Challenging Legacy Burn Resuscitation Paradigms with Fluid Restriction and Early Plasma

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BACKGROUND: Fresh frozen plasma (FFP) as an adjunct in burn resuscitation to decrease endothelial cell permeability by restoring the glycocalyx is not yet standard of care despite increasing evidence showing benefits. We hypothesize that using an adjusted body weight index (ABWI) and starting resuscitation at a low rate of 2 mL/kg/% total body surface area (TBSA) with early plasma results in less fluid administration and superior clinical outcomes compared with traditional resuscitation methods, such as the Parkland formula.

STUDY DESIGN: This was a retrospective comparative study of burn patients (>20% TBSA) resuscitated with 2 mL/kg/%TBSA lactated Ringer's using their ABWI, early FFP, plus rescue FFP as needed for oliguria. ABWI = ideal weight + 0.3 (actual weight – ideal weight). Patients with >30% TBSA were given 1 to 2 units of FFP at admission. Fluids were titrated 10% to 20% per hour based on urine output (UOP). If oliguric for 2 hours, patients received 1 to 2 U "rescue" FFP. Legacy groups were resuscitated with Parkland formula ("4 mL/kg" group) or a less restrictive 3 mL/kg ABWI group w/rescue FFP only. Demographics, injury characteristics, fluids administered during resuscitation, UOP, outcomes, and death were recorded. Legacy groups were compared with the "2 mL/kg + FFP" ABWI group.

RESULTS: Patients given 2 mL/kg + FFP received significantly less fluid than the 3 and 4 mL groups (1.7 vs 3.3 [$p < 0.05$] vs 4.15 mL/kg/%TBSA [$p < 0.0001$]). UOP was significantly reduced from 1.4 to 1 to 0.7 mL/kg/h ($p < 0.0001$), approaching the goal of 0.5 mL/kg/h. Mortality, mechanical ventilation, tracheostomy, and hemodialysis were significantly less in the 2 mL/kg + FFP group ($p < 0.05$).

CONCLUSIONS: Patients treated with the restrictive 2 mL/kg + FFP formula received less fluid than the 3 mL/kg and Parkland formula controls. With reduced fluids, patients had less mechanical ventilation, less dialysis, fewer tracheostomies, and better survival. Acute kidney injury was minimal despite fluid restriction. Early experience suggests the new protocol is safe and feasible for further study. (J Am Coll Surg 2025;240:339–347. © 2025 by the American College of Surgeons. Published by Wolters Kluwer Health, Inc. All rights reserved.)

Fluid resuscitation after severe burn injury is a complex, dynamic process that must optimize tissue perfusion to minimize subsequent morbidity. Burn pathophysiology creates massive shifts in intravascular volume that occur primarily due to endotheliopathy and an ensuing capillary leak. For the past 10 years, understanding of endotheliopathy has evolved to a focus on the role of the glycocalyx.[1] The glycocalyx is a complex structure composed of

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Abbreviations and Acronyms

AIBW	=	adjusted ideal body weight
FFP	=	fresh frozen plasma
HD	=	hemodialysis
LOS	=	length of stay
LR	=	lactated Ringer's
TBSA	=	total body surface area
UOP	=	urine output

carbohydrates and proteins that coat the endothelial lining of blood vessels, essential for maintaining vascular integrity. Shedding of the endothelial glycocalyx increases commensurably with increasing severity of thermal burn,[2] followed by third spacing and burn shock.

Underresuscitation in the setting of rapid intravascular volume depletion from burn shock leads to end organ malperfusion, which can progress to multiple organ dysfunction syndrome, particularly in the most severely injured patients.[3,4] Overresuscitation with resultant edema formation may be even more poorly tolerated. Excess fluid increases the risk of abdominal compartment syndrome, increased burn conversion,[5,6] acute respiratory distress syndrome, and risk of infection. These entities were previously described as "resuscitation morbidity" by Chung and colleagues.[7] Although both hypervolemia and hypovolemia are associated with poor outcomes in the burned patient,[8] recent evidence suggests that overresuscitation may be the more deadly entity.[9] Fluid resuscitation should be done according to the "Goldilocks Principle"—not too little, not too much, but just the right amount based on the individual's dynamic capillary leak.

Fluid creep, a term first coined by Dr Basil Pruitt in 2000, refers to the trend of gradually increasing overall fluid administration over time. Modern burn patients have been found to receive volumes of fluid during initial resuscitation almost twice that predicted by the Parkland formula.[8] Fluid creep is likely multifactorial[1] and may be partially attributed to the use of crystalloid only (with or without albumin), a strategy that does not reverse the capillary leak. The burn community moved away from plasma resuscitations in the mid-20th century when pooled donor plasma was unsafe due to hepatitis.[1] Despite plasma now being very safe, it has not reemerged as a universal standard of care.[1,10]

In attempts to mitigate fluid creep, Advanced Burn Life Support guidelines recommend 2 to 4 mL/kg body weight × % total body surface area (TBSA) burn per hour of lactated Ringer's (LR) to maintain a minimum hourly urine output (UOP) of 0.5 mL/kg/h.[11] However, these "consensus formula" guidelines are nonspecific. The authors initially took a conservative approach to fluid reduction in their practice during the early 2010s and began giving most patients 3 mL/kg/%TBSA (instead of 4 mL/kg/%TBSA), coupled with rescue plasma. This strategy was designed to further reduce the amount of crystalloid given by not using the actual body weight in patients who are overweight or obese. Instead, we used an adjusted body weight index (ABWI), a concept used in hydrophilic medication dosing in obese patients on dialysis. In a recent publication, we described a reduction from 4.15 to 3.2 mL/kg/%TBSA and better mortality with the novel formula.[12] Over time, the authors began preemptively giving plasma to larger burns on admission in anticipation of expected oliguria. Empirically, these patients tolerated resuscitation better than expected. When the authors opened a new academic burn center in 2020, plasma on admission was built into resuscitation protocol for burns >30% TBSA, overcoming the dogmatic fear of colloid in the first 8 hours after injury. Trepidation of early colloid began after ovine studies in the 1980s by Demling and colleagues[13] showed leakage of albumin. In contrast to the current study, Demling's sheep received albumin, which does not reverse the capillary leak[14] in the same manner as plasma, yet the studies resulted in avoidance of any colloid use.[1] Based on preclinical data, older burn studies,[15,16] randomized studies in trauma patients,[17] and their own clinical experience,[12] the authors feel early plasma is not only safe but improves outcomes post-burn injury.

The concept of fluid creep is especially salient in the population of obese patients who have relatively more avascular adipose tissue whose resuscitation requirement will be overpredicted by current formulas relying on total body weight. Liu and colleagues[18] identified that increasing weight was associated with lower resuscitation volumes than predicted. This suggests that when resuscitation is titrated on an hourly basis based on urine output, the patients do not need the same degree of fluid administrated per kilogram of adipose tissue as they do for lean mass. Despite obesity not being associated with inhalation injury or the need for renal replacement therapy, there was a statistically significant increased risk of mortality when compared with nonobese patients.[18] This increased risk of continuous renal replacement therapy requirement or mortality was not observed in a similar study by Rosenthal and colleagues,[19] but they also identified that obese patients require commensurably less fluids with increasing BMI. The authors of the current study have attempted to address with discrepancy with the ABWI, aiming to give less fluid per kg for their adipose tissue.

We hypothesize that further restricting fluid to 2 mL/kg using ABWI coupled with early plasma to reverse the capillary leak on admission and rescue fresh frozen plasma

(FFP) as needed would safely result in less total volume administration compared with the traditional Parkland formula (4 mL/kg/%TBSA) and our previously published cohort of 3 mL/kg/%TBSA with rescue plasma only. The purpose of this study is to characterize the safety and efficacy of additional restrictions in fluid by clinical outcomes between groups. We also hypothesize that despite even less fluid, the new protocol would be protective for dialysis risk. With this study, we aimed to build on the existing data repository for burn resuscitation about the use of an adjusted ideal body weight formula in conjunction with FFP as an adjunct.

METHODS

Study design

A retrospective chart review of patients between June 2020 and April 2024 was performed to examine the total amount of resuscitation fluids received during a 24-hour postinjury period for all patients with second- and third-degree burns affecting ≥20% TBSA. Patients younger than 17 years or older than 79 years, those who survived less than 48 hours, and those who had an early decision (less than 7 days) for palliative extubation were excluded. Patients with high-voltage electrical injury with deep tissue injury and/or body part loss were also excluded. Patients with combined mechanical and thermal injury were also excluded. Patients with severe congestive heart failure and renal failure on HD were often treated "off" protocol with early inotropic agents, vasopressors, or continuous renal replacement therapy and were excluded from the study. These patients' demographics, injury characteristics, and outcomes were compared with patients treated with 3 mL/kg/%TBSA ABWI with plasma rescue (3 mL/kg group) and to patients treated with 4 mL/kg/%TBSA ± albumin. The newer data (2 mL/kg + FFP) were collected at a single academic burn center in the Southeastern US and compared with historical control data from another similar center that the authors worked in previously. The 3 mL/kg group was admitted between June 2015 and September 2017. The Parkland group (4 mL/kg) was admitted between January 2010 and May 2014.

Demographic and injury data were collected for all patients, including age, sex, weight, burn size (%TBSA), and the presence of inhalation injury. Inhalation injury was diagnosed by fiberoptic bronchoscopy and given an abbreviated injury severity grade in the 2 mL/kg and 3 mL/kg groups. In the historical control 4 mL group, it was a clinical diagnosis based on facial burns or the presence of soot, and patients rarely had a confirmatory bronchoscopy. Outcomes included ventilator-free days, transfusion-related lung injury (defined by the 2019 consensus guidelines[20]), total volume and type of fluids administered in the first 24 hours postinjury, UOP in the first 24 hours postinjury, escharotomy, maximum creatinine level in the first 72 hours after injury, acute kidney injury (AKI) requiring dialysis, tracheostomy, length of stay (LOS), and inpatient mortality. AKI was defined as an increase in serum creatinine greater than 0.3 or an increase in serum creatinine to 1.5 times baseline within a 72-hour period. Dialysis was included if a patient required dialysis during their hospital stay.

Care protocols

Figures 1 and 2 describe our approach to second- and third-degree burns >20% TBSA in patients older than 13 years. Each patient's burn size is captured with a Lund and Browder chart that is uploaded at the time of admission. An ABWI is then calculated using the following formula: ABWI in kg = (ideal body weight + 0.3) + (actual body weight – ideal body weight). A 24-hour fluid estimate

Burn Resuscitation Flow Sheet for Patients ≥ 13 Years of Age

Indications: 2nd and/or 3rd degree burns ≥20% Total Burn Surface Area (TBSA), ages ≥ 13 years
Exclusions: Severe CHF, Renal Failure on HD, Electrical Injury

1. Calculate burn size, upload using Canto/Haiku into EMR and label as "Lund and Browder".
2. Calculate Adjusted Body Weight Index (ABWI) in kg = *(Ideal Body Weight + 0.4) + (Actual Body Weight –Ideal Body Weight)*.
3. Calculate 24-hour fluid estimates:
   - 2mL LR x ABWI {in kg} x %TBSA **OR**
   - Use 3mL instead of 2mL if patient has mostly 3rd degree burns **AND** a confirmed inhalation injury.
   - Use 4ml instead of 2ml or 3ml if the patient has a confirmed electrical injury.
4. Divide this number by 16: this is your initial Burn Resuscitation IVF (BR-IVF) rate. If too little fluid has been given prior and delay in presentation, consider adding 25% to initial rate.
5. Call burn attending to discuss initiating plasma, and to determine the expected UOP goal.
6. Titrate BR-IVF hourly based on UOP until maintenance rate is reached as follows:

Figure 1. Burn resuscitation instructions. These instructions are provided with the flow sheet (Figure 2). This file is stored with a more detailed set of instructions that covers starting tube feed rates and "maintenance fluid" calculations, provided in **Supplemental Digital Content 1**, Appendix A (http://links.lww.com/JACS/A451). ABWI, adjusted body weight index; BR-IVF, burn resuscitation-IV fluid; CHF, congestive heart failure; EMR, electronic medical record; HD, hemodialysis; LR, lactated Ringer's; TBSA, total body surface area; UOP, urine output.

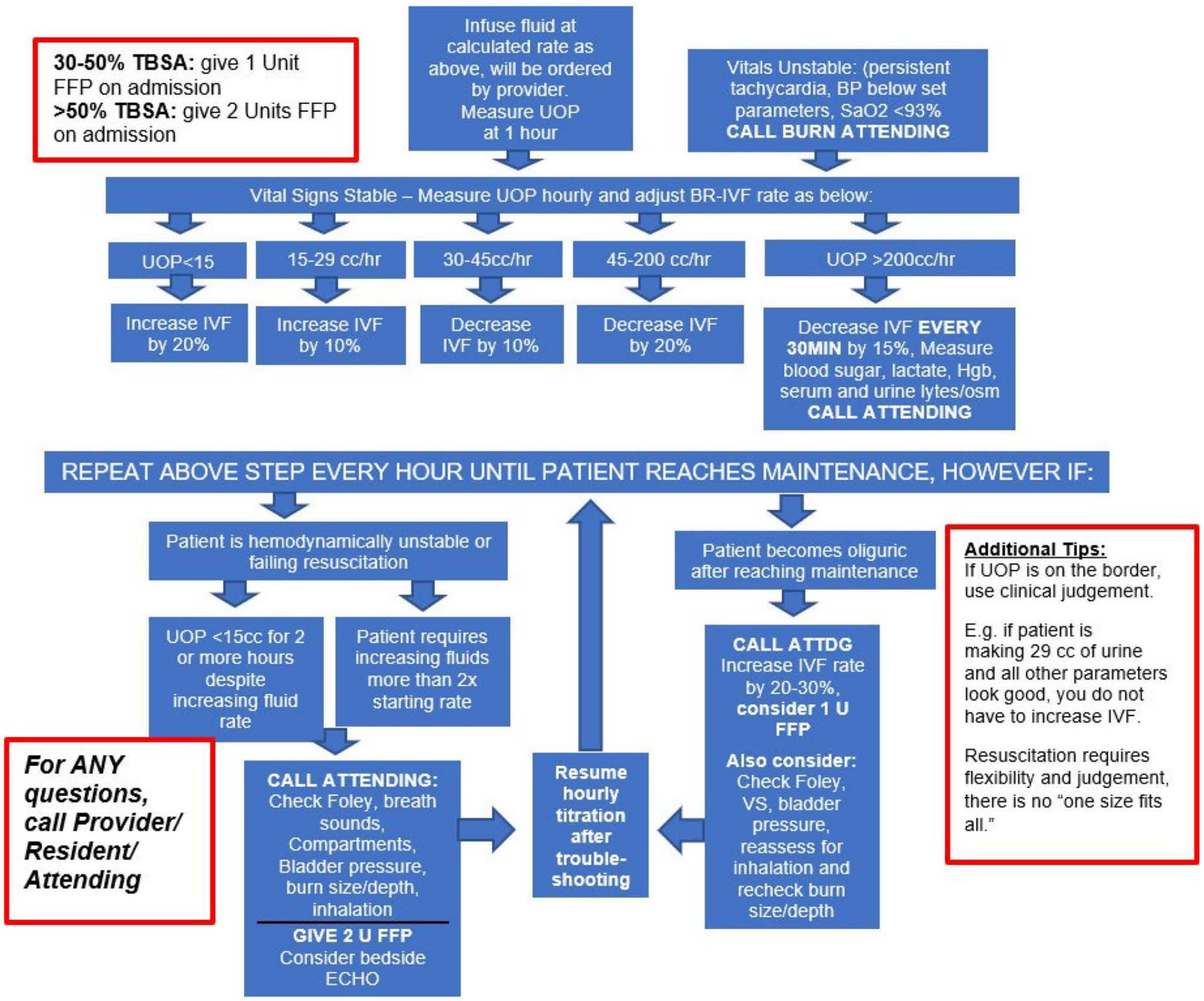

Figure 2. Burn resuscitation flow sheet for patients 13 years or older. BP, blood pressure; BR-IVF, burn resuscitation-IV fluid; ECHO, echocardiogram; FFP, fresh frozen plasma; osm, osmolality; TBSA, total body surface area; UOP, urine output; VS, vital sign.

is calculated through the following formula: 2 mL LR × ABWI (in kg) × %TBSA. However, if a large TBSA burn is predominantly third degree with confirmed high-grade inhalation injury, the initial multiplier is changed to 3 mL. The initial multiplier is higher in this group as these injuries generally need more fluid. For electrical injury, 4 mL is used as the multiplier for the starting rate. The calculated ABWI is divided by 16 to yield the initial burn resuscitation IV fluid rate. If the patient is clinically hypovolemic or there was a delay in presentation, a 25% increase can be added to the initial rate based on attending discretion. Initiating plasma outside of the protocol for patients with <20% TBSA injury is determined on a case-by-case basis as determined by Burn Surgery Attending Physicians. Burn resuscitation IV fluid is then titrated by UOP until a normal maintenance rate is achieved. Patients with 30% to 50% TBSA burns were given 1 unit of FFP on admission, whereas those with >50% TBSA received 2 units.

Using a nursing-driven protocol, fluids were titrated 10% to 20% per hour based on a deviation from the target UOP of 30 mL/h. Within this protocol, the attending physician could elect to reset the UOP goal to 0.5 mL/ABWI/h. for patients who were extremely underweight or overweight. For example, if the patient weighs more than 100 kg, the attending would likely aim for 50 mL/h. If patients were oliguric for more than 2 hours despite crystalloid administration, 1 to 2 units of FFP were administered as rescue therapy.

The protocol also provides guidance on troubleshooting oliguria and using judgment to individualize resuscitation or take a patient "off protocol."

Statistical analysis

Descriptive statistics were generated for the entire sample. Data were reported as median (interquartile range 25% to 75%) unless otherwise noted. Categorical variables were presented as percentages. Data were tested for normality. Analyses were 2-tailed with a p value of <0.05 considered statistically significant. Fisher's exact test was used for categorical variables, and the Wilcoxon rank-sum test was used for continuous variables.

The data analysis for this article was generated using R Language Software version 4.3.1 (2023-06-16 ucrt; Copyright 2023 The R Foundation for Statistical Computing).[21]

RESULTS

Demographics and injury data

No significant differences in age, weight, or burn size were detected between either of the 3 groups. The only difference in injury characteristics detected was that more patients were reported to have inhalation injury in the 4 mL/kg group (Table 1).

Outcomes

Patients resuscitated with 2 mL/kg ABWI + FFP received significantly less fluid than the 3 and 4 mL groups, as in Table 1 (1.7 vs 3.3 [$p < 0.05$] vs 4.15 mL/kg [$p < 0.001$], respectively). Urine output was significantly reduced compared with both historical control groups and closer to the goal rate of 0.5 mL/kg/h. Of the 57 patients included in the 2 mL/kg + FFP group, only 1 was started at a 4 mL/kg rate due to a presumed electrical conduction injury that was actually arc flash only. Two additional patients were started at a 3 mL/kg rate and given early plasma (Table 2).

Pulmonary

The authors performed significantly fewer tracheostomies compared with the 4 mL/kg group and less time on the ventilator (measured in ventilator-free days). Compared with the 3 mL group, 2 mL/kg patients' ventilator-free days were significantly improved ($p = 0.005$), with a trend for fewer tracheostomies ($p = 0.12$). Additionally, none of the patients in either the 2 or 3 mL/kg groups experienced transfusion-related lung injury.

Table 1. Demographics and Injury Characteristics

Variable	2 mL/kg ABWI + FFP	3 mL/kg ABWI + FFP	Parkland (4 mL/kg)
Total patients, n	57	40	116
Age, y, median (IQR)	47 (34–57)	45 (32–58)	38 (31–53)*
Weight, kg, median (IQR)	83 (71–101)	88 (75–104)	84 (72–98)
Burn size, % TBSA, median (IQR)	32 (26–38)	34 (22–54)	31 (24–47)
Inhalation injury, %	21	25	52*

Comparisons between groups are shown. Nonsignificant p values are omitted or mentioned in the text. The 4 mL group was compared with the 2 mL group and the 3 mL group was compared with the 2 mL group.
*$p < 0.05$ compared with the 2 mL/kg group.
ABWI, adjusted body weight index; FFP, fresh frozen plasma; IQR, interquartile range; TBSA, total body surface area.

Table 2. Outcomes

Outcomes	2 mL/kg ABWI + FFP	3 mL/kg ABWI + FFP	Parkland (4 mL/kg)
Fluid, mL/kg/%TBSA, median (IQR)	1.7 (1.2–2.4)	3.16 (2.1–4.3)*	4.16 (3.1–5.7)*
UOP, mL/kg/h, median (IQR)	0.78 (0.4–1.3)	1.01 (0.6–1.3)*	1.45 (0.9–2.1)*
Ventilator-free days, median (IQR)	30 (27–30)	27 (24–30)†	23 (17–30)*
Hemodialysis, %	3.5	5	19‡
Tracheostomy, %	3.5	13	19‡
LOS, d, median (IQR)	32 (19–35)	29 (21–51)	21 (12–40)†
Mortality. %	3.5	5	20‡

Comparisons of outcomes between groups are shown. Nonsignificant p values are omitted or mentioned in the text. The 4 mL group was compared with the 2 mL group and the 3 mL group was compared with the 2 mL group.
*$p < 0.0001$ compared with the 2 mL/kg group.
†$p < 0.001$ compared with the 2 mL/kg group.
‡$p < 0.05$ compared with the 2 mL/kg group.
ABWI, adjusted body weight index; FFP, fresh frozen plasma; IQR, interquartile range; LOS, length of stay; TBSA, total body surface area; UOP, urine output.

Renal

Overall, patients in both the 2 mL and 3 mL groups with plasma received less hemodialysis (HD) than the 4 mL group. Only 3.5% of patients underwent HD, a nonsignificant decrease from the 3 mL group (p = 0.52) but a large decrease from the Parkland group (p = 0.0008).

Only 13% of the patients experienced elevated creatinine in the first 72 hours after resuscitation, including the 2 who progressed to dialysis. The other patients who experienced AKI but did not progress to HD had a max Cr of 1.7 mg/dL. Dialysis was temporary in both patients.

Mortality and length of stay

Mortality was significantly reduced in the 2 mL/kg + FFP group, while LOS was paradoxically increased. The mortality for the entire burn center was <1% during the study period, and the O/E ratio was 0.4. The patients in the 2 mL/kg group had a 1 day/%TBSA LOS under the time expected (1.6 days/%TBSA) based on a query of Burn Quality Care Platform Benchmark data (performed 11/24). Nationally reported O/E Vizient LOS data were 0.9 for the burn center during that time period.

Plasma vs no plasma

The majority of the patients treated in this study received plasma during their resuscitation, and 60% of the patients were given FFP. In a breakdown of those who received it and those who did not, there were no significant differences in fluid administered (1.6 vs 1.83 mL/kg/%TBSA), with no significant differences in injury characteristics, but a trend for smaller burn size.

DISCUSSION

Fluid resuscitation in the burned patient remains a controversial topic about optimal volumes, the ideal fluid, and even measuring resuscitation success. The patients in this study who received early plasma and were resuscitated with an ABWI as opposed to actual weight received less than 2 mL/kg/%TBSA, while the data also suggest less morbidity and mortality for this group. This is encouraging in the war against fluid creep, because there is continued evidence to support that modern patients still frequently receive fluid volumes that exceed even Parkland formula estimates.[22] The protocol used in the current study represents the lowest published fluid administration in the modern burn literature in a review performed in December 2024. Despite further restricting fluid, outcomes are also at least equivalent or improved when compared with the 3 mL/kg group. No increases in renal failure or dialysis were found; all other outcomes were either slightly improved or statistically noninferior. The volume given to these patients is very similar to the earliest resuscitation formulas, specifically the Evans Formula and the Brooke Formula. Both also aimed to provide 2 mL/kg/%TBSA and used plasma.

Most recent studies show a reduction of first 24-hour volumes to, at best, around 4 mL/kg/%TBSA,[9,23-25] one of the biggest advances in modern resuscitation, the Burn Navigator, is an AI algorithm developed at the US Army Institute of Surgical Research and Brooke Army Medical Center. Randomized clinical trials and real-world data show that the navigator also reduces fluid administration to approximately 4 mL/kg/%TBSA, even when providers start with a rate of 2 mL/kg/%TBSA. The main differences between the current study and the Burn Navigator studies are in whether colloid was used, which type of colloid was used, and at what interval it was used. Compared with the Burn Navigator studies, the ABWI protocol uses a lower starting rate coupled with FFP to reverse capillary leak, resulting in a >50% reduction in fluid administration, with a similar patient population regarding age and burn size.

The ABRUPT trial[22] was a recently published multicenter observational study of 21 American Burn Association Verified Burn Centers to characterize variations in fluid resuscitation practice patterns. The authors aimed to characterize total volume of crystalloid in the first 48 hours as well as patterns of albumin supplementation. They found that fluid received in the first 24 hours was equal to or in excess of Parkland formula estimates.[22] The patients resuscitated with albumin received 5.2 mL/kg/%TBSA, approximately 300% more fluid than the 2 mL/kg + plasma ABWI patients in this article, with a similar burn size and age reported in both studies. The authors believe that one of the main differences in outcome is related to the fact that although albumin and FFP are both considered "colloid," albumin does not reverse the capillary leak nor restore the glycocalyx in the same manner as plasma.[14]

As noted earlier, the importance of the glycocalyx and its role in protection against endotheliopathy in burn injury has been a relatively recent development. The glycocalyx, a glycoprotein-polysaccharide matrix, primarily shields the endothelium from direct blood flow, regulates vascular permeability, inhibits anticoagulation, and deters adhesion of leukocytes.[26] Disruption of the glycocalyx, such as in large burn injuries, results in extravascular fluid leak that strongly contributes to the large volume fluid shifts that characterize distributive shock in burns. Restoration of glycocalyx has been shown to reverse capillary leak in rodent models, and this has been extrapolated to clinical settings with the use of FFP.[14]

FFP has been described as a useful adjunct in reducing crystalloid administration during burn shock as it decreases endothelial cell dysfunction after a burn injury.[26] The benefits of FFP in the role of restoring and protecting the syndecan backbone of the glycocalyx (glycoprotein-polysaccharide matrix) of blood vessels has been shown in vivo and in vitro studies.[27,28] Therefore, FFP conceivably leads to a decrease in vascular leak and a decrease in total volume of fluid used during burn resuscitation. Previous evaluation of the efficacy of FFP in burn resuscitation demonstrated that patients who received plasma-inclusive resuscitation had less intra-abdominal hypertension with less total volume required than those who received crystalloid-only resuscitation.[15] Several clinical studies using the West Penn Formula show that the use of plasma[15,16] results in less fluid administration, with variability in whether other outcomes were improved. However, the current study stands out in that it also showed less fluid administration in the experimental group but also found an association between lower mortality, less time on the ventilator, less dialysis, and fewer tracheostomies. Additionally, the patients in our study received less fluid than those reported in the West Penn articles. The West Penn Formula provides a constant, steady, higher volume of FFP that may be more than some patients need based on their individual capillary leak and degree of endotheliopathy. Plasma administration also comes with risks, including immunosuppression and various transfusion reactions. Therefore, the current formula was designed to provide a bolus early on to reverse the leak and only administer it again when the patient shows clinically significant signs of hypovolemia, such as oliguria or hypotension. Specifically, this "bolus" is usually administered for a 30-minute period, as opposed to a rapid, pressure-bag infusion. Providing unnecessary crystalloid boluses in this population is frowned upon as they tend to rapidly extravasate. In this paradigm, the plasma is functionally a medication, therefore, running in rapidly to address the capillary leak, very different compared with running in a liter of LR rapidly. In general, the ABWI formula is more of an individualized formula, particularly in that it adjusts for each individual's variable amount of hypovascular adipose tissue.

Limitations of this study include its retrospective design and observational nature. Additionally, the most recent cohort had data collected at a different burn center than the 3 mL and Parkland groups, creating risk for unmeasured confounders in care that might have influenced outcomes. In addition, other care parameters have changed since the original Parkland formula cohort was treated in the 2010s, including advances in critical care and regenerative medicine technologies for wound closure. These limitations will hopefully be addressed with a randomized multicenter study (PREEVENT-LITES 2 Network), currently in the planning stages. A larger cohort of patients across a greater geographic spread increased the statistical power and generalizability of this study's findings, along with randomization and prospective data collection. Additionally, measuring objective serum measures of endotheliopathy or microscopy would add crucial data to strengthen study conclusions. A surprising finding was the increased LOS, which can be attributed to several factors. The catchment area of the authors' new burn center spans a larger distance than that of the burn center where the historical controls were treated (a 4-hour drive vs a 2.5-hour drive). Fewer self-pay patients are able to obtain Medicaid or other funding due to more strict statewide definitions of disability. Also, social determinants of health are empirically more likely to keep patients in the hospital now than they were 10 or more years ago; providers more routinely screen for them in current times. The population is also aging, CPI has increased more than salaries, and gas is much more expensive, creating barriers for patients to return to the clinic and creating longer hospital stays. Some of the more complex patients likely survived in the newer groups, given the lower mortality found in the more recent cohorts, creating long hospital stays. Although the mortality for the 2 mL/kg group in the study was 7.9% for >20% TBSA injuries, mortality for the entire burn center was <1% during the study interval, with observe to expected ratios of 0.45. Another confounder is that it initially appeared more patients sustained inhalation injury in the 4 mL/kg group, indicating that maybe they had a larger inflammatory response with higher fluid requirements. However, almost half of these patients were extubated within 24 to 48 hours without a bronchoscopy, suggesting that that number might be spurious due to false positives. The manner in which inhalation injury was diagnosed changed in that burn center between the time that the 4 mL and 3 mL groups were cared for, with bronchoscopy being adopted as the gold standard for diagnosis with the 3 mL group in 2015 with a change in leadership, possibly creating some false positives in the 4 mL group. When looking back, there likely was no actual difference in the frequency of inhalation in the 4 mL/kg group.

Individualizing resuscitation efforts is paramount in combating modern fluid creep. In general, consensus supports individualized goal-directed fluid resuscitation.[29] We continue to assert that there are several general principles in facilitating a tailored resuscitation: (1) judiciously using crystalloid fluid, (2) titrating fluids hourly, (3) selecting a starting rate based on injury severity (burn size and inhalation injury), and (4) decreasing capillary leak with early

FFP and as needed with FFP rescue. Additionally, early FFP on admission appears to be safe, as it correlated with better outcomes compared with historical controls who did not receive it. Our data continue to support the efficacy and safety of using an adjusted ideal body weight-based formula for fluid resuscitation and indicate that FFP rescue is a safe practice in burn resuscitation.

In summary, the patients treated with early FFP and the ABWI formula received less than 2 mL/kg/%TBSA, with the fluid being a mix of crystalloid and FFP. The authors feel the combination of starting with 2 mL/kg/%TBSA, giving early plasma to reverse the capillary leak, and only resuscitating lean, vascular mass all play a role in this study's findings. The current formula is very similar to the earliest resuscitation formulas, such as the Evans and Brooke formulas. Although 70 years have passed, we have come full circle to doing it the way that we did it in the old days.

CONCLUSIONS

The 2 mL/kg restrictive ABWI formula plus early FFP is safe and feasible. Patients received less total fluid than the previously published iteration of the 3 mL/kg ABWI formula (1.7 vs 3.3 mL/kg/%TBSA) and less than half of the traditional Parkland formula (4 mL/kg/%TBSA). They also received far less than the patients resuscitated in the recently published multicenter albumin or ABRUPT study (4.6 mL/kg/%TBSA). Despite reduced fluids, clinically significant AKI was minimal, patients received less HD and less mechanical ventilation, and mortality was lower than in comparable studies. Preliminary data suggest that this protocol is safe and effective, but additional prospective study is necessary.

Author Contributions

Conceptualization: Kahn, Bright
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Formal analysis: Kahn, Huff
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Methodology: Kahn, Hink, Bright, Baliga
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Discussion

DR STEVE WOLF (Galveston, TX): My notes say this is a study investigating a renewed hot topic. However, in my humble opinion, it has never *not* been a hot topic for those of us interested in the process of resuscitation after severe burn. For context, my fellows, residents, and students often ask, what exactly is a "good" resuscitation—how do you define that? My answer is always, well, the patient is alive at the end of it with all their parts, right? In this case, you have shown that giving a defined amount of fresh frozen plasma (FFP) upfront and less crystalloid seems to improve on that expectation. So, the first question is, what happened to FFP in the first place? Why did we stop using it? It was in all the original burn resuscitation formulas, including the Higgins formula, the first Brooke formula, and the Evans formula, but we cannot get it anymore without wailing and gnashing of teeth from the blood bankers. Should that be changed and become the standard of care? Second, you claim that FFP has beneficial effects on the glycocalyx of endothelial cells, which it probably does, but is something else at play in FFP on which these effects rely? Does some other effect of FFP drive this that we just have not discovered yet? The third question is related to the demonstration of effects in 24-hour increments. While we were developing the Burn Navigator Decision Support Tool, we noticed that resuscitation physiology differs at hour 8 from hours 12, 16, and 24; you have shown just the 24-hour data. Would it be possible to look at this a little bit closer in smaller time increments? Fourth, you noted that increased length of stay was related to decreased mortality. In the article, you claimed this has to do with operations in your hospital system, but I suggest that it is probably because they did not die in the first place and were available to accrue more hospital days to add to the right tail of the frequency distribution. So, you will end up with longer lengths of stay because these patients will not die. Is that the explanation? Also, you looked at length of stay, but this does not account for burn size, which generally elicits a nonlinear response. It should probably be indexed to total body surface area (TBSA) burn to make it linear for the article itself. Finally, how many of these patients received pressors during resuscitation, which is fairly common now? Thanks for presenting this intriguing article, and I look forward to your answers.

DR JEFFREY KERBY (Birmingham, AL): This article details the results of a fluid-restrictive approach that incorporates early plasma administration for major burn wound resuscitation.

Using this resuscitation protocol, the authors have been able to reduce the initial 24-hour fluid requirement by half, compared with their own historical experience in recently published data, while maintaining end-organ perfusion with a reduction in hemodialysis, reduced ventilatory requirement, and lower mortality.

This article adds to the clinical experience that supports the safety and efficacy of plasma-based resuscitation, albeit with multiple methodological issues that were discussed in the presentation and the article.

How many patients in the current burn resuscitation protocol group received FFP? Based on your protocol, plasma administration was reserved for those with larger burns, more than 30% TBSA, and for rescue of patients with persistent oliguria.

Were there differences in outcomes between those who received plasma and those who did not?

In other words, how much of a role do you feel plasma administration played in reducing fluid requirements for these patients?