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Review Article

Burn and Hypertension: How Are They Related?

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ABSTRACT

Background: A burn tissue injury is one of the most severe forms of trauma which results in severe life-threatening disturbances. Burn injury has many morbid complications, so it needs a multi-disciplinary care team according to the burn center to reduce its mortality and morbidity.
Methods: This article aims to review drawbacks and complications associated with the burning injury including Acute Kidney Injury (AKI), Acute lung injury, Heart Failure, Electrolyte imbalance, intra-abdominal hypertension in children and adult burn patients, and recent challenging treatments.
Results: Improved understanding of the pathophysiology of burn-induced complications can contribute to organizing a well-treatment plan, which leads to improved outcomes.
Conclusions: Herein, the evidence available on the management of all burn induced-complications is summarized.

Introduction

Burn is a significant health problem around the world and the most burn injuries occur because of contact with a heat source like hot solids, liquids or fire. Burn injuries are important cause of morbidity and mortality throughout the world. Damage rate from burns is dependent on the burn severity, the extent of it and the age of the patient [1-2]. Although burn occurs in both children and adults, it is more severe in children Because of their more sensitive skin [3]. Burn in children is the third cause of annual child mortality [4]. These children face different challenges like pain control, electrolyte imbalances, cardiovascular instability and sepsis just like adults [5]. After burn injuries, especially severe burns, immune and inflammatory response occurs within a few hours of injury. Distributive shock and

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metabolic changes are challenges that happen after this unique hypermetabolic response [6].

In spite of major advances in burn care, systemic complications and burn wound specific problems are common [7-10]. In this study, we review the incidence of complications associated with the burning injury include Acute Kidney Injury (AKI), Acute lung injury, Heart Failure, Electrolyte imbalance, intraabdominal hypertension in children, and adults burn patients and recent challenging treatments. As The mentioned complications are associated with the presence of Hypertension, we examine the relationship between hypertension and burns [9, 11-13].

Hypertention

Blood pressure is essential for the proper functioning of the organs and it is obtained by multiplying the value of Cardiac output and Systemic vascular resistance. Arterial blood pressure is controlled by sympathetic nervous system, the plasma volume, and the renin-angiotensin-aldosterone system. Some genetic and environmental factors affect these controlling elements and lead to hypertension [14-15].

Hypertension is a condition in which systolic blood pressure is at 140 mm Hg, or higher, and diastolic blood pressure is at 90 mm Hg, or higher, in adults 18 years of age or older [16-17]. If it is not diagnosed and cured, its long-term effects can cause significant problems like myocardial infarction, stroke, aneurysms, renal failure, and death [16].

The World Health Organization (WHO) considers hypertension is a main reason of premature death worldwide, with upwards of 1 in 5 women and 1 in 4 men (over a billion people) [17].

Hypertension is divided into two main types, primary and secondary. Primary or essential hypertension accounts for 90-95% of hypertensive patients in adults. Primary hypertension is a heterogeneous disorder and its exact etiology is not clear. Many factors such as genetic, Family history, obesity, high sodium diet, poor potassium intake, and lack of physical fitness can cause primary hypertension [18-19]. secondary hypertension is rare and factors including medication with side effects or medical conditions, most commonly Renal parenchymal disease cause this type of hypertension [20]. In many cases, secondary hypertension is not diagnosed [21].

Primary and secondary hypertension is seen in children, too. Some factors that have relationship with essential hypertension in childhood are heredity, diet and obesity. Interestingly, secondary hypertension is more prevalent than primary one in infants and young children. The secondary causes of hypertension in children vary with age. Some of the main reasons are Congenital kidney, heart, and other organs defect and malformations, renal artery thrombosis, renal parenchymal disease, essential hypertension and etc. Whether the hypertension is secondary or primary, these children need considerable attention and care to reduce the mortality and morbidity associated with high blood pressure [22-24]. Notably, hypertension is a complication of burn injuries in children [25].

Burn

Burn is a tissue injury that is a consequence of exorbitant exposure to thermal, chemical, and electrical agents and has the second-highest morbidity among the world's trauma-related injuries. The skin destruction due to a severe burn injury can disturb fluid and heat regulation which predominantly will cause damage to organs within a vast range of pathophysiologies [26-27]. Cardiovascular troubles ensuing from severe burn injuries consist of two phases. Immediately after injury, the cardiac output will decrease as a result of depressed myocardial function leading to tissue hypoperfusion due to hypovolemia. In contrast, blood flow increases during the hypermetabolic phase, and patients may suffer from constant tachycardia and systemic hypertension [27-29]. Hypertension is a common complication following burn injuries with an unknown etiology specially in children, nonetheless hyponatremia and plasma renin elevation has been proposed as a reason of hypertension in burn patients [30].

Burn injuries are classified into four groups based on their severity: superficial, superficial partial-thickness, deep partial-thickness, full-thickness, and fourth-degree burns [31]. This categorization is mainly based on the depth of the burn and the total body surface area (TBSA) covered by the injury [31-32]. The TBSA is measured by the rule of 9's in adults, while in children, because of larger head size, it is a bit different [5, 31]. Numerous ways of predicting mortality in burn patients have been proposed, but the valid ones involve Abbreviated Burn Severity Index (ABSI), Baux score, Belgian Outcome in Burn Injury (BOBI) [32]. Approximately all of these scoring systems predict mortality based on age, sex, TBSA, and the degree to which inhalation injury has occurred [32-34]. Although several studies have been done to devise new predictive scores, these are primarily appropriate for research, not for bedside decision-making and decisions are mostly made based on doctors' experience. A more robust scoring system that combines existing scores is needed [32].

Burn management is a complicated field, including a wide range from initial management, checking the patient's ABCs (airway, breathing, and circulation), to skin grafts and cosmetic surgeries. Massive fluid losses occur following severe burn injuries, so fluid management is vital in burn patients [5, 35]. During the hypermetabolic phase of burn patients due to loss of skin, sepsis management needs to be incorporated in these

patients' plan service [35]. In response to burn, the human body reacts in a complex manner; therefore, more studies must be conducted to discover different aspects of this complicated trauma injury.

Acute Kidney Injury in Burn Patients

Acute kidney injury (AKI) is a prevalent complication in patients who are admitted to hospitals after severe burn injuries. Several studies demonstrated that AKI is closely related to morbidity and mortality in these cases; for instance, Clemens et al. [36] spotted that AKI in intensive care units is correlated with mortality of 40-60% [37-38]. Kidney injuries after severe burn are divided into early and late categories, which have different etiologies. Early AKI mostly occurs as a consequence of hypovolemia, poor renal perfusion, and direct cardiac suppression from TNF-alpha; meanwhile, late AKI is frequently the result of sepsis, multi-organ failure, and nephrotoxic drugs [39-41]. Recent studies emphasize on the association of intra-abdominal hypertension with AKI in burn patients, which indicates that it's early diagnosis will lead to a reduced mortality rate [42]. Early diagnosis is immensely difficult due to its wide range of etiologies, and Several biomarkers have been introduced in order to diagnose AKI instantly after admission; as a result, the incidence of AKI vary exceptionally in different studies (from 1% to 64%), but the normal incidence is 30-50%; however, abrupt changes in serum creatinine (sCr) and urine output (UOP) are routinely accessible clinical biomarkers which are used to classify the severity of AKI [39, 43-44]. Recent studies have suggested the use of whole blood neutrophil gelatinase associated lipocalin (NGAL), serum cystatin C, and neutrophil/lymphocyte ratio as an early biomarker for diagnosis of AKI in burn patients because, unlike traditional ones; these three have the potential to predict AKI as soon as the patient is undergoing resuscitation after extreme burn injury (Figure 1) [41, 45-47].

Although AKI is a known complication in burn patients, its treatment is mainly based on the avoidance of nephrotoxins such as aminoglycosides, cephalosporins, and other agents which are used in burn patients, and renal replacement therapy is only used in severe AKI cases [39, 48]. One study in 2013 reveals the role of Umbilical Cord Mesenchymal Stem Cell (UC-MSCs) in decreasing the number of renal apoptotic cells in rats with burn-induced AKI, but further studies need to be done in this regard [49]. Heme oxygenase-1 activation by intraperitoneal hemin is shown to be ameliorative in major-burn rat models via Toll-like receptor (TLR) 4 signaling pathway, and TLR4/nuclear factor kappa B (NF-κB) signaling pathway has been proposed as a possible regulator of renal inflammation that may preserve renal function following severe burns [50-51]. Therapeutic strategies in AKI are mostly hinged upon preventive cares, and to this day, there is no approved pharmacologic intervention for it, so further animal studies and clinical trials need to be conducted to discover novel curative agents for this complication which is utterly correlated with high mortality rate in burn patients.

Acute Lung Injury in Burn Patients

Acute lung injury (ALI) is one of the most common complications of burn, which increases the risk of death by 20_40%. ALI is a respiratory failure in which epithelial cells of alveoli and blood capillaries are damaged. Subsequently, the patient experiences hemorrhage and edema in the lungs. Also, reduction of campeliance and oxygenation, along with clot formation and increased shunt, exacerbate hypoxemia [52]. It is estimated that 335,000 people have infected annually [53]. Burns can be caused directly by inhaling smoke or toxic gases, or by severe burns in other areas of the body [54].

After that, the production of reactive oxygen species (ROS), most notably nitric oxide, increases. Nitric oxide produced by induceable nitric oxide syntase (iNOS), in reaction with superoxides, produces peroxintrates, which is very cytotoxic, and activates inflammazomes. Also, the production of NO from arginine reduces it as an antioxidant and intensifies oxidative stress [55]. Nucleotide-binding domain-like receptor protein 3 (NLRP3) is one of the strongest inflammazomes that stimulates the migration of inflammatory cells [56]. Because the non-histone chromosomal protein High morbidity group box protein 1 (HMGB1) is responsible for the synthesis of proinflammatory cytokines [57], Liang et al. [58] claim that p38 mitogen-activated protein kinases (p38MAPK) have a role in regulating this process. Furthermore, according to O'Connor et al. [59] substance P (SP), an endogenous molecule, promotes leukocyte production and secretion by binding to neurokinin receptor 1(NK 1R). In sum, the result is a severe inflammation at the burned site. Proinflammatory cytokines are transmitted by blood to the lungs, causing inflammation in the lungs. The persistence of this inflammation in the lung causes acute lung damage [60]. Alongside this, it has been shown that sympathetic signaling pathways can also play a role in the migration of inflammatory cells [61]. Also, in ALI, the renin-angiotensin-aldosterone system (RAAS) is damaged and the persistence of hypertension worsens hypoxia in two ways: exacerbation of inflammation in the lungs and reduction of oxygenation (Figure 1) [62].

In addition, damage to vascular endothelial cells and their dysfunction cause clot formation and thromboembolism. Hypoxia and inflammation help to form this clot itself. The formed clot intensifies pulmonary hypertension and, if left untreated, is converted into chronic

thromboembolism pulmonary hypertension (CTEPH) which is very lethal [63]. In recent years, various treatments have been proposed for ALI. Among them are vagal nerve stimulation [64], intensive insulin treatment [65], sildenafil [66], ligustrazine [67] and ulinastatin [68] (Table 1).

Heart Failure in Burn Patients

Patients with severe burn injury have increased morbidity and mortality over the long term. One of the leading causes of mortality is due to reversals in the cardiovascular system. Heart failure is a common complex clinical syndrome that is associated with a functional or structural heart disorder disrupting ventricular filling or ejection of blood to the systemic circulatory system. Cardiac dysfunction truly contributes to a reduction in the quality of life of burnt patients after severe burn trauma [69-70]. Cardiovascular troubles ensuing from severe burn injuries consist of two phases. Immediately after injury, the cardiac output will decrease as a result of depressed myocardial function leading to tissue hypoperfusion due to hypovolemia. In contrast, blood flow increases during the hypermetabolic phase and patients may suffer from constant tachycardia and systemic hypertension. It has been shown to occur without dependence on intravascular plasma loss. Therefore, other mechanisms such stress induced sarcoplasmic reticulum (SR) Ca+2 leakage, imbalance of oxidant/antioxidants, generation of harmful mediators such as mitochondria-derived danger associated molecular patterns (DAMPS), proinflammatory cardiac cytokines (TNF a, IL-B, IL-6) likely play an important role in the pathogenesis of burn-induced heart failure.

To correct the stress-induced alteration in cellular signaling pathways specially SR leakage due to oxidative stress, Deng et al. [71] has shown that pretreatment of 30% burnt rat models with antioxidant vitamin C, E prevent burn induced SR leakage leading heart failure. similar to other studies, J Wen et al. [72] found that treatment of male rats with 60% total body surface area (TBSA) with mitochondrial-targeted antioxidant, Triphenylphosphonium chloride (Mito-TEMPO) significantly reversed burn induced cardiac dysfunction. In another in vitro study by them [73], treatment of 60% total body surface area burnt rat models with AMPK (AMP-activated protein kinase) and PGC1α (peroxisome proliferator-activated receptor-Y coactivator-1α) agonists improved Ac16 cell cardiac mitochondrial damage through suppressing cardiac oxidative stress. As a result, they found that Burn induced heart failure occurs via the AMPK-SIRT1-PGC1α-NFE2L2-ARE (AMP-activated protein kinase_ Sirtuin 1_ Peroxisome proliferator-activated receptor-Y coactivator-1α_ nuclear factor erythroid 2-related factor 2_ antioxidant response element) signaling pathway.

There is evidence that proinflammatory cytokines contribute to the development of heart failure following a severe burn injury so previous studies have been conducted to suppress this pathway. Kita et al. [74] proved that p38 mitogen-activated protein kinase (p38MAPK) induced expression of pro-inflammatory cytokine. In another study, D. Niederbichler et al. [75] demonstrated that Vagus nerve stimulation improve cardiac function via decreasing production of proinflammatory cytokines. Another study noted that 17-Estradiol has cardio-protective effect in rat models by suppressing DAMPs and inhibiting production of inflammatory cytokines after burn injury [76].

Electrolyte Imbalance in Burn Patients

In the setting of burn patients, severe electrolyte abnormalities are less reported in burned patients' follow-up. Burn can disarrange the concentration of important ions in the body such as sodium, potassium, phosphate, and calcium. Calcium plays an important role in our bodies. Hypocalcemia development is most known in thermal injuries but some studies have been shown that hypercalcemia is also seen in burn patients in burn intensive care [77-78]. In the study by Gordon et al. [79] severe burn children who have hypocalcemia experienced hypomagnesemia and parathyroid hormone (PTH) concentration reduction and PTH-end organ resistance (Figure 1).

Phosphate is another important ion that has variance concentration change in burn patients. Incidence of hypophosphatemia (66.4%- 79.5%) [80-82] is more than hyperphosphatemia (17.2%) (83) in burn patients. Hyperphosphatemia is seen in AKI patients and patients with higher total body surface area (TBSA). on the other hand, hypophosphatemia is more common in patients that stay in burn units and have complications that involve multiple organs [83].

Potassium is a major intracellular fluid and has the highest concentration in ICF. In burn patients, erythrocyte destruction happens, and intracellular potassium release into plasma causes hyperkalemia [84]. A study done by Hauhouot-Attoungbre et al. [77] showed that potassium concentration had increased in 34% of burn patients in the first three days, and another study demonstrated that potassium concentration reduction and elevation in the burned tissue and unburned tissues, respectively [85].

In burn patients' skin, as a barrier to infections, destroy and the body is exposed to microbes like staphylococcus. In these patients, we use oral trimethoprim-sulfamethoxazole (TMP-SMX) [86-87] which causes hyperkalemia in 10-20% of patients who used this drug [88-95]. Further, a study by Ackerman et al. [86] showed that thermal injury is not a risk factor for trimethoprim-induced hyperkalemia and genetic predisposition is more

associated with hyperkalemia. Sodium is one of the most important extracellular ions which make osmolality pressure in blood. The balance of sodium changes in burn patients and thermal injuries lead to hypernatremia. Incidence of hypernatremia is reported in various numbers (9.9%, 11%, 24.4, 43.33%) [96-99]. Hypernatremia can increase mortality rate by up to 60% and higher ICU and hospital stay is observed in severe burn patients who developed hypernatremia [99-101].

Fluid therapy for burn patients is used to manage electrolyte abnormalities and there are some fluids in burn resuscitation. Primary fluid replacement should be crystalloid fluids. Colloid fluid should not be used because it causes increased capillary permeability. In large resuscitation, Ringer's acetate is suitable to keep electrolyte balance in a normal range. Hypertonic fluid, albumin, and plasma are used in the first hours in patients who require lower volume [102] (Table 2).

Intra-Abdominal Hypertension

Burned patients are vulnerable to the development of intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) due to the shift of excessive fluid to abdomen cavity which is caused by increased capillary permeability (as a systematic inflammatory response to burn injury) in combination with excessive or poorly managed fluid resuscitation [103-105]. Normal intra-abdominal pressure (IAP) is about 5–7 mm Hg [106-107]. When IAP oversteps 12 mm Hg, IAH exists and when it reaches 20 mmHg with new organ dysfunction, ACS happens [42, 106, 108]. There is a correlation between percentage of total body surface area (TBSA) that is involved with burn and mean IAP [109-110]. Level of peritoneal fluid cytokines (such as IFN-g, IL-10, IL-6, and IL-4) correlate with severity of the injury in ACS patients [111].

Boehm et al. [112] believes that there are different risk factors for early-onset (first 4 days after trauma) and late-onset (from day 5 after trauma or later) ACS. In late-onset ACS-patients, fluid therapy seems to have some effects on the development of ACS but it has no significant effect on appearance of the early-onset ACS. Lyv et al. [113] noted that IAH develops in 70% of severely burned patients. In patients with major burns, IAP should be measured every 2 hours [106].

ACS causes decreased cardiac output, oliguria or anuria, decreased pulmonary compliance, hypoxia, and bowel ischemia and it is lethal when it remains untreated [113-114]. percutaneous decompression is an effective way to decrease IAH and due to that prevents ACS [115]. In burn patients with ACS When non-surgical methods lose out, Decompressive laparotomy should be done and it can reduce the mortality rate [116]. A protracted open abdomen which is one of the side effects of decompressive laparotomy has significant morbidities [117] (Figure 1, Table 3).

Hypertension and Burn in Children

Hypertension has been observed as complication of thermal injury in children [118-119]. This high occurrence of hypertension in pediatric burned patients offers a possibility that cardiovascular system of children be more vulnerable to effects of burn injury in physiologic and metabolic functions than adults [119]. Physiologic changes (including metabolic, cardiovascular and respiratory rearrangements) happen in pediatric burned patients [26]. Local and systemic mediators of inflammation are released after severe burn injury in such a way that local mediators cause capillary leak locally and systemically which causes edema and systemic mediators cause a systemic inflammatory response immediately after burn injury [5]. Popp MB et al. [120] suggested that this hypertension develops encephalopathy and seizures. monitoring blood pressure and treatment in burned children is important to prevent encephalopathy and seizures (Figure 1) [121].

Pediatric burned patients are divided in two groups A) hypertensive patients and B) normotensive patients. Renin-angiotensin-aldosterone system (RAAS) is directly stimulated as a response to trauma in hypertensive and normotensive patients which means trauma stimulus is stronger than normal blood pressor controls [120]. there is no

difference in catecholamine level in hypertensive and normotensive burned children [119]. Falkner B et al. suggests that high occurrence of hypertension in pediatric burned patients with no increased mortality rate shows that sustained

hypertension does not in itself worsen prognosis in burned children which means this hypertension might be important for survival [119].

Hypertrophic scars (making disorganized collagen rather than in the normal parallel orientation) and keloids (overproduction of ECM and overgrowth of scar tissue) are sequelae of burns in children. The best strategy in the management of this scares in pediatric burned patients is prevention [122]. Standard care of scars and wounds of burn includes cleaning and removing devitalized tissue, followed by daily dressing changes [26]. Due to severe pain that pediatric burned patients feel, using of drugs for sedation (such as ketamine) is important [26, 123].

In the management of severe burns, sufficient fluid resuscitation is a vital component but we have to consider that sometimes Over-resuscitation result in pneumonia, acute respiratory distress syndrome (ARDS), Multiple Organ Dysfunction (MODS), cerebral edema and abdominal and limb compartment syndromes (ACS). To avoid those effects of over-resuscitation, modified Parkland formula (3 ml/ kg/ % burn) is useful for fluid

resuscitation calculations, but the patient 's general condition should be considered in the healing process [124]. Treatment of burn hypertension includes use of diuretics, angiotensin-converting enzyme inhibitors and beta-blockers [25] (Table 4).

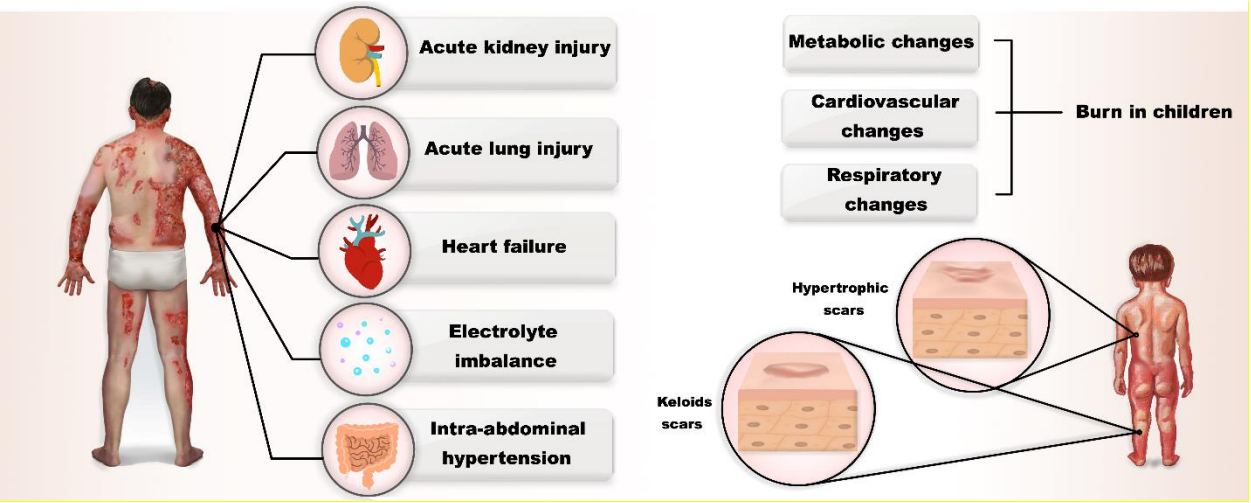

Figure 1- Burn and its complications in multi-systemic view

Table 1- AKI in burn patients

Author	Year	Participants	%TBSAΔ		Comorbidity		Outcomes	
			AKI	No AKI	AKI	No AKI	AKI	No AKI
Karakaya et al.[40]	2021	Total sample: 172 (AKI patients: 78)	47(21.3)	29(9)	HTN: 9(5.2%) DM: 7(4%) CAD: 1(0.6%)	HTN: 2(1.1%) DM: 4(2.3%) CAD: 0(0%)	Mortality: 37(21.5%)	Mortality: 7(4%)
Thalji et al.[37]	2016	Total sample: 18155 (AKI patients: 842)			Elixhauser comorbidities score: 3.19 (3.05)	Elixhauser comorbidities score: 1.34 (1.32)	Mortality: 32.54 length of stay, d (SD): 31.9 (40.3)	Mortality: 1.89% length of stay, d (SD): 8.9 (13.6)
Kim et al.[41]	2019	Total sample: 473 (AKI patients: 71)	47(26)	35(21)	HTN: 9(12.7) DM: 7(9.9)	HTN: 67(16.7) DM: 28(7.0)	Increased TBSA burned and occurrence of inhalation injury were independent predictors of postoperative AKI.	
Palmieri et al. [125]	2009	Total sample:	45.2(19)	27.1(6.7)	Comorbidities (%): 35.8%	Comorbidities (%): 32.1%	Sepsis during	Sepsis during

		60 (AKI patients: 32)					ICU stay: 75.8% ICU mortality: 34.4%	ICU stay: 28.7% ICU mortality: 0%
Kim et al. [45]	2018	Total sample: 133 (AKI patients: 35)	60.5(21.1)	34.2(11.9)			Mortality: 29 (82.9%)	Mortality: 0 (0.0%)
Kym et al. [44]	2015	Total sample: 85 (AKI patients: 48)	63.1(19.4)	40.3(16.1)			LD, lactic acid and serum creatinine were favorable in order to diagnose AKI in burn patients.	
Rakkolainen et al.[126]	2018	Total sample: 187 (AKI patients: 51)	48.1(17.2)	33.2(13.1)	Pre-existing comorbidity: 22(43.1)	Pre-existing comorbidity: 47(34.6)	Mortality: 27(52.9%) ICU stay time (days): 31.8 (21.9)	Mortality: 10(7.4%) ICU stay time, d (SD): 23.1 (14.6)
Putra et al.[127]	2021	Total sample: 89 (AKI patients: 18)	46.4(24.7)	28.5(21.4)			Mortality: 15(83%) Length of stay (days): 14.9 (9)	Mortality: 14(20%) Length of stay (days): 16.5 (10.2)

Δ TBSA is reported by mean (SD).

AKI, Acute Kidney Injury; CAD, Coronary Artery Disease; DM, Diabetes Mellitus; HTN, Hypertension; ICU, Intensive Care Unit; LD, Lactate Dehydrogenase; SD, Standard Deviation; TBSA, Total Body Surface Area

Table 2- Electrolyte imbalance in burn patients.

Authors	**Year**	**Participants**	**% TBSA**	**Comorbidity**			**Outcomes**
				DM	**HTN**	**HF**	
Sam R et al. [78]	2007	54 Hypercalcemia patients: 10 (6 male; 4 female) (19%)	In patients with serum calcium > 10.5 mg/dl, n = 10 (%) <25% = 3 (11%) >25% = 7 (27%)				Mortality in patients with serum calcium > 10.5 mg/dl n = 10 (%): 30% Length of stay 28-40: 2 (8) 40-60: 2 (20) >60: 6 (46)
Klein GL et al. [79]	1997	10 children (8 boys; 2 girls)	57.1 ± 17.2				Hypocalcemia: 9 (90%)

Leite HP et al. [80]	2017	78 children (54 male; 24 female	No. of patients with TBSA burn ≥ 40%: 24.4			Length of hospital stay* (days): 32.5 (19–66) Length of ICU stay*: 9 (4–22) Severe sepsis and/or septic shock [n (%)]: 23 (29.5)
Rimaz S, Moghadam et al. [81]	2019	137 (96 male; 41 female)	<40% [n(%)]: 72 (53) 40-60% [n(%)]: 29 (21) >60% [n(%)]: 36 (26) Mean ± SD: 32.6 ± 14%			Inhalation injury [n(%)]: 41 (29) Need to mechanical ventilation [n(%)]: 29(21) Hypophosphatemia: 75.1%
Kuo G et al. [83]	2018	301 (236 male; 65 female)	Normal P (2.5 to 4.5mg/dL) 43.4±22.9 High P (>4.5 mg/dL) 57.0±30.7	28 (11.2%) 6 (11.5%)	38 (15.3%) 13 (25.0%)	Ninety-day mortality: 45 (18.1) Renal replacement therapy: 20 (8.0) Sepsis 76 (30.5) Ninety-day mortality: 28 (53.8) Renal replacement therapy: 8 (15.4) Sepsis: 14 (26.9)
Ackerman BH et al. [86]	2013	With hyperkalemia 34 Without hyperkalemia 166	18.9 ± 21.7 11.7 ± 14.7			Length of stay (days): 41.6 ± 42.0 Ventilated (Days): 32.7 ± 44.0 Length of stay (days): 18.8 ± 22.0 Ventilated (Days): 20.0 ± 26.9
Stewart IJ et al. [96]	2013	1973 (1701 male; 272 female)	Median (IQR): 9 (4–20)			Inhalation injury, n (%) 250 (13) Electrical burn, n (%) 103(5) Hypernatremia, n (%) 194 (9.9) Hyponatremia, n (%) 134 (6.8) Median ICU days (IQR) Hypernatremia patient → 35 (15–65) Hyponatremic patients → 11 (3–32) Median hospital days (IQR) Hypernatremia → 63 (34–100) Hyponatremia→42 (18–72) Mortality, % Hypernatremia patient: 33.5 Hyponatremic patients: 13.8

Namdar T et al. [97]	2010	40 (12 female; 28 male)	Without hypernatremia (Group A) Hypernatremia (Group B) 23 (11) 30 (13)	ICU mortality [n (%)]: 0 (0) In-hospital mortality [n (%)]: 0 (0) ICU mortality [n (%)]: 3 (20) In-hospital mortality [n(%)]: 3 (20)
Warden GD et al. [98]	1973	135 severe burn patients (111 male; 24 female)	Burn surface area (%): 54.2 ± 21.4 Full-thickness burn area (%): 24.8 ± 22.3	Inhalation injury (n, %): 22 (24.4) Hypernatremia (n, %): 33 (24.4) Hypernatremia onset (day): 8.3 ± 4.8 (5-21)

*Median and interquartile range.
DM, Diabetes mellitus; ICU, Intensive Care Unit; HTN, Hypertension; HF, Heart Failure; TBSA, Total body surface area.

Table 3- Intra-abdominal hypertension.

Year	Authors	Participants	TBSA	Comorbidity	Outcomes
2014	McBeth et al.[128]	Male: 139 Female: 36	Average: 31.4%		110 patients required ICU/ 39 patients died from their injuries
2019	Talizin TB et al.[129]	Male: 33 Female: 13	Average: 30.5%		38 patients developed IAH/ 32 patients developed AKI/ 11 patients developed ACS/ 25 patients died
2021	S. G. Strang et al.[130]	Total sample: 58	10%<TBSA<40%		31 patients developed IAH/ 17 patients developed new organ failure/ no patients developed ACS

ACS, Acute Coronary Syndrome; AKI, Acute Kidney Injury; IAH, Intraabdominal Hypertension; TBSA, Total body surface area

Table 4- Hypertension and burn in children

Year	Authors	Participants	TBSA	Comorbidity	Outcomes
1980	Pop et al. [29]	987 children	TBSA<20%: 451 20%<TBSA<40%: 300 TBSA>40%: 236		7.4% developed hypertension 26% developed hypertension 38.5% developed hypertension
2018	Ojeda et al. [131]	104 children	30%<TBSA<92%		Prescribed dose of Propranolol to sedate the pain was not affected by the range of TBSA or gender
2019	Weis et al. [132]	Total sample: 258 children Male: 158 Female: 100	Average: 20.4%	Incidence of HTN: 62.8%	Prescription of Tumescence during operation in burned children has significant correlation with hypertension.

HTN, Hypertension; TBSA, Total Body Surface Area

Conclusions

In burns, hypertension is caused by systematic inflammation, oxidative stress, sepsis and hypermetabolism in the body, which causes dysfunction in vital organs such as the heart, Lungs, and kidneys. Also, edema in the abdominal space causes intraabdominal hypertension and leads to electrolyte imbalances. The mentioned injuries are more severe in children in comparison to adults. Hence, managing burn patients in the emergency department is a critical issue.

Abbreviation

AKI: Acute Kidney Injury
TBSA: Total Body Surface Area
ABSI: Abbreviated Burn Severity Index
BOBI: Belgian Outcome in Burn Injury

patient's ABCs: airway, breathing, and circulation
SCr: Serum Creatinine
UOP: Urine Output
NGAL: Neutrophil Gelatinase Associated Lipocalin
UC-MSCs: Umbilical Cord Mesenchymal Stem Cell
TLR: Toll-Like Receptor
NF-kB: Nuclear Factor kappa B
ALI: Acute Lung Injury
ROS: Reactive Oxygen Species
iNOS: Induceable nitric oxide syntase
NLRP3: Nucleotide-biding domain-like Receptor Protein 3
HMGB1: High Morbidity Group Box Protein 1
p38MAPK: p38 Mitogen-Activated Protein Kinases
SP: Substance P
NK 1R: Neurokinin Receptor 1
RAAS: Renin-Angiotensin-Aldosterone System
CTEPH: Chronic Thromboembolism Pulmonary Hypertension
SR: Sarcoplasmic Reticulum
DAMPS: Danger Associated Molecular Patterns
AMPK: AMP-activated protein kinase
PGC1α: peroxisome proliferator-activated receptor-Y coactivator-1α
AMPK-SIRT1-PGClaNFE2L2-ARE: AMP-activated 4 protein kinase_ Sirtuin 1_Peroxisome proliferator-activated receptor-Y coactivator-la nuclear factor erythroid 2-related factor 2_ antioxidant response element
PTH: Parathyroid Hormone
ICF: Intracellular Fluid
TMP-SM: Trimethoprim-Sulfamethoxazole
IAH: Intra-Abdominal Hypertension
ACS: Abdominal Compartment Syndrome
IAP: Intra-Abdominal Pressure
ACS: Abdominal and limb Compartment Syndromes
ARDS: Acute Respiratory Distress Syndrome
MODS: Multiple Organ Dysfunction

References

[1] Warby R, Maani CV. Burn Classification. StatPearls. Treasure Island (FL): StatPearls Publishing. Copyright © 2022, StatPearls Publishing LLC.; 2022.

[2] Martin NA, Falder S. A review of the evidence for threshold of burn injury. Burns. 2017;43(8):1624-39.

[3] Sharma RK, Parashar A. Special considerations in paediatric burn patients. Indian J Plast Surg. 2010; 43(Suppl):S43-50.

[4] Toon MH, Maybauer DM, Arceneaux LL, Fraser JF, Meyer W, Runge A, et al. Children with burn injuries--assessment of trauma, neglect, violence and abuse. J Inj Violence Res. 2011;3(2):98-110.

[5] Fuzaylov G, Fidkowski CW. Anesthetic considerations for major burn injury in pediatric patients. Paediatric anaesthesia. 2009; 19(3):202-11.

[6] Jeschke MG, van Baar ME, Choudhry MA, Chung KK, Gibran NS, Logsetty S. Burn injury. Nat Rev Dis Primers. 2020;6(1):11.

[7] Moncrief JA. Complications of burns. Ann Surg. 1958;147(4):443-75.

[8] Niederbichler AD, Westfall MV, Su GL, Donnerberg J, Usman A, Vogt PM, et al. Cardiomyocyte function after burn injury and lipopolysaccharide exposure: single-cell contraction analysis and cytokine secretion profile. Shock. 2006;25(2):176-83.

[9] Duke JM, Randall SM, Fear MW, Boyd JH, Rea S, Wood FM. Understanding the long-term impacts of burn on the cardiovascular system. Burns. 2016;42(2):366-74.

[10] Sun J, Sun H, Sun Z, Yang X, Zhou S, Wei J. Intra-abdominal hypertension and increased acute kidney injury risk: a systematic review and meta-analysis. J Int Med Res. 2021;49(5):3000605211016627.

[11] Davidson AJ, Ferencz SE, Sosnov JA, Howard JT, Janak JC, Chung KK, et al. Presenting hypertension, burn injury, and mortality in combat casualties. Burns. 2018;44(2):298-304.

[12] Stewart IJ, Sosnov JA, Snow BD, Batou A, Howard JT, Janak JC, et al. Hypertension after injury among burned combat veterans: A retrospective cohort study. Burns. 2017;43(2):290-6.

[13] 13.Szczech LA, Granger CB, Dasta JF, Amin A, Peacock WF, McCullough PA, et al. Acute kidney injury and cardiovascular outcomes in acute severe hypertension. Circulation. 2010;121(20):2183-91.

[14] Forman JP, Stampfer MJ, Curhan GC. Diet and lifestyle risk factors associated with incident hypertension in women. Jama. 2009; 302(4):401-11.

[15] Staessen JA, Wang J, Bianchi G, Birkenhäger WH. Essential hypertension. Lancet. 2003; 361(9369):1629-41.

[16] James PA, Oparil S, Carter BL, Cushman WC, Dennison-Himmelfarb C, Handler J, et al. 2014 evidence-based guideline for the management of high blood pressure in adults: report from the panel members appointed to the Eighth Joint National Committee (JNC 8). Jama. 2014; 311(5):507-20.

[17] The World Health Organization [Available from: https://www.who.int/health-topics/hypertension#tab=tab_1.

[18] Wahl L, Tubbs RS. A review of the clinical anatomy of hypertension. Clin Anat. 2019;32(5):678-81.

[19] Sawicka K, Szczyrek M, Jastrzebska I, Prasal M, Zwolak A, Daniluk J. Hypertension–the silent killer. Journal of Pre-Clinical and Clinical Research. 2011; 5(2).

[20] Bell K, Twiggs J, Olin BR, Date IR. Hypertension: the silent killer: updated JNC-8 guideline recommendations. Alabama pharmacy association. 2015; 334:4222.

[21] Hirsch JS, Hong S. The Demystification of Secondary Hypertension: Diagnostic Strategies and Treatment Algorithms. Curr Treat Options Cardiovasc Med. 2019; 21(12):90.

[22] Patel N, Walker N. Clinical assessment of

hypertension in children. Clin Hypertens. 2016; 22:15.
[23] Gupta-Malhotra M, Banker A, Shete S, Hashmi SS, Tyson JE, Barratt MS, et al. Essential hypertension vs. secondary hypertension among children. Am J Hypertens. 2015; 28(1):73-80.
[24] Falkner B. Hypertension in children. Pediatr Ann. 2006; 35(11):795-801.
[25] Arun K, Venkatesh C, Gunasekaran D, Nandhini V, Narayanan V. Burns: a forgotten cause of hypertension in children. J Hypertens. 2014;32(1):200.
[26] Bayat A, Ramaiah R, Bhananker SM. Analgesia and sedation for children undergoing burn wound care. Expert Rev Neurother. 2010;10(11):1747-59.
[27] Jeschke MG, Chinkes DL, Finnerty CC, Kulp G, Suman OE, Norbury WB, et al. Pathophysiologic response to severe burn injury. Ann Surg. 2008; 248(3):387-401.
[28] Reynolds EM, Ryan DP, Sheridan RL, Doody DP. Left ventricular failure complicating severe pediatric burn injuries. J Pediatr Surg. 1995;30(2):264-70.
[29] Popp MB, Friedberg D, Macmillan BG. Clinical characteristics of hypertension in burned children. Ann Surg. 1980; 191:473-8.
[30] Brizio-Molteni L, Molteni A, Cloutier LC, Rainey S. Incidence of Post Burn Hypertensive Crisis in Patients Admitted to Two Burn Centers and A Community Hospital in the United States. Scand J Plast Reconstr Surg. 1979; 13(1):21-8.
[31] Krishnamoorthy V, Ramaiah R, Bhananker SM. Pediatric burn injuries. Int J Crit Illn Inj Sci. 2012; 2(3):128-34.
[32] Sheppard NN, Hemington-Gorse S, Shelley OP, Philp B, Dziewulski P. Prognostic scoring systems in burns: a review. Burns. 2011; 37(8):1288-95.
[33] Development and validation of a model for prediction of mortality in patients with acute burn injury. Br J Surg. 2009;96(1):111-7.
[34] Clark CJ, Reid WH, Gilmour WH, Campbell D. Mortality probability in victims of fire trauma: revised equation to include inhalation injury. Br Med J (Clin Res Ed). 1986; 292(6531):1303-5.
[35] Greenhalgh DG. Management of Burns. N Engl J Med. 2019; 380(24):2349-59.
[36] Clemens MS, Stewart IJ, Sosnov JA, Howard JT, Belenkiy SM, Sine CR, et al. Reciprocal Risk of Acute Kidney Injury and Acute Respiratory Distress Syndrome in Critically Ill Burn Patients. Critical care medicine. 2016; 44(10):e915-22.
[37] Thalji SZ, Kothari AN, Kuo PC, Mosier MJ. Acute Kidney Injury in Burn Patients: Clinically Significant Over the Initial Hospitalization and 1 Year After Injury: An Original Retrospective Cohort Study. Ann Surg. 2017; 266(2):376-82.
[38] Kuo G, Yang SY, Chuang SS, Fan PC, Chang CH, Hsiao YC, et al. Using acute kidney injury severity and scoring systems to predict outcome in patients with burn injury. J Formos Med Assoc. 2016;115(12):1046-52.
[39] Clark A, Neyra JA, Madni T, Imran J, Phelan H, Arnoldo B, et al. Acute kidney injury after burn. Burns. 2017; 43(5):898-908.
[40] Karakaya E, Akdur A, Aydoğan C, Türk E, Sayin CB, Ayvazoğlu Soy E, et al. A model for acute kidney injury in severe burn patients. Burns. 2022;48(1):69-77.
[41] Kim HY, Kong YG, Park JH, Kim YK. Acute kidney injury after burn surgery: Preoperative neutrophil/lymphocyte ratio as a predictive factor. Acta Anaesthesiol Scand. 2019;63(2):240-7.
[42] Talizin TB, Tsuda MS, Tanita MT, Kauss IAM, Festti J, Carrilho C, et al. Acute kidney injury and intra-abdominal hypertension in burn patients in intensive care. Rev Bras Ter Intensiva. 2018; 30(1):15-20.
[43] Clark AT, Li X, Kulangara R, Adams-Huet B, Huen SC, Madni TD, et al. Acute Kidney Injury After Burn: A Cohort Study From the Parkland Burn Intensive Care Unit. J Burn Care Res. 2019;40(1):72-8.
[44] Kym D, Cho YS, Yoon J, Yim H, Yang HT. Evaluation of diagnostic biomarkers for acute kidney injury in major burn patients. Ann Surg Treat Res. 2015;88(5):281-8.
[45] Kim Y, Cho YS, Kym D, Yoon J, Yim H, Hur J, et al. Diagnostic performance of plasma and urine neutrophil gelatinase-associated lipocalin, cystatin C, and creatinine for acute kidney injury in burn patients: A prospective cohort study. PloS one. 2018;13(6):e0199600.
[46] Yim H, Kym D, Seo DK, Yoon J, Yang HT, Lee J, et al. Serum cystatin C and microalbuminuria in burn patients with acute kidney injury. Eur J Clin Invest. 2015;45(6):594-600.
[47] Sen S, Godwin ZR, Palmieri T, Greenhalgh D, Steele AN, Tran NK. Whole blood neutrophil gelatinase-associated lipocalin predicts acute kidney injury in burn patients. J Surg Res. 2015; 196(2):382-7.
[48] Folkestad T, Brurberg KG, Nordhuus KM, Tveiten CK, Guttormsen AB, Os I, et al. Acute kidney injury in burn patients admitted to the intensive care unit: a systematic review and meta-analysis. Critical care (London, England). 2020; 24(1):2.
[49] Lu G, Huang S, Chen Y, Ma K. Umbilical cord mesenchymal stem cell transplantation ameliorates burn-induced acute kidney injury in rats. Int J Low Extrem Wounds. 2013;12(3):205-11.
[50] Chen H, Xing B, Wang L, Weng X, Chen Z, Liu X. Toll-like receptor 4 is involved in renoprotective effect of ischemic postconditioning after renal ischemia/reperfusion injury in rats. Urology. 2015; 85(2): 483.e1-7.
[51] Guo S, Yu M, Fang Q, Zhang L, You C, Wang X, et al. Heme oxygenase-1 induction mitigates burn-associated early acute kidney injury via the TLR4 signaling pathway. Burns. 2022;48(1):156-67.
[52] Mowery NT, Terzian WTH, Nelson AC. Acute lung injury. Curr Probl Surg. 2020;57(5):100777.
[53] Rubenfeld GD, Caldwell E, Peabody E, Weaver J,

Martin DP, Neff M, et al. Incidence and outcomes of acute lung injury. N Engl J Med. 2005;353(16):1685-93.
[54] Enkhbaatar P, Cox RA, Traber LD, Westphal M, Aimalohi E, Morita N, et al. Aerosolized anticoagulants ameliorate acute lung injury in sheep after exposure to burn and smoke inhalation. Crit Care Med. 2007;35(12):2805-10.
[55] Fang Y, Fu XJ, Gu C, Xu P, Wang Y, Yu WR, et al. Hydrogen-rich saline protects against acute lung injury induced by extensive burn in rat model. J Burn Care Res. 2011; 32(3):e82-91.
[56] Han S, Cai W, Yang X, Jia Y, Zheng Z, Wang H, et al. ROS-Mediated NLRP3 Inflammasome Activity Is Essential for Burn-Induced Acute Lung Injury. Mediators Inflamm. 2015; 2015:720457.
[57] Ipaktchi K, Mattar A, Niederbichler AD, Hoesel LM, Vollmannshauser S, Hemmila MR, et al. Attenuating burn wound inflammatory signaling reduces systemic inflammation and acute lung injury. J Immunol. 2006;177(11):8065-71.
[58] Liang X, Wang RS, Wang F, Liu S, Guo F, Sun L, et al. Sodium butyrate protects against severe burn-induced remote acute lung injury in rats. PloS one. 2013; 8(7):e68786.
[59] O'Connor TM, O'Connell J, O'Brien DI, Goode T, Bredin CP, Shanahan F. The role of substance P in inflammatory disease. J Cell Physiol. 2004; 201(2):167-80.
[60] Bone RC. Toward a theory regarding the pathogenesis of the systemic inflammatory response syndrome: what we do and do not know about cytokine regulation. Crit Care Med. 1996;24(1):163-72.
[61] Liu J, Liu J, Wang H, Bai M. Protective effect of celastrol for burn-induced acute lung injury in rats. Int J Clin Exp Pathol. 2019;12(2):576-83.
[62] Akpinar E, Halici Z, Cadirci E, Bayir Y, Karakus E, Calik M, et al. What is the role of renin inhibition during rat septic conditions: preventive effect of aliskiren on sepsis-induced lung injury. Naunyn Schmiedebergs Arch Pharmacol. 2014;387(10):969-78.
[63] Cao Y, Geng C, Li Y, Zhang Y. In situ Pulmonary Artery Thrombosis: A Previously Overlooked Disease. Front Pharmacol. 2021; 12:671589.
[64] Krzyzaniak MJ, Peterson CY, Cheadle G, Loomis W, Wolf P, Kennedy V, et al. Efferent vagal nerve stimulation attenuates acute lung injury following burn: The importance of the gut-lung axis. Surgery. 2011; 150(3):379-89.
[65] Zhang WF, Zhu XX, Hu DH, Xu CF, Wang YC, Lv GF. Intensive insulin treatment attenuates burn-initiated acute lung injury in rats: role of the protective endothelium. J Burn Care Res. 2011;32(3):e51-8.
[66] Gökakın AK, Atabey M, Deveci K, Sancakdar E, Tuzcu M, Duger C, et al. The effects of sildenafil in liver and kidney injury in a rat model of severe scald burn: a biochemical and histopathological study. Ulus Travma Acil Cerrahi Derg. 2014; 20(5):319-27.
[67] Zheng H, Chen XL, Han ZX, Zhang Z, Wang SY, Xu QL. Ligustrazine attenuates acute lung injury after burn trauma. Burns. 2005; 31(4):453-8.
[68] Fang Y, Xu P, Gu C, Wang Y, Fu XJ, Yu WR, et al. Ulinastatin improves pulmonary function in severe burn-induced acute lung injury by attenuating inflammatory response. J Trauma. 2011; 71(5):1297-304.
[69] Metra M, Teerlink JR. Heart failure. The Lancet. 2017; 390(10106):1981-95.
[70] King M, Kingery J, Casey B. Diagnosis and evaluation of heart failure. American family physician. 2012;85(12):1161-8.
[71] Deng J, Wang G, Huang Q, Yan Y, Li K, Tan W, et al. Oxidative stress-induced leaky sarcoplasmic reticulum underlying acute heart failure in severe burn trauma. Free Radic Biol Med. 2008; 44(3):375-85.
[72] Wen JJ, Williams TP, Cummins CB, Colvill KM, Radhakrishnan GL, Radhakrishnan RS. Effect of Mitochondrial Antioxidant (Mito-TEMPO) on Burn-Induced Cardiac Dysfunction. J Am Coll Surg. 2021; 232(4):642-55.
[73] Guillory AN, Clayton RP, Herndon DN, Finnerty CC. Cardiovascular Dysfunction Following Burn Injury: What We Have Learned from Rat and Mouse Models. Int J Mol Sci. 2016;17(1).
[74] Kita T, Ogawa M, Sato H, Kasai K, Tanaka T, Tanaka N. Role of p38 mitogen-activated protein kinase pathway on heart failure in the infant rat after burn injury. Int J Exp Pathol. 2008; 89(1):55-63.
[75] Niederbichler AD, Papst S, Claassen L, Jokuszies A, Ipaktchi K, Reimers K, et al. Burn-induced organ dysfunction: vagus nerve stimulation improves cardiac function. Eplasty. 2010;10:e45.
[76] Yao X, Wigginton JG, Maass DL, Ma L, Carlson D, Wolf SE, et al. Estrogen-provided cardiac protection following burn trauma is mediated through a reduction in mitochondria-derived DAMPs. Am J Physiol Heart Circ Physiol. 2014;306(6):H882-94.
[77] Hauhouot-Attoungbre ML, Mlan WC, Edjeme NA, Ahibo H, Vilasco B, Monnet D. [Disturbances of electrolytes in severe thermal burns]. Ann Biol Clin (Paris). 2005; 63(4):417-21.
[78] Sam R, Vaseemuddin M, Siddique A, Haghighat L, Kazlauskaite R, An G, et al. Hypercalcemia in patients in the burn intensive care unit. J Burn Care Res. 2007; 28(5):742-6.
[79] Klein GL, Nicolai M, Langman CB, Cuneo BF, Sailer DE, Herndon DN. Dysregulation of calcium homeostasis after severe burn injury in children: possible role of magnesium depletion. J Pediatr. 1997;131(2):246-51.
[80] Leite HP, Pinheiro Nogueira LA, Teodosio AH. Incidence and Clinical Outcome of Hypophosphatemia in Pediatric Burn Patients. J Burn Care Res. 2017; 38(2):78-84.

[81] Rimaz S, Moghadam AD, Mobayen M, Nasab MM, Rimaz S, Aghebati R, et al. Changes in serum phosphorus level in patients with severe burns: A prospective study. Burns. 2019;45(8):1864-70.
[82] Yang HT, Yim H, Cho YS, Kim D, Hur J, Kim JH, et al. Change of serum phosphate level and clinical outcome of hypophosphatemia in massive burn patient. J Trauma Acute Care Surg. 2012;73(5):1298-302.
[83] Kuo G, Lee CC, Yang SY, Hsiao YC, Chuang SS, Chang SW, et al. Hyperphosphatemia is associated with high mortality in severe burns. PloS one. 2018;13(1):e0190978.
[84] Beutler E. Hemolytic Anemia Due to Chemical and Physical Agents. 2001; 629-32.
[85] FOX CL Jr, LASKER SE, WINFIELD JM, MERSHEIMER WL. Albumin, potassium, sodium, and chloride redistribution and erythrocyte loss after surgical trauma and extensive burns. Ann Surg. 1954; 140(4):524-34.
[86] Ackerman BH, Patton ML, Guilday RE, Haith LR, Jr., Stair-Buchmann M, Reigart CL. Trimethoprim-induced hyperkalemia in burn patients treated with intravenous or oral trimethoprim sulfamethoxazole for methicillin-resistant Staphylococcus aureus and other infections: nature or nurture? J Burn Care Res. 2013; 34(1):127-32.
[87] Unal S, Ersoz G, Demirkan F, Arslan E, Tütüncü N, Sari A. Analysis of skin-graft loss due to infection: infection-related graft loss. Ann Plast Surg. 2005;55(1):102-6.
[88] Perlmutter EP, Sweeney D, Herskovits G, Kleiner M. Case report: severe hyperkalemia in a geriatric patient receiving standard doses of trimethoprim-sulfamethoxazole. Am J Med Sci. 1996;311(2):84-5.
[89] Perazella MA. Drug-induced hyperkalemia: old culprits and new offenders. Am J Med. 2000; 109(4):307-14.
[90] Mori H, Kuroda Y, Imamura S, Toyoda A, Yoshida I, Kawakami M, et al. Hyponatremia and/or hyperkalemia in patients treated with the standard dose of trimethoprim-sulfamethoxazole. Internal medicine (Tokyo, Japan). 2003;42(8):665-9.
[91] Margassery S, Bastani B. Life threatening hyperkalemia and acidosis secondary to trimethoprim-sulfamethoxazole treatment. J Nephrol. 2001;14(5):410-4.
[92] Elisaf M, Terrovitou C, Tomos P, Siamopoulos KC. Severe hyperkalaemia after cotrimoxazole administration in a patient with hyporeninaemic hypoaldosteronism. Nephrol Dial Transplant. 1997; 12(6):1254-5.
[93] Eiam-Ong S, Kurtzman NA, Sabatini S. Studies on the mechanism of trimethoprim-induced hyperkalemia. Kidney Int. 1996; 49(5):1372-8.
[94] Perazella MA. Trimethoprim-induced hyperkalaemia: clinical data, mechanism, prevention and management. Drug safety. 2000;22(3):227-36.
[95] Marinella MA. Trimethoprim-induced hyperkalemia: An analysis of reported cases. Gerontology. 1999;45(4):209-12.
[96] Stewart IJ, Morrow BD, Tilley MA, Snow BD, Gisler C, Kramer KW, et al. Dysnatremias and survival in adult burn patients: a retrospective analysis. Am J Nephrol. 2013; 37(1):59-64.
[97] Namdar T, Siemers F, Stollwerck PL, Stang FH, Mailänder P, Lange T. Increased mortality in hypernatremic burned patients. Ger Med Sci. 2010; 8:Doc11.
[98] Warden GD, Wilmore DW, Rogers PW, Mason AD, Pruitt BA, Jr. Hypernatremic state in hypermetabolic burn patients. Arch Surg. 1973; 106(4):420-7.
[99] Lam NN, Minh NTN. Risk factors and outcome of Hypernatremia amongst severe adult burn patients. Ann Burns Fire Disasters. 2018; 31(4):271-7.
[100] Ma F, Bai M, Li Y, Yu Y, Liu Y, Zhou M, et al. Continuous Venovenous Hemofiltration (CVVH) Versus Conventional Treatment for Acute Severe Hypernatremia in Critically Ill Patients: A Retrospective Study. Shock. 2015;44(5):445-51.
[101] Kolmodin L, Sekhon MS, Henderson WR, Turgeon AF, Griesdale DE. Hypernatremia in patients with severe traumatic brain injury: a systematic review. Ann Intensive Care. 2013; 3(1):35.
[102] Guilabert P, Usúa G, Martín N, Abarca L, Barret JP, Colomina MJ. Fluid resuscitation management in patients with burns: update. Br J Anaesth. 2016; 117(3):284-96.
[103] Streit S, Hebra A. Abdominal compartment syndrome in a three year old child following a severe burn injury. Journal of Pediatric Surgery Case Reports. 2013;1(7):177-9.
[104] Ivy ME, Possenti PP, Kepros J, Atweh NA, D'Aiuto M, Palmer J, et al. Abdominal compartment syndrome in patients with burns. J Burn Care Rehabil. 1999;20(5):351-3.
[105] Strang SG, Breederveld RS, Cleffken BI, Verhofstad MHJ, Van Waes OJF, Van Lieshout EMM. Prevalence of intra-abdominal hypertension and markers for associated complications among severe burn patients: a multicenter prospective cohort study (BURNIAH study). Eur J Trauma Emerg Surg. 2022; 48(2):1137-1149.
[106] Shanmugakrishnan RR, Loh CYY, Wakure A, El-Muttardi N. Serial abdominal closure with Gore-tex mesh and Rives-Stoppa for an open abdomen secondary to intra-abdominal hypertension in burns. Indian J Plast Surg. 2018; 51(3):324-6.
[107] Strong B, Spoors C, Richardson N, Martin N, Barnes D, El-Muttardi N, et al. Abdominal compartment syndrome in burns patients: Introduction of an evidence-based management guideline and algorithm. J Trauma Acute Care Surg. 2021; 90(6):e146-e54.
[108] Malbrain ML, De Keulenaer BL, Oda J, De Laet I, De Waele JJ, Roberts DJ, et al. Intra-abdominal hypertension and abdominal compartment syndrome in burns, obesity, pregnancy, and general medicine.

Anaesthesiol Intensive Ther. 2015; 47(3):228-40.
[109] Heimes J, Carlton E, McDonnell J, McDonald T, Udobi K, Moncure M. Use of an abdominal reapproximation anchor (ABRA) system in a patient with abdominal compartment syndrome after severe burns: A case report. Burns. 2013; 39(4):e29-33.
[110] Wise R, Jacobs J, Pilate S, Jacobs A, Peeters Y, Vandervelden S, et al. Incidence and prognosis of intra-abdominal hypertension and abdominal compartment syndrome in severely burned patients: Pilot study and review of the literature. Anaesthesiol Intensive Ther. 2016; 48(2):95-109.
[111] Kowal-Vern A, Ortegel J, Bourdon P, Chakrin A, Latenser BA, Kimball D, et al. Elevated cytokine levels in peritoneal fluid from burned patients with intra-abdominal hypertension and abdominal compartment syndrome. Burns. 2006; 32(5):563-9.
[112] Boehm D, Schröder C, Arras D, Siemers F, Siafliakis A, Lehnhardt M, et al. Fluid Management as a Risk Factor for Intra-abdominal Compartment Syndrome in Burn Patients: A Total Body Surface Area-Independent Multicenter Trial Part I. J Burn Care Res. 2019; 40(4):500-6.
[113] Ivy ME, Atweh NA, Palmer J, Possenti PP, Pineau M, D'Aiuto M. Intra-abdominal hypertension and abdominal compartment syndrome in burn patients. J Trauma. 2000; 49(3):387-91.
[114] Tsoutsos D, Rodopoulou S, Keramidas E, Lagios M, Stamatopoulos K, Ioannovich J. Early escharotomy as a measure to reduce intraabdominal hypertension in full-thickness burns of the thoracic and abdominal area. World J Surg. 2003; 27(12):1323-8.
[115] Kirkpatrick AW, Ball CG, Nickerson D, D'Amours SK. Intraabdominal hypertension and the abdominal compartment syndrome in burn patients. World J Surg. 2009;33(6):1142-9.
[116] McBeth PB, Sass K, Nickerson D, Ball CG, Kirkpatrick AW. A necessary evil? Intra-abdominal hypertension complicating burn patient resuscitation. J Trauma Manag Outcomes. 2014; 8:12.
[117] Ng JW, Cairns SA, O'Boyle CP. Management of the lower gastrointestinal system in burn: A comprehensive review. Burns. 2016;42(4):728-37.
[118] Akrami C, Falkner B, Gould AB, DeClement FA, Bendlin A. Plasma renin and occurrence of hypertension in children with burn injuries. J Trauma. 1980; 20(2):130-4.
[119] Falkner B, Roven S, Declement FA, Bendlin A. Hypertension in Children with Burns. J Trauma. 1978;18(3).
[120] Popp MB, Silberstein EB, Srivastava LS, Loggie JM, Knowles HC Jr, MacMillan BG. A pathophysiologic study of the hypertension associated with burn injury in children. Ann Surg. 1981;193(6):817-24.
[121] Popp MB, Friedberg DL, MacMillan BG. Clinical characteristics of hypertension in burned children. Ann Surg. 1980;191(4):473-8.
[122] Berman B, Viera MH, Amini S, Huo R, Jones IS. Prevention and management of hypertrophic scars and keloids after burns in children. J Craniofac Surg. 2008;19(4):989-1006.
[123] Canpolat DG, Esmaoglu A, Tosun Z, Akn A, Boyaci A, Coruh A. Ketamine-propofol vs ketamine-dexmedetomidine combinations in pediatric patients undergoing burn dressing changes. J Burn Care Res. 2012; 33(6):718-22.
[124] Rogers AD, Karpelowsky J, Millar AJ, Argent A, Rode H. Fluid creep in major pediatric burns. Eur J Pediatr Surg. 2010; 20(2):133-8.
[125] Palmieri T, Lavrentieva A, Greenhalgh DG. Acute kidney injury in critically ill burn patients. Risk factors, progression and impact on mortality. Burns. 2010;36(2):205-11.
[126] Rakkolainen I, Lindbohm JV, Vuola J. Factors associated with acute kidney injury in the Helsinki Burn Centre in 2006-2015. Scand J Trauma Resusc Emerg Med. 2018;26(1):105.
[127] Putra ON, Saputro ID, Diana D. Rifle Criteria For Acute Kidney Injury In Burn Patients: Prevalence And Risk Factors. Ann Burns Fire Disasters. 2021;34(3):252-8.
[128] McBeth PB, Sass K, Nickerson D, Ball CG, Kirkpatrick AW. A necessary evil? Intra-abdominal hypertension complicating burn patient resuscitation. J Trauma Manag Outcomes. 2014;8(1):1-7.
[129] Pinto GCC, Zaupa MC, Troster EJ. To: Acute kidney injury and intra-abdominal hypertension in burn patients in intensive care. Rev Bras Ter Intensiva. 2019; 31:271-2.
[130] Strang SG, Breederveld RS, Cleffken BI, Verhofstad MH, Van Waes OJ, Van Lieshout EM. Prevalence of intra-abdominal hypertension and markers for associated complications among severe burn patients: a multicenter prospective cohort study (BURNIAH study). Eur J Trauma Emerg Surg. 2022; 48(2):1137-1149.
[131] Ojeda S, Blumenthal E, Stevens P, Andersen CR, Robles L, Herndon DN, et al. The Safety and Efficacy of Propranolol in Reducing the Hypermetabolic Response in the Pediatric Burn Population. J Burn Care Res. 2018;39(6):963-9.
[132] Weis HB, Meinhardt KE, Minhajuddin A, Viroslav H, Colletti M, Weis JJ, et al. Administration of Tumescence in Pediatric Burn Patients Causes Significant Hypertension. J Burn Care Res. 2019; 40(6):752-6.