but the rate of false positive results for RFI (23%) was lower than that for all other indices: FI, Baux, RBS, PBI, ABSI, BOBI, and Ryan ($p<0.001$; $p<0.001$; $p<0.001$; $p<0.001$; $p<0.001$; $p<0.001$ and $p<0.001$, respectively; PC), and the accuracy of burn injury outcome prediction

(89%) was the highest among other indices (p=0.002; p=0.005 ; p=0.005; p=0.005; p=0.002; p<0.001 and p<0.001, respectively; PC). FI, Baux Score, ABSI, and BOBI had similar to each other sensitivity (69–75 %), specificity (78–83%), PPV (55–61%), and NPV (88–90%); and the predictive accuracy was 78–81% (Table 5).

Table 5. Sensitivity, specificity, positive and negative predictive values of index-applying results

Index	Sensitivity, % [95% CI]	Specificity, % [95% CI]	PPV, % [95% CI]	NPV, % [95% CI]	Accuracy, % [95% CI]
RFI	81 [73–88]	92 [89–94]	77 [70–83]	93 [90–96]	89 [85–92]
FI	74 [65–82]	82 [79–85]	59 [52–65]	90 [86–93]	80 [75–84]
Baux	75 [66–83]	83 [80–86]	61 [54–67]	90 [87–93]	81 [76–85]
RBS	84 [75–90]	80 [77–83]	60 [54–65]	93 [90–96]	81 [77–85]
PBI	81 [72–88]	82 [78–84]	61 [54–66]	93 [89–95]	81 [77–85]
ABSI	69 [59–77]	83 [80–86]	59 [51–66]	88 [85–91]	80 [75–84]
BOBI	75 [66–83]	78 [75–81]	55 [48–61]	90 [86–93]	78 [73–82]
Ryan	95 [88–98]	49 [47–50]	40 [37–41]	97 [92–99]	61 [57–63]

Discussion

According to the literature, mortality among patients with thermal injury ranges from 26.44 to 34.8% [12, 13, 15], which is comparable to 26%, the result we obtained. The exception was the data from the studies involving pediatric patients: 11.8% [14], 5.9% [8], 0.76% [19].

There is no consensus among authors as to which Index better predicts the outcome in patients with thermal injury [15, 20–23]. We have made a comparative analysis of the discriminatory and predictive ability for the most well-known indices in relation to the fatal outcome.

The Baux Score demonstrated the AUC being 0.860, sensitivity 75%, specificity 83%, which was consistent with the data from other authors reporting the AUC being 0.900, sensitivity 74.2%, specificity 88.1% [14]; or the AUC of 0.862, sensitivity 75%, specificity 85% [15].

We were unable to find studies analyzing and comparing the predictive ability of the FI presented in national clinical guidelines [3]. A paper published in 2018 presents a comparison with the FI_m properties [15]. In our previous work we compared RFI with FI_m [16].

The results of studies for RBS differ: according to our data, RBS had an AUC of 0.891, sensitivity of 84%, specificity of 80%; other authors reported the AUC of 0.898 and 0.940, sensitivity 90.3%, specificity 80.6% [13, 14]; or the AUC being 0.852, sensitivity 83%, specificity 74% [15].

The PBI developers reported an AUC of 0.900 [8], and other authors had an AUC of 0.853, sensitivity of 79%, specificity of 73% [13], or AUC of 0.866, sensitivity of 78%, specificity of 80% [15]. According to our data for PBI, the AUC was 0.893, sensitivity 81%, specificity 82%.

Authors of ABSI did not calculate AUC [9]. Other researchers calculated the AUC for ABSI to be 0.890 [12] and 0.866 [13]; in some other studies, the AUC was 0.920, sensitivity 87.1%, specificity 84.2% [14]; and the AUC was 0.851, sensitivity 74%, specificity 83% [15]. The predictive value we have determined for ABSI is lower, the AUC being 0.838, sensitivity 69%, specificity 83%. And the ABSI takes into account the female gender as a predictor of death.

The studies of patient gender significance for burn injury outcome are ongoing [9, 24]. Our ROC analysis for the RFI showed that the inclusion of gender as one of the predictors of fatal outcome worsened the discriminatory ability of the index [16].

According to the authors of the BOBI index, AUC was 0.940 [10], according to other authors: the AUC was 0.872 [13]; AUC was 0.910, sensitivity 90.3%, specificity 74.7% [14]; and the AUC was 0.768, sensitivity 81%, specificity 58% [15]. According to our data, the AUC was 0.865, sensitivity 75%, specificity 78%.

The authors of the Ryan Index did not determine an AUC. According to other authors, the AUC for Ryan was 0.867, sensitivity 90.3%, specificity 70.0% [14]. According to the results of our study, the AUC was 0.816, sensitivity 95%, specificity 49%.

In our study, the best discriminatory ability was demonstrated by RFI, the AUC was 0.942, which turned out to be the largest among the compared indices. For the prediction of death, the sensitivity was 81%, the specificity was 92%, the rate of false positives (23%) was the lowest, and the accuracy of the prediction (89%) was the highest compared to the other assessed indices. We attribute this to the fact that the Baux, RBS, BOBI, and Ryan indices take into account only the total area of burns, but do not take into account their depth; in ABSI, only 1 point of 18 is added for the presence of deep (full-thickness) burns. The PBI adds a score equal to the area of deep burns, but this is not enough to predict a fatal outcome. The RFI adds 3 points for each percentage of a deep (full-thickness) burn and one point for each percentage of superficial/partial-thickness burns, thus reflecting the severity of the burn injury. In 1960, G. Frank in his work emphasized that it was deep (full-thickness) burns that significantly aggravate the patient’s condition [2], which was also noted by foreign colleagues in 2022 [25]. We have proven that it is necessary to take patient's age into the account in the Index calculations, which we have included into the RFI formula in the form of an absolute number of years. In addition, we added a unified score of 30 points for inhalation injury [16].

Differences in the AUC, sensitivity, specificity, PPV, and NPV between different researchers can be explained primarily by the heterogeneity of samples, for example, the presence of pediatric patients, patients with electrical trauma and chemical burns, as well as with inhalation injury [8, 12, 14].

To improve the accuracy of scoring indices, the understanding of their limitations is necessary [26]. Most prediction indices, although designed for thermal injury, have limited application conditions, that is, they are suitable only for certain groups of patients. All indices, except for RFI, underestimate the contribution of deep (full-thickness) burns and inhalation injury to the severity of the patient's condition. The FI, Baux, and PBI indices do not include inhalation injury as a predictor of death and therefore cannot be used for mixed patient samples [27].

Conclusion

The comparison of burn outcome prediction indices showed that the Revised Frank Index is objectively more accurate than other currently used specialized indices in predicting death and can be used to develop treatment algorithms for patients with thermal injury. Despite the fact that we used a continuous sampling method and the number of patients was sufficient, the data we obtained may not coincide with the data of other researchers, which can be explained by the described characteristic features of the prediction indices when applied to mixed samples.

Thus, based on the results obtained in the study, we can make the following conclusions:

- The area under the ROC curve for RFI (0.942 [0.913–0.971]) was the largest compared to other prediction indices.
- The rate of false positive results for RFI (23%) was significantly lower than for all other prediction indices: FI, Baux Score, RBS, PBI, ABSI, BOBI, and Ryan ($p<0.001$; “probability calculator”).
- The accuracy of RFI in the burn injury outcome prediction (89%) was statistically significantly higher than that of other prediction indices: FI, Baux Score, RBS, PBI, ABSI, BOBI, and Ryan ($p=0.002$;

p=0.005; p=0.005; p=0.005; p=0.002; p<0.001 and p<0.001, respectively; “probability calculator”).

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11%, scientific editing of the article

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10%, editing critical intellectual content

The article was received on September 15, 2023;
approved after reviewing October 3, 2023;
accepted for publication December 27, 2023