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Strategic Planning of Primary Burn Wound Excision Volume in Severe Burn Trauma

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ABSTRACT

Radical excision with immediate autografting represents the standard of care for severe burn trauma, however, its application during the toxemia phase is frequently limited by hemodynamic instability and coagulopathy risks, particularly Disseminated Intravascular Coagulation (DIC). Currently, no objective method exists for determining the optimal extent of single-stage excision, leaving decisions reliant on subjective clinical judgment. This study aimed to optimize preoperative planning of primary tangential excision volume through a risk-stratified algorithm. We conducted a single-center cohort study combining retrospective (n=102) and prospective (n=25) designs. Patients were stratified into low, moderate, and high DIC risk categories using a predictive nomogram incorporating injury characteristics, age, heart rate, and D-dimer levels. The algorithm calculated the optimal excision area based on circulating blood volume and risk-specific blood loss coefficients (99, 132, and 171 mL per 1% TBSA). Predictive accuracy and clinical outcomes were compared between cohorts. The algorithm demonstrated high accuracy for intraoperative blood loss prediction: 91% for low/high-risk subgroups (weighted mean absolute percentage error 9%) and 86% for moderate-risk (14%). In the low-risk prospective subgroup, algorithm-guided planning enabled increased excision volume, reducing surgical interventions required to restore the skin (4 vs. 6, p=0.008) and shortening hospital stays (53 vs. 64 days, p=0.043). In the high-risk subgroup, reduced excision volume significantly lowered mortality during the toxemia phase (27.3% vs. 71.4%, p=0.013). No significant changes were observed in the moderate-risk group. This study has several limitations, including its single-center design and the relatively small size of the prospective validation cohort. The proposed algorithm objectively optimizes preoperative planning by integrating DIC risk stratification, circulating blood volume, and relative blood loss coefficients. It enhances clinical decision-making by enabling aggressive excision in low-risk patients while limiting invasiveness in high-risk patients, ultimately reducing mortality, surgical burden, and hospital length of stay.

Introduction

Severe burn trauma remains a significant global health burden, with high morbidity and mortality rates despite advances in critical care and surgical techniques[1,2,3]. The management of patients with extensive deep burns is particularly challenging during the toxemia phase, a critical period characterized by systemic inflammatory response, metabolic derangement, and heightened susceptibility to infectious and coagulopathic complications[2,3,4]. During this phase, the primary surgical intervention is radical excision of necrotic tissue combined with immediate autografting, which has been demonstrated to reduce the risk of wound infection, shorten hospital stay, and improve overall survival.

However, determining the optimal extent of excision in patients with extensive deep burns presents a complex clinical dilemma. Overly aggressive resection may precipitate hemodynamic instability, exacerbate coagulopathy, and increase transfusion requirements, whereas insufficient excision may leave nonviable tissue in place, promoting bacterial colonization and delaying wound healing[2,3,4,5]. Furthermore, delayed removal of necrotic tissue is a well-established risk factor for the development of invasive wound infections and sepsis[4,5,6]. In the presence of burn-induced coagulopathy, a pathological vicious cycle may emerge: surgical intervention necessitating blood transfusion can exacerbate coagulopathy, which are further aggravated by significant intraoperative blood loss, potentially leading to disseminated intravascular coagulation (DIC) syndrome[3,4,6].

Currently, decisions regarding the extent of single-stage excision rely predominantly on the subjective experience of the surgical team, with limited objective criteria to guide preoperative planning[5,6,7]. The absence of validated, individualized predictive tools represents a significant gap in contemporary burn care. Statistically derived algorithms incorporating patient-specific factors such as injury characteristics, physiological parameters, and laboratory markers of coagulation offer a promising approach to objective decision-making[5,7]. This study aims to address this gap by developing and validating an algorithm for optimizing the volume of primary tangential excision in patients with severe burn trauma during the toxemia phase, stratified by the risk of DIC syndrome development

Objective

Optimize preoperative planning of the volume of primary tangential excision in patients with severe burn trauma.

Materials and Methods

Patient management for severe burn trauma was conducted in accordance with an approved national clinical protocol for the treatment of thermal injuries and their sequelae.

The inclusion and exclusion criteria for patient enrollment in the study are summarized in Table 1.

Inclusion criteria	
Age	Over 18 years old
Severity of the burn injury	Modified Franc Index more than 30 units of severity of injuries
Time from injury to hospitalization	No more than 24 hours
Concomitant pathology	The absence of SARS-COVID-19 infection, congenital diseases of hemostasis system, and malignant neoplasms in subject of the study at the time of the study
Criteria for non-inclusion	
Age	Less than 18 years old
Severity of the burn injury	Modified Franc Index less than 30 units of severity of injuries
Combined injury	Burns complicated by severe trauma (severe traumatic brain injury, chest, abdominal cavity, pelvis, or long tubular bones)
Concomitant pathology and taking anticoagulants	Predisposing tendency to bleeding or the use of anticoagulants before receiving a burn injury, a history of blood diseases (for example, hemophilia, idiopathic thrombocytopenic purpura and von Willebrand disease) and malignant neoplasms, diagnosed coronavirus infection SARS-COVID-19 during the study period
Treatment before admission to the burn center	Treatment with concentrated additives of blood clotting factors (for example, cryoprecipitate and concentrated platelets) before hospitalization
Exclusion criteria	
Fatal outcome in the early period	The death of the subject of the study during the period of burn shock (1-3 days from the moment of injury).

Table 1. Inclusion and patient exclusion criteria for the study

Study Design

This study is a single-center cohort study combining retrospective and prospective designs, conducted in two sequential phases. In the first phase, medical records of 102 patients with severe burn trauma treated at the Republican Burn Center, based at the City Clinical Hospital of Emergency Medical Care, were analyzed for the period from 2019 to 2024. In the second phase, the developed algorithm was applied in the treatment of patients in the prospective group (25 patients).

All patients underwent primary radical tangential excision with immediate autografting during the burn toxemia phase. Necrotic tissues were excised layer-by-layer until viable tissue was reached. Wound closure was performed using split-thickness (0.2–0.3 mm) perforated (1:4) skin autografts. To minimize intraoperative blood loss, local infiltration with a saline solution containing epinephrine was performed under the burn eschar prior to excision and at the donor sites during graft harvesting.

Patients in both the retrospective and prospective groups were stratified into three subgroups based on the risk of developing Disseminated Intravascular Coagulation (DIC) syndrome during the burn toxemia phase. The prediction of DIC syndrome was performed using a previously proposed prediction model[5].

The formula developed by the I.I. Dzhanclidze Research Institute of Emergency Care was used to determine the volume of intraoperative blood loss in all patients[7].

Ethical Considerations

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2024 revision) and the Commonwealth of Independent States (CIS) legislation governing biomedical research (Law No. 26-10 dated November 18, 2005). Informed consent was obtained from all study participants or their legal representatives.

The study protocol was reviewed and approved by the Independent Ethics Committee of the City Clinical Hospital of Emergency Medical Care and the Committee on Biomedical Ethics of the Belarusian State Medical University (Protocol No. 2 dated October 30, 2024).

Statistical Analysis

The normality of distribution for continuous variables was assessed using the Kolmogorov-Smirnov test. Quantitative data are presented as median with interquartile range (Me [Q25; Q75]). The Mann-Whitney U test was used to compare quantitative variables between two independent groups, while the Kruskal-Wallis test was applied for comparisons across three groups. Categorical variables are described using absolute and relative frequencies (n, %). Differences were considered statistically significant at $p < 0.05$.

All statistical analyses were performed using R software (version 4.3), Statistica 10.0, and MS Excel with the Attestat statistical add-in.

Results

The baseline characteristics of patients in the retrospective cohort are summarized in Table 2.

Indicator	High-risk subgroup patients, n=43	Intermediate-risk subgroup patients, n=34	Low-risk subgroup patients, n=25	p-value
Social and epidemiological indicators				
Age, years	57 (44, 66)	57 (40;67)	45 (37;58)	0.164
Height, cm	173 (164;179)	172 (162;177)	173 (164;178)	0.493
Weight, kg	75 (65;88)	77 (65;88)	78 (63;90)	0.874
Sex (male/female), n (%)	28/15 (65.1/34.9)	22/8 (64.7/35.3)	18/7 (72.0/28.0)	0.810
BMI, kg/m²	24.8 (22.6, 28.6)	25.5 (22.2;31.6)	25.0 (22.9, 29.7)	0.836
Injury Indicator				
Modified Franc Index	138 (105;168)	90,5 (70;106)	77 (56;94)	<0.001
Index Baux	131 (121;145)	125 (97;134)	90.5 (80,5;117,0)	<0.001
Lethality rate, abs. (%)	34 (79.1)	12 (35.3)	8 (32.0)	<0.001
Total area of burn wounds, % TBSA	45 (35, 60)	32,5 (31;40)	31 (20;32)	<0.001
Deep burn wound area, % TBSA	32 (20, 42)	15 (12;22)	15 (10;18)	<0.001
Inhalation injury, n (%): Was absent I degree II degree III degree	 4 (9.3) 8 (18.6) 11 (25.6) 20 (46.5)	 10 (29.4) 13 (38.2) 1 (2.9) 10 (29.4)	 12 (48.0) 11 (44.0) 1 (4.0) 1 (4.0)	 0.001 0.055 0.004 0.001
Traumatic agent, n (%): Flame Hot liquid Hot steam Contact burn Electrothermal	 39 (90.7) 1 (2.3) 2 (4.7) 0 (0.0) 1 (2.3)	 28 (82.4) 3 (8.8) 1 (2.9) 2 (5.9) 0 (0.0)	 21 (84,0) 2 (8,0) 0 (0,0) 1 (4.0) 1 (4.0)	 0.536 0.428 0.553 0.300 0.538

Table 2. Main characteristics of research subgroups, n=102

Due to the subgroup stratification criteria, statistically significant differences were observed in injury characteristics among the study groups, including severity of injury, total body surface area (TBSA) of burns, and the Thermal Injury Index (TII). No statistically significant differences were found in sociodemographic characteristics (age, sex, body weight, body mass index [BMI]) or burn etiology between the comparison groups.

Features of surgical management in patients with burn toxemia across the comparison groups are summarized in Table 3.

Indicators	High-risk subgroup patients, n=43	Intermediate-risk subgroup patients, n=34	Low-risk subgroup patients, n=25	p-value
TBSA undergoing burn wound excision, % TBSA	9 (6;14)	9,5 (6;12)	7 (5;10)	0.198
TBSA treated with autografts, % TBSA	5 (0;9)	5 (0;13)	5 (4;7)	0.990
Operative time, min	110 (85;140)	117.5 (85;140)	95 (75;130)	0.336

Table 3. Characteristics of Surgical Interventions in Study Subgroups, n=102

No statistically significant differences were observed among the study subgroups regarding the area of necrotic tissue excised in a single procedure (p = 0.198), the area of autografting performed (p = 0.990), or operative time (p = 0.336).

The volume of intraoperative blood loss across the study subgroups is summarized in Table 4.

Calculation methodology	High-risk subgroup patients, n=43	Intermediate-risk subgroup patients, n=34	Low-risk subgroup patients, n=25	p-value
Total blood loss volume, ml	1555 (1142;2117)	1183 (923;1363)	762 (527;925)	<0.001
Blood loss volume per 1% TBSA, ml	171 (125;321)	132 (85;176)	99 (81;131)	<0.001
Blood loss per 1 cm^2, ml	0.96 (0.70;1.18)	0.69 (0.45;1.06)	0.53 (0.43;0.67)	<0.001

Table 4. Quantification of blood loss in primary burn wound excision, n=102

In the high-risk subgroup for DIC syndrome development, intraoperative blood loss relative to circulating blood volume (CBV) was 31% [23%; 40%]; in the moderate-risk subgroup, it was 20% [17%; 28%]; and in the low-risk subgroup, it was 14% [12%; 16%]. Statistically significant differences were also observed in the frequency of intraoperative bleeding events stratified by severity – massive (p = 0.003), large (p < 0.001), moderate (p < 0.001), and minor (p = 0.009) – across the comparison subgroups.

Based on the analysis of intraoperative blood loss volume, an algorithm was developed to determine the extent of primary radical tangential excision during the burn toxemia phase, stratified by the risk level of DIC syndrome development. The proposed algorithm is illustrated in Figure 1.

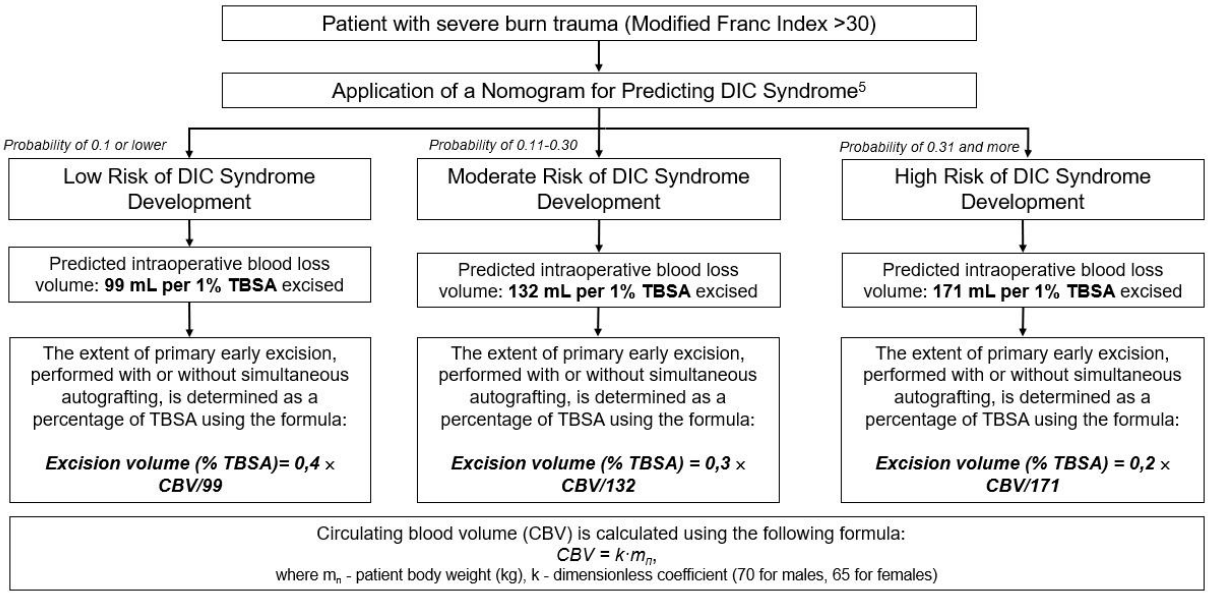

Figure 1. Calculation method for the area of primary radical tangential wound excision during burn toxemia based on DIC-syndrome risk assessment

The initial step of the algorithm involves determining the risk of DIC syndrome development during the burn toxemia phase of severe burn trauma, according to a predictive model[5]. This model accounts for the multiplicative effect of injury characteristics (total burn TBSA, deep burn TBSA, severity of thermal inhalation injury), age, physical examination findings indicating shock severity (heart rate), and the laboratory marker of fibrin degradation (D-dimer)[5]. Following the application of the DIC syndrome predictive model, patients are stratified into one of three risk categories: low (probability ≤0.1), moderate (probability 0.11–0.3), and high (probability ≥0.31).

Subsequently, the optimal extent of surgical intervention is calculated on a personalized basis, derived from the predicted volume of intraoperative blood loss.

Analysis of sociodemographic characteristics (age, sex, body weight, BMI) revealed no significant intergroup differences ($p > 0.05$). Conversely, statistically significant differences ($p < 0.05$) were observed in burn injury parameters, including the Thermal Injury Index (TII), Baux score, and total and deep burn surface area. These differences are attributable to the criteria used for stratifying patients into study subgroups. In all cases (100%), the mechanism of injury was flame. Specifics of surgical management across the study subgroups are summarized in Table 5.

Indicators	High-risk subgroup patients, n=13	Intermediate-risk subgroup patients, n=6	Low-risk subgroup patients, n=6	p-value
TBSA undergoing burn wound excision, %	7 (7;8)	12 (11;12)	14 (12;16)	<0,001
TBSA treated with autografts, %	2 (0;6)	8,5 (0;10)	7 (0;12)	0,216
Operative time, min	100 (90;115)	110 (105;135)	128 (120;145)	0,255

Table 5. Characteristics of Surgical Interventions in Study Subgroups, n=25

In the comparison groups, statistically significant differences were observed in the area of necrotic tissue excised in a single procedure ($p < 0.001$), attributable to the novel surgical approach incorporating DIC syndrome risk stratification. No statistically significant differences were found in the area of autografting performed ($p = 0.216$) or operative time ($p = 0.255$).

The predicted intraoperative blood loss volume, calculated using the proposed method, was 1,274 mL [1,197; 1,539] across all comparison subgroups: 1,197 mL [1,197; 1,368] in the high-risk subgroup, 1,584 mL [1,452; 1,584] in the moderate-risk subgroup, and 1,274 mL [1,092; 1,456] in the low-risk subgroup. The absolute prediction error across all subgroups was 123 mL [64; 183], with a relative error of 9.8% [4.2; 13.9]. Stratified by risk category, the absolute/relative errors were: high-risk subgroup — 113 mL [64.5; 143.4] and 8.2% [4.2; 13.9]; moderate-risk subgroup — 184 mL [130.9; 265.5] and 11.8% [9.0; 16.7]; low-risk subgroup — 118 mL [28.2; 158.8] and 8.6% [2.5; 12.5], respectively.

Prediction accuracy for intraoperative blood loss volume reached 91% (weighted mean absolute percentage error [WAPE]): 9% in patients at high and low risk of DIC syndrome development, compared to 86% accuracy (WAPE 14%) in the moderate-risk subgroup.

To evaluate the algorithm's effect in patients at low risk of DIC syndrome, the prospective and retrospective subgroups were compared regarding hospital length of stay and the number of surgical procedures required for skin coverage restoration. Hospital length of stay in the prospective group was 53 days [40; 54], compared to 64 days [56; 80] in the retrospective group ($p = 0.043$). To assess the number of procedures required for skin coverage, only interventions involving necrotic tissue excision and surgical wound closure were included; dressing changes performed in the operating room and revision surgeries for hemostasis or autograft repositioning were excluded. The number of procedures required for skin coverage was 4 [4; 4] in the prospective group versus 6 [5; 9] in the retrospective group ($p = 0.008$).

Application of the algorithm in patients at moderate risk of DIC syndrome did not result in statistically significant changes in the volume of primary tangential excision, blood loss relative to CBV, or transfusion requirements relative to CBV compared to the retrospective cohort.

Evaluation of the algorithm's effect in patients at high risk of DIC syndrome was based on three outcomes: mortality following the initial surgical procedure, mortality during the burn toxemia phase, and survival time to death.

Postoperative mortality following the initial procedure occurred in 2 cases (18.3%) in the prospective group versus 14 cases (50.0%) in the retrospective group ($p = 0.076$). Mortality during the burn toxemia phase occurred in 3 cases (27.3%) in the prospective group versus 20 cases (71.4%) in the retrospective group ($p = 0.013$). Survival time to death was 18 days [8; 30] in the prospective group compared to 7 days [7; 12] in the retrospective group ($p = 0.014$).

Discussion

The concepts of "disseminated intravascular coagulation" (DIC) and "coagulopathy" in severe burn injury are closely interrelated pathophysiologically[4,8]. Coagulopathy in burned patients represents a spectrum of hemostatic disturbances, while DIC constitutes its most severe form, developing in response to endothelial damage, tissue factor release, and cytokine storm[4,8,9]. Acute burn-induced coagulopathy frequently corresponds to the early, hypercoagulable phase of DIC, particularly in extensive burns[10,11,12].

Despite widespread adoption of ISTH and JAAM-DIC criteria, their application in burn patients has substantial limitations, as these systems were validated predominantly in sepsis or polytrauma[4,9].

Discrepancies in diagnostic criteria and population heterogeneity have led to considerable uncertainty in estimating coagulopathy prevalence: DIC incidence ranged from 0.1% (Barret and Gomez, TBSA ≥20%)[13,14] to 91.1% (Lavrentieva et al., TBSA ≥25%)[15]. Similarly, acute burn-induced coagulopathy prevalence varied from 0%[11] to 39%[12] depending on criteria and populations studied.

Early prediction of DIC syndrome assumes paramount clinical importance. First, DIC is associated with increased mortality, multiorgan dysfunction, and prolonged intensive care stay[4,8]. Prospective identification of high-risk patients enables preemptive hemostatic support before overt complications develop[4,8]. Second, accurate risk stratification directly informs surgical decision-making: high-risk patients may benefit from staged, conservative excision, whereas low-risk patients may safely undergo aggressive single-stage procedures[5,7]. Third, early prediction facilitates rational resource allocation – critical in high-volume burn centers[8,9]. A predictive approach aligns with precision medicine principles, enabling tailored hemostatic strategies to mitigate the vicious cycle of blood loss, transfusion, and coagulopathic exacerbation[4,8,9].

Intraoperative blood loss remains a primary limiting factor for burn wound excision extent and pace[17,18,19,20]. Aggregated data suggest approximately 0.9 (0.3 - 4)% of circulating blood volume (CBV) is lost per 1% TBSA excised with immediate autografting[17]. Strategies to reduce blood loss – including subeschar epinephrine infiltration[17,18], tourniquets[19], and topical hemostatics[22] show variable efficacy, and predictive models remain imprecise[14,21,22]. The algorithm proposed herein addresses this gap by incorporating DIC risk stratification, CBV, and risk-specific blood loss coefficients for personalized prediction.

Currently, no objective method exists for determining optimal excision extent; decisions rely predominantly on subjective experience[5,6,7]. The proposed algorithm – incorporating DIC risk, CBV, and relative blood loss coefficients – demonstrated high predictive accuracy (91% for low/high-risk subgroups, WAPE 9%; 86% for moderate-risk, WAPE 14%) and strong correlation with measured blood loss (Spearman's rho=0.74). Application in low-risk patients increased excision volume, reduced procedures for skin coverage (4 vs. 6, p=.008), and shortened hospital stay (53 vs. 64 days, p=.043). In high-risk patients, reduced excision volume lowered mortality during toxemia (27.3% vs. 71.4%, p=.013) and prolonged survival.

These findings suggest risk-adapted planning enhances outcomes by balancing early necrotic tissue removal against hemodynamic and coagulopathic risks. Limitations include single-center design and modest prospective cohort size; multicenter validation is warranted. Further refinement – including integration of point-of-care coagulation testing – may enhance precision[4,8,9].

In conclusion, the proposed algorithm enables objective optimization of preoperative planning for primary tangential excision, yielding greatest benefit in patients at low and high DIC risk. By addressing diagnostic uncertainty, surgical constraints, and personalized decision-making, this approach represents a meaningful step toward evidence-based, risk-stratified management of severe burn trauma.

Conclusion

The application of an algorithm for determining the extent of primary tangential excision—accounting for DIC syndrome risk, circulating blood volume, and the relative blood loss coefficient per unit area of excision—enables objective optimization of preoperative surgical planning, yielding the greatest clinical benefit in patients at low and high risk of DIC syndrome development.

Conflicts of Interest Statement:

The author declare that there are no conflicts of interest.

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