

Simple Derivation of the Initial Fluid Rate for the Resuscitation of Severely Burned Adult Combat Casualties: In Silico Validation of the Rule of 10

Kevin K. Chung, MD, José Salinas, PhD, Evan M. Renz, MD, Ricardo A. Alvarado, MD, Booker T. King, MD, David J. Barillo, MD, Leopoldo C. Cancio, MD, Steven E. Wolf, MD, and Lorne H. Blackbourne, MD

Background: In practice, current burn resuscitation formulas, designed to estimate 24-hour fluid resuscitation needs, provide only a starting point for resuscitation. To simplify this process, we devised the “rule of 10” to derive the initial fluid rate.

Methods: We performed an in silico study to determine whether the rule of 10 would result in acceptable initial fluid rates for adult patients. A computer application using Java (Sun Microsystems Inc., Santa Clara, CA) generated a set of 100,000 random weights and percentage of total body surface area (%TBSA) values with distributions matching the model characteristics with which the initial fluid rate was calculated using the rule of 10. The initial rate for 100,000 simulations was compared with initial rates calculated by using either the modified Brooke (MB, 2 mL/kg/%TBSA) or the Parkland (PL, 4 mL/kg/%TBSA) formulas.

Results: Analysis of calculated initial fluid rates using the rule of 10 showed that 87.8% (n = 87,840) of patients fell between the initial rates derived by the MB and the PL formulas. Less than 12% (n = 11,502) of patients had rule of 10 derived initial rates below the MB. Among these patients, the median difference of the initial rate was 14 mL/hr (range, 2–212 mL/hr). Among those who had initial rule of 10 calculated rates greater than the PL formula (<1%, n = 658), the median difference in rate was 33 mL/hr (range, 1–213 mL/hr), with a mean %TBSA of 21% ± 1% and mean weight of 130 kg ± 11 kg.

Conclusion: For the majority of adult burn patients, the rule of 10 approximates the initial fluid rate within acceptable ranges.

Key Words: Resuscitation, Adult burn patients, Fluid rate, Rule of 10.

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In 1979, Pruitt¹ observed that among published fluid resuscitation recommendations, considerable variability existed in the recommended volume and salt loads. Regardless of the resuscitation formula used, the development of effective fluid

resuscitation is widely regarded as one of the greatest advances in modern burn care with direct impact on patient survival.² Over time, debate over which of the many formulas is most appropriate evolved into a consensus guideline that is currently accepted by the American Burn Association (ABA).^{3,4} ABA guidelines recommend initiating fluid resuscitation of the burn patient by using lactated Ringer’s solution at a rate of infusion based on 2 mL/kg/% to 4 mL/kg/% total body surface area (TBSA) burn administered over the first 24 hours postburn, providing one-half of the estimated fluid over the first 8 hours and the remainder over the next 16 hours. Once this initial fluid rate is calculated and initiated, an optimal resuscitation can only occur with an attentive bedside clinician carefully titrating fluids based on patient response. Regardless of the formula used, each requires the same multiple steps to derive in the initial fluid rate and thus is too cumbersome for combat prehospital providers who often must assess and resuscitate several burn patients simultaneously. In an effort to simplify the derivation of the initial fluid rate, we developed the following formula:

1. Estimate burn size to the nearest 10.
2. $\%TBSA \times 10 =$ initial fluid rate in mL/hr (for adult patients weighing 40 kg to 80 kg).
3. For every 10 kg above 80 kg, increase the rate by 100 mL/hr.

Once fluid resuscitation is initiated, our ultimate goal is to maintain end-organ perfusion by gradually restoring fluid balance while simultaneously replacing insensible losses and avoiding the consequences of both under- and overresuscitation. Our objective was to determine whether this approach would result in an appropriate initial fluid rate when compared with existing resuscitation formulas.

PATIENTS AND METHODS

We performed an in silico study and simulation to determine whether the rule of 10 would result in the derivation of acceptable initial fluid rates for patients with a variety of weights and burn sizes. Our first step was to determine a contemporary weight and burn size distribution for the simulation. Using our institute’s trauma database, under a protocol approved by the Institutional Review Board, we extracted the weights and the percentage of TBSA (%TBSA) burns for all patients admitted to the Burn Intensive Care Unit

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From the US Army Institute of Surgical Research (K.K.C., J.S., E.M.R., B.T.K., D.J.B., L.C.C., S.E.W., L.H.B.), Fort Sam Houston, Texas; and University of Texas Health Science Center at San Antonio (R.A.A., S.E.W.), San Antonio, Texas.

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Address for reprints: Kevin K. Chung, MD, US Army Institute of Surgical Research, 3400 Rawley E. Chambers Avenue, San Antonio, TX 78234-6315; email: kevin.chung@amedd.army.mil.

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at the US Army Institute of Surgical Research from January 2003 to October 2008 with >20% burns. Weight and %TBSA data sets were fitted to an underlying distribution based on the shape of the data to determine an appropriate model to use for a computational simulation. Next, a computer application using Java (Sun Microsystems Inc, Santa Clara, CA) was written to simulate the shape of both the %TBSA and weight model. The application generated a simulation set of 100,000 random weights and %TBSA values with distributions matching the model characteristics. Then, the rule of 10 was used to calculate, for each of the 100,000 patients, the initial fluid rate for the various weights and burn size combinations encountered. Then, the initial rate for 100,000 simulations was compared with initial rates calculated by using either the modified Brooke (MB, 2 mL/kg/%TBSA) or the Parkland (PL, 4 mL/kg/%TBSA) formulas. Finally, we analyzed the patients who fell outside the ABA acceptable guideline. Data analysis was performed by using the Statistical Package for the Social Sciences (SPSS), version 16 (SPSS Inc., Chicago, IL) and Microsoft Excel (Microsoft Inc., Redmond, WA).

RESULTS

Between January 2003 and October 2008, 494 patients were admitted to our burn intensive care unit with >20% TBSA. Of these, 449 patients had available weights recorded. Distribution was a slight left-shifted normal distribution with a mean of 88 kg $\pm$ 21 kg. Approximately 95% of the population had a weight range of 46 kg to 130 kg. In these patients, the %TBSA frequency distribution was characterized by a continuously declining function with a mean %TBSA of 42% $\pm$ 20%. This cohort had ~71% patients with a %TBSA $\leq$ 50%. Univariate regression on the TBSA data set was performed to check the data fit with several standard model distributions including linear, power, logarithmic, and polynomial models. The logarithmic model achieved the highest fit values with an R^2 of 0.91. Logarithmic fit formula of the cohort is given by the following equation:

$$\text{Expected frequency} = 6.4111 \ln(\text{TBSA}) + 17.716.$$

Figure 1 illustrates the results of the weight distribution for an estimated population of 100,000 patients using the developed weight model. The mean of the simulated population was 88 kg $\pm$ 20 kg, which was not significantly different from the subject population used for model development. Mean %TBSA of the simulated population was 44% $\pm$ 20%, which was not significantly different from the subject population (Fig. 2).

The initial fluid rates (mL/hr) derived by the rule of 10 over a wide range of weights and burn sizes were plotted against the boundaries set by the MB and PL formulas over the same range of weights and %TBSA burns. To depict this in a two-dimensional graph, we converted the rule of 10 derived fluid rates into a mL/kg/%TBSA unit that would have been used to derive the same initial rate using the traditional methods (i.e., taking the 24-hour total fluid calculated into milliliters and infusing the first half over 8 hours). The rule of 10 derived rate was multiplied by 8 and then by 2, and the

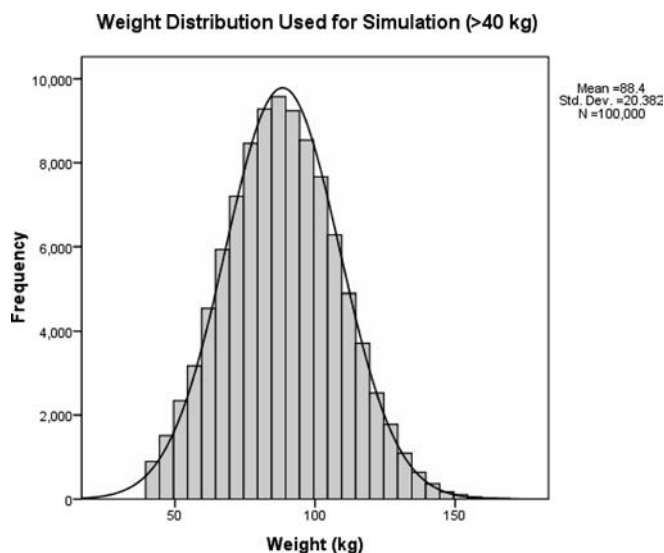


Figure 1. Simulated weight distribution used for simulation (n = 100,000).

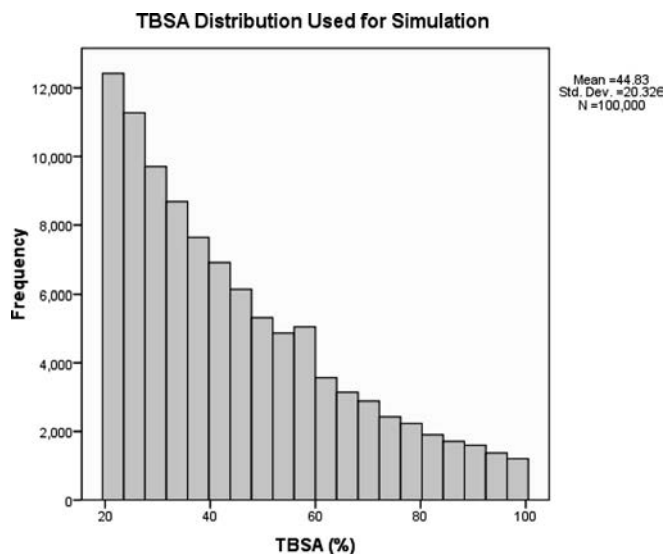


Figure 2. Simulated TBSA (%) distribution used for simulation (n = 100,000).

resulting total 24-hour fluids was then divided by the weight and %TBSA to obtain a mL/kg/%TBSA value. We determined that 87.8% (n = 87,840) of the patients had calculated initial fluid rates that fell between rates that would have been derived by using MB and PL formulas (Fig. 3). Approximately 11.5% (n = 11,502) of the patients had rule of 10 derived fluid rates that fell below the MB formula, with 0.7% falling above the PL formula (n = 658). Among these patients, the median difference of volume for the initial rate between the rule of 10 derived rate and the rate derived by the MB formula was 14 mL/hr (range, 2–212 mL/hr). Additionally, these patients had a mean %TBSA of 59% $\pm$ 26% and a mean weight of 90 kg $\pm$ 13 kg. Among those who had initial rule of 10 calculated rates greater than the PL formula

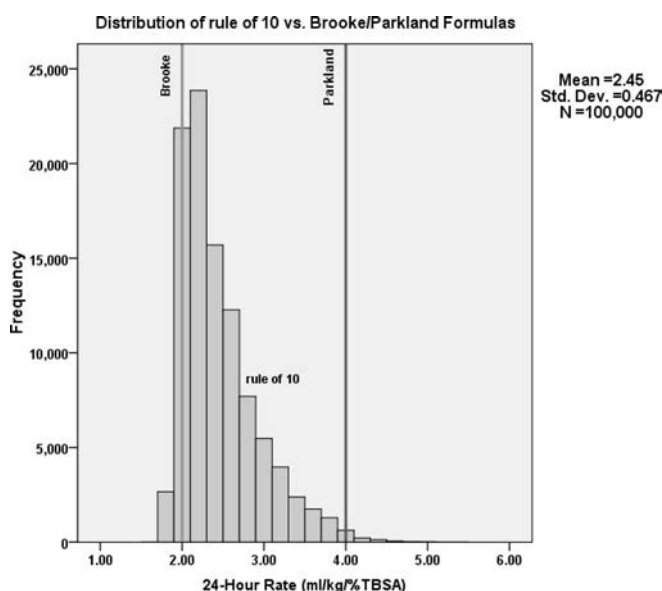


Figure 3. Categorization of rule of 10 by ml/kg/%TBSA (n = 100,000) compared with the modified Brooke and Parkland formulas in a two-dimensional graph.

(<1%, n = 658), the median difference in rate was 33 mL/hr (range, 1–213 mL/hr), with a mean %TBSA of 21% ± 1% and a mean weight of 130 kg ± 11 kg.

DISCUSSION

According to the most recent guidelines published by the ABA, the most common formulas used to estimate 24-hour fluid needs are calculated between 2 and 4 mL/kg/%TBSA.³ The number (in milliliters) is multiplied by the patient's weight and %TBSA, which determines the predicted total volume in a 24-hour period. To derive the initial fluid rate, we divide this total volume by half, with the first half of the volume to be infused over the first 8 hours. Thus, half of the total volume is divided by 8, which results in the initial fluid rate. For these traditional formulas, four separate variables are used in the derivation (time, weight, surface area, and volume) with a minimum of four computations that need to be performed. Bhat et al.⁵ recently reported that of ~200 physicians surveyed, only 26% could accurately recall a recognized burn formula. Thus, they called for a more simplified guideline for those with less experience in burn care. For prehospital providers caring for multiple casualties simultaneously as sometimes encountered in military combat operations or civilian disasters, these formulas are too cumbersome to perform and thus are often abandoned.^{6–9} A simple formula that helps a provider most rapidly determine a reasonable starting point in burn resuscitation is likely to be used more consistently. A sample patient comparing the calculated initial rates derived by the MB, PL, and rule of 10 is provided in Figure 4.

Several recent reports have emphasized that the primary purpose for traditional formulas in practice is simply to derive a reasonable starting point.^{2,10,11} The rule of 10 does just that by enabling providers to derive the initial fluid rate

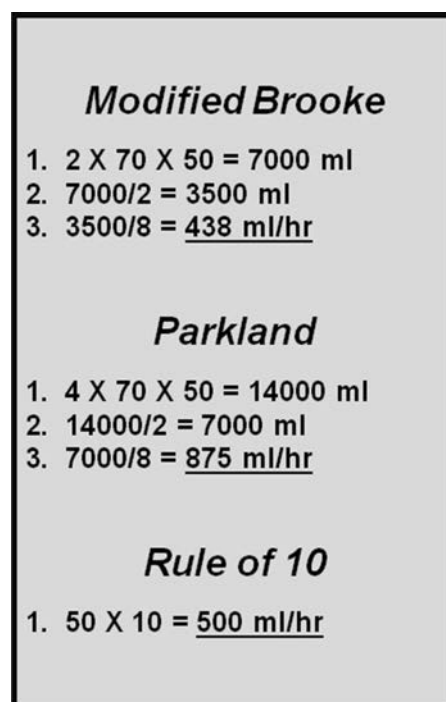


Figure 4. Comparison of initial fluid rate calculations for an adult weighing 70 kg with a 50% TBSA burn using the Modified Brooke, Parkland, and rule of 10.

in just two easy steps. The %TBSA is multiplied by 10, which determined the initial fluid rate in milliliters per hour. In those that exceed 80 kg, for every 10 kg above 80, 100 mL/hr is added to the rate. In this in silico validation of 100,000 simulations, we have demonstrated that for the majority of patients (87.8%), this simple formula derives a reasonable starting point for the resuscitation. Once initiated, fluid resuscitation must ultimately maintain end-organ perfusion by gradually restoring fluid balance while simultaneously replacing insensible losses and avoiding the consequences of both under- and overresuscitation. As many authors have indicated, optimal care of the burn patient during the resuscitation requires a bedside clinician titrating fluid therapy based on a compilation of various end points centered on a goal of maintaining a urine output of 0.5 mL/kg/hr to 1.0 mL/kg/hr or 30 mL/hr to 50 mL/hr.^{2,11–13}

Two main issues in our analysis warrant close scrutiny. First, it is clearly evident in Figure 5 that a significant majority of those simulated patients who fell between the MB and the PL favored the MB in mL/kg/%TBSA units. In other words, using the rule of 10 will favor an initial rate that is closer to a MB formula derived rate in a large percentage of patients. This is most likely of little clinical consequence and may even be advantageous and result in less total fluid given at the 24-hour mark. Our group recently reported that “fluid begets more fluid,” as those who were initiated on a fluid rate determined by the MB formula ended up with 3.8 mL/kg/%TBSA resuscitation, whereas those initiated on a fluid rate determined by the PL formula ended up with a 5.9 mL/kg/%TBSA resuscitation.¹⁴ Thus, the higher the starting point in

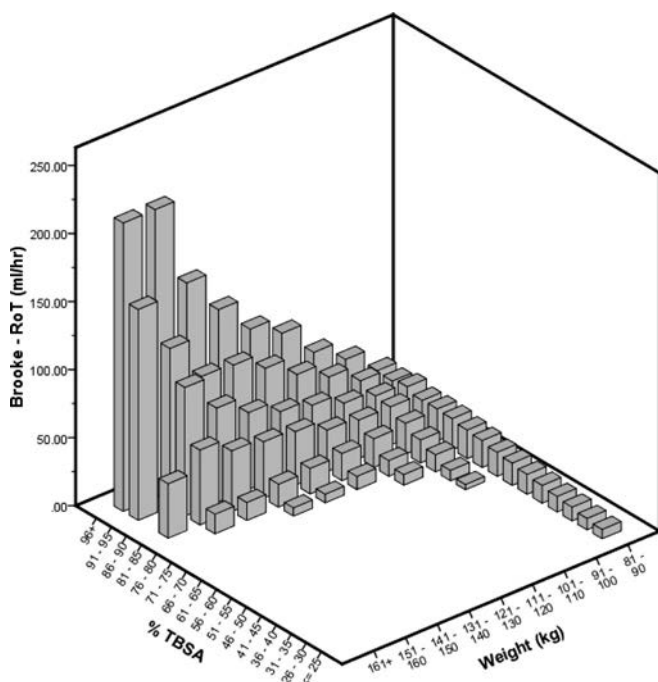


Figure 5. Differences in initial rate in those simulated patients who fell below the modified Brooke calculated rate by weight and %TBSA. The largest differences are seen among those that are >80%TBSA burns and >120 kg.

terms of initial fluid rate, the higher the final 24-hour resuscitation volume. To our surprise, however, even though the MB group received significantly fewer 24-hour volumes, there was no difference in morbidity or mortality between the two groups. The absence of any difference in outcome may be due to the fact that the initial fluid rate is only one small variable in a complex dynamic that requires an attentive bedside clinician to process simultaneously multiple variables to guide the resuscitation. These findings emphasize our earlier point that perhaps the starting point is less relevant than the actual resuscitation itself that is guided by the attentive bedside clinician.

The second issue that warrants discussion is that the rule of 10 under- or overcalculated the initial rate when compared with the rates determined by the traditional formulas over 12% of the time. In 11.5% of simulated patients, the rule of 10 derived rate fell below the MB calculated rate while going above the PL in ~0.7% of patients. All that went above the PL formula were <30% TBSA burns in those that weighed >110 kg. In addition, the median difference in initial rate was 33 mL/hr (range, 1–213 mL/hr). The likelihood of overresuscitation as defined by a 24-hour fluid volume in excess of 250 mL/kg¹⁵ is dramatically less in larger patients with smaller burns due to the fact that the absolute initial fluid volume (in mL/kg) will be less. The 11.5% who fell under the MB rate tended to be the larger burns. Among these patients, the median difference of volume for the initial rate between the rule of 10 derived rate and the rate derived by the MB formula was 14 mL/hr (range, 2–212 mL/hr). The largest differences in rate (>100 mL/hr) are seen among

those larger patients (>120 kg) with the largest burns (>80%TBSA; Fig. 5). In these combinations of weights and %TBSA, shooting slightly lower than the initial rate derived by the traditional formulas may be preferred given the massive amount of 24-hour fluids anticipated in these types of patients. Thus, the rule of 10 appropriately corrects in favor of starting lower in those most likely to require the largest 24-hour resuscitation volumes. Nevertheless, providers must be cautious as to prevent under-resuscitation by titrating subsequent volumes accordingly.

Several limitations exist in this evaluation. First, this evaluation is an *in silico* study to determine whether the initial fluid rate calculations would be reasonable in a simulated population of 100,000 burn patients with more than 20%TBSA burns. By its very nature, this study may be perceived as being inherently flawed. Second, this simulation study was based on average weights and %TBSA burns seen in one hospital. Average weights and %TBSA may differ in other hospitals and may have affected our simulation. Third, the rule of 10 is only applicable to adults who weigh >40 kg. We do not condone this formula for pediatric patients. Thus, it is not an easy “one-size-fits-all” solution, which may hinder its wide acceptance. Finally, application of the rule of 10, much like any other burn formula, is dependent on accurate burn size estimations. This may not all always be true. Thus, there is a possibility of a compounded error for the initial rate calculation. However, as mentioned previously, given that the rule of 10 only gives a starting point, a carefully titrated resuscitation based on patient response would correct this problem.

Despite being merely a simulation, however, it provides valuable insight on whether the rule of 10 will result in a reasonable starting point for a wide range of burn sizes and patient weights. It is our belief that use of this simplified formula will allow providers in the field to calculate initial fluid rates more rapidly, possibly resulting in less frustration and higher compliance, especially in a mass casualty situation where multiple calculations for multiple burned patients can overwhelm even the most experienced providers. Simplifying this mathematical process allows the provider to focus on necessary fluid rate adjustments based on the patient’s clinical response to therapy, such as urine output, etc. In 2000, Pruitt¹⁶ called for a reverse of the pendulum swing that has led to excessive resuscitation volumes and stressed the need for reassessment of resuscitation regimens. The rule of 10 allows for the provider to easily implement fluid resuscitation and then allows the focus to shift toward the patient’s response to the resuscitation to dictate the amount of fluid administered over the first 24 hours.

CONCLUSION

For the majority of adult patients, the rule of 10 approximates the initial fluid rate within acceptable ranges. The rule of 10 falls slightly under the traditional estimates for those with larger burns, which may be preferred to avoid overresuscitation, while going slightly above for those with smaller burns (likely of little clinical consequence). We recommend that the rule of 10 replace traditional resuscita-

tion formulas for the rapid derivation of the initial fluid rate for severely burned adult patients requiring fluid resuscitation in the combat prehospital setting. Traditional resuscitation formulas can still be used as a benchmark to assess the adequacy of the resuscitation post hoc. Recommendations for wider application of this formula in the civilian population await results from prospective studies.

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DISCUSSION

Dr. Timothy Nunez (US Army, Fort Sam Houston, TX): I would like to thank the Combat Casualty Care research program for the invitation to discuss this work by Chung et al. at the United States Army Institute of Surgical Research. Thank you for the privilege of the floor.

The purpose of this work by Chung et al. was to validate a simplified method of calculating the initial fluid requirement for patients with total body surface area burn >20%. The method is quite simple, which I favor, and can be computed “in the prehospital provider’s head.” They also call into question the need for the Parkland or modified Brooke 24-hour fluid requirement computations. Illustrating that what is actually needed is an IV rate to start at and then close

clinical observation. It seems easy to say that the “ISR rule of 10” will put in the ballpark of where you need to be in regard to an initial IV rate. I am pleased that their rule tends to error on the low side of volume resuscitation. As a military surgeon, I am in the choir on limited crystalloid resuscitation and applaud their efforts to avoid overresuscitation.

The method that they chose to validate their “rule of 10” deserves some attention. In silico computations or mathematical computer modeling has not been widely used in the past as a substitute for a clinical trial. The use of computer mathematical modeling has certainly been more popular in the basic science arena and in nonmedical endeavors. The use of computer modeling can greatly decrease cost and decrease the amount of time to obtain appropriate answers. An excellent example of this outside of medicine was Boeing’s development of the 777. It was completely designed using mathematical modeling and computer simulation. This obviously demonstrates an enormous benefit in safety and cost in the development of an aircraft. In medicine, this has been often used when cost and safety are at issue. Such as in genomics, biochemistry, and clinically in the critical care environment, when the actual clinical trial would be cost prohibitive, the components of the issue are excessively complex, or patient safety or accrual is an issue. The Society for Complexity in Acute Illness was formed specifically to combine the clinical world with computer simulations and mathematics to attempt to answer complex clinical questions. Again, emphasizing the obvious cost and safety of simulations, I do not see excessive cost, safety, or complexity in the calculation method the authors are trying to validate. Also, as the authors admit in the article, the model is only as good as the data that is put into the model. Therefore, we are relying on population averages and in this study only a single institution’s data. My question is why did the authors feel the need to validate their data in a complex computer model when safety and cost are not at issue? Did they consider using their data and another institution to alleviate the bias of a single institution study? I would appreciate more detail in the article on the technique of in silico, how and why it was chosen as the method of analysis.

The authors specifically wanted a simplified calculation for the prehospital provider. As well in the authors’ conclusions, they recommend replacing the traditional Parkland and Modified Brooke calculations. As everyone here knows, we are currently at war; and in wartime, the military will often field initiatives in a rapid fashion if it is of benefits to the warriors. The ISR has demonstrated that during this conflict in its changing hemostatic dressing recommendation. Have you started to pass this on to medics who are deploying or are you waiting to validate this in a prospective manner, what are your plans? Will you incorporate this into combat medic training at Fort Sam Houston?

I do like the simplicity of this rule and will likely add it to my clinical toolbox on my next deployment. I am in complete agreement with the authors that the need to calculate a 24-hour fluid requirement is not what is needed but we need a starting point and then a clinician to follow the patient closely.

I would like to thank the authors for the timely delivery of the article well in advance of the meeting. I would also like to congratulate them on another significant contribution from one of the world's finest Burn Centers.

Kevin K. Chung, MD (US Army Institute of Surgical Research, Fort Sam Houston, TX): Thank you, Dr. Nunez, for your insightful comments. The rule of 10 is merely a simple way to derive the initial fluid rate for severely burned adults. It has little to do with the process or the "art" of resuscitation. The purpose of our current study was to establish that the rule of 10 would derive an acceptable initial rate over a wide range of burn sizes and patient weights. This *in silico* design was sufficient to answer our primary question with sufficient power. Although most *in silico* studies require complex algorithms to predict a given outcome, our methods were quite rudimentary. The "simulation" generated 100,000 different combinations of weights and %TBSA with a distribution similar to a population similar to our patients. For each of these "simulated patients," the initial fluid rates were calculated using the modified Brooke, the Parkland, and the rule of 10. These initial rates were compared to determine how well the initial rate derived by the rule of 10 "fit" between the initial rate derived by the modified Brooke and

the Parkland. Does the rule of 10 estimate an initial rate that fits between the boundaries set by the traditional calculations? Our answer is yes.

On the other hand, if the question is, "Does this make a difference clinically when compared with the status quo in terms of total volume infused or other hard endpoints?" The answer would be "we don't know." We doubt that any given starting point that fits within a conventionally accepted boundary would result in any difference in outcomes assuming that there is no difference in the method of resuscitation. It is possible that this method of calculating the initial fluid rate, because of its simplicity, will result in a higher compliance rate to current standards among prehospital providers. Regardless, prospective clinical trials will be necessary to sufficiently answer these questions.

In the meantime, we have already pushed this method of calculating the initial fluid rate out to the military medical community and plan to incorporate it into standard military burn care training. Based on our current study, this method does not veer from the current practice standards. We have appropriately taken the emphasis out of a calculation and have placed it where it needs to be; the careful hourly titration of fluids based on patient response.