Graphic Aids for Calculation of Fluid Resuscitation Requirements in Pediatric Burns

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Abstract: The Parkland formula is currently the most widely used protocol to guide fluid resuscitation of acute burns and has been adapted for pediatric use. We describe 3 novel graphic devices (a nomogram, slide rule, and disc calculator) based on this formula, which have significant advantages over existing graphic and electronic devices. The robust low-cost graphic devices would be particularly suited to developing countries and difficult locations, but could be used as the primary means of calculation in any environment. If a computer or calculator is used as the primary means of calculation, the graphic devices provide a simple and rapid means of checking and preventing errors that may arise because of inadvertent miskeying of data or incorrect application of the pediatric Parkland formula.

Key Words: burns, resuscitation, fluids, Parkland formula, nomogram, slide rule, disc calculator

(*Ann Plas Surg* 2012;69: 260–264)

BACKGROUND

The aim of fluid resuscitation in acute burns is to maintain adequate organ perfusion and prevent extension of the burn injury, while avoiding the complications of underresuscitation or overresuscitation.

Inadequate fluid resuscitation results in tissue hypoperfusion, which causes extension of the zone of stasis and burn injury. It is also associated with organ hypoperfusion and multiple organ failure. Excessive fluid resuscitation ("fluid creep") results in tissue edema and hypoxia, and may cause impaired wound healing and conversion of partial thickness to full thickness burns.[1] Systemic effects include acute respiratory distress syndrome,[2,3] pulmonary edema,[4] compartment syndrome of the abdomen and extremities, airway obstruction, and increased incidence of tracheostomy.[5,6]

The optimal volume, type, and protocol for administration of resuscitation fluids remain controversial; however, all protocols in common use calculate resuscitation fluid requirements based on the patient's body weight (BWt, kg) and percentage of total body surface area burned (TBSA, %). A crystalloid-based strategy that uses the Parkland formula[7] (Text Box 1a) has been increasingly adapted and is currently the most commonly used worldwide.[8,9] The original Parkland formula has been modified for pediatric use by decreasing the volume of resuscitation fluid (as Hartmann solution) from 4 to 3 mL/kg/% TBSA, and by the addition of maintenance fluids (as Hartmann solution; or 4% dextrose in 0.18% sodium chloride, "D-Saline") based on BWt[6,10,11] (Text Box 1b).

Received December 15, 2011, and accepted for publication, after revision, April 2, 2012.

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Conflicts of interest and sources of funding: none declared.

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ISSN: 0148-7043/12/6903–0260
DOI: 10.1097/SAP.0b013e3182586d4e

a. The Parkland formula for adults.[6,7]

Resuscitation fluid:

VTBI/24 hours = 4 mL × BWt (kg) × TBSA (%)

50% given in first 8 hours from time of burn ("First Period")
50% given in subsequent 16 hours ("Second Period")

Given as Hartmann solution (Ringer lactate)

Subtract any fluid already received from amount required for First Period

b. The Parkland formula adapted for pediatric burns (after Hettiaratchy and Papini[6] and Fodor et al[11]).

Resuscitation fluid:

VTBI/24 hours = 3 mL × BWt (kg) × TBSA (%)

—given as adult formula as previously mentioned.

Plus Maintenance fluid at a rate of:
4 mL/kg/h for the first 10 kg BWt
+ 2 mL/kg/h for the second 10 kg BWt
+ 1 mL/kg/h for > 20 kg BWt

Given as D-Saline or Hartmann solution.

Numerous aids to calculation of burns fluid resuscitation requirements have been described previously[10,12–20]; however, many of these simply indicate the total volume of resuscitation fluid to be infused during the first 24 hours postburn rather than the actual rate of fluid administration (mL/h) in each period. They do not calculate the volume or infusion rate of the additional maintenance fluids, which are required for resuscitation of pediatric burns; they do not include adjustment for the variable delay between the time of the burn injury and commencement of the first resuscitation period; and they do not make allowance for any resuscitation fluids which may have been administered by the referring hospital or emergency services before admission to the receiving hospital.

These calculations can be performed with the aid of electronic devices such as a calculator, computer, or smart phone. However, graphical devices have the advantages of being low cost and robust, do not require an electric power supply, and are unaffected by electromagnetic interference, which makes them particularly suitable for use in developing countries and difficult environments. They are also resistant to data entry errors caused by inadvertent miskeying of data, because all input and output scales are confined to values within the clinical range. Correct data entry may be readily confirmed by performing the calculation in reverse graphically: this is extremely difficult to do using other systems.

Tables based on the Parkland formula have been described to perform these calculations in adults[13,16,17]; however, they are inflexible, and the discrete values can introduce rounding errors. This is not a problem with graphic methods, which use continuous scales. Furthermore, the scales are logarithmic, which provide increased precision at the more clinically significant lower end of the data range.

The author has previously described 2 Parkland formula nomograms (graphical charts) for resuscitation of adult and pediatric patients[21]; and these have subsequently been refined to improve accuracy and ease of use. A specialized slide rule has been described to aid calculation of fluid resuscitation in both adult and pediatric burns[15] based on the Muir and Barclay[22] formula; but a similar device has not been described to perform these calculations using the Parkland formula.

We have therefore developed an improved nomogram, slide rule, and disc calculator (a slide rule in a circular format) for resuscitation of pediatric burns based on the Parkland formula.

METHODS

Construction

The modified Parkland formula was converted into a graphic format using the techniques of functional scales and matrix determinants.[23–28] Plotting and typesetting of the logarithmic scales were aided by the use of software (Excel, Microsoft Corp, Redmond, WA; PyNomo; Rhinoceros3D, McNeel North America, Seattle, WA; Illustrator, Adobe Systems Inc, San Jose, CA). Principles of good graphic design and typography were applied to optimize legibility and usability.[29–32]

In response to user feedback, the original pediatric nomogram[21] was completely redesigned to optimize legibility, remove all extraneous scales and information, and simplify the procedure for use. The nomogram and instructions were ink-jet printed directly onto A4 waterproof paper ("ToughPrint"; EVO Distribution Ltd, Aldermaston, UK); with a pediatric chart of Lund and Browder[33] chart for estimation of TBSA (%) on the reverse (Fig. 1).

In the case of the slide rule and disc calculator, the scales and a summary of instructions for use were ink-jet printed onto self-adhesive vinyl sheets ("Creative Sticker"; Photo Paper Direct, London, UK), sprayed with protective matte sealant and affixed to plastic blanks (Fig. 2). Copies of the pediatric Lund and Browder[33] chart were printed on self-adhesive vinyl and affixed to the reverse of both devices.

The slide rule blanks (255 × 60 × 4 mm) were made from 2-mm-thick ABS sheet with a 45-degree chamfer between the fixed and sliding components. Scales were oriented on the blanks by aligning their origins, and the alignment was subsequently checked with a series of example calculations. The rotating component of the

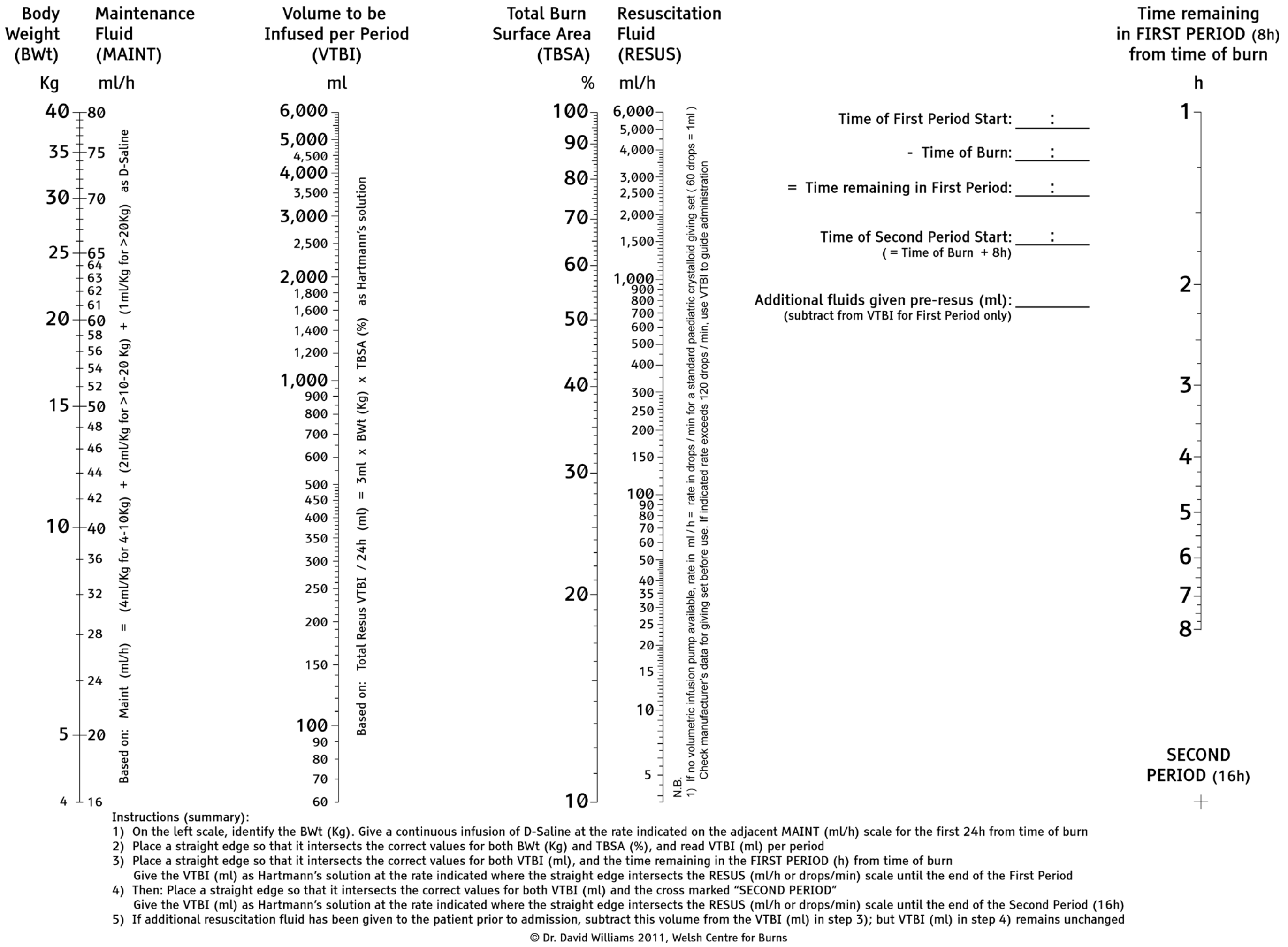

FIGURE 1. An improved Parkland formula nomogram for resuscitation of pediatric burns (after Williams[21]).

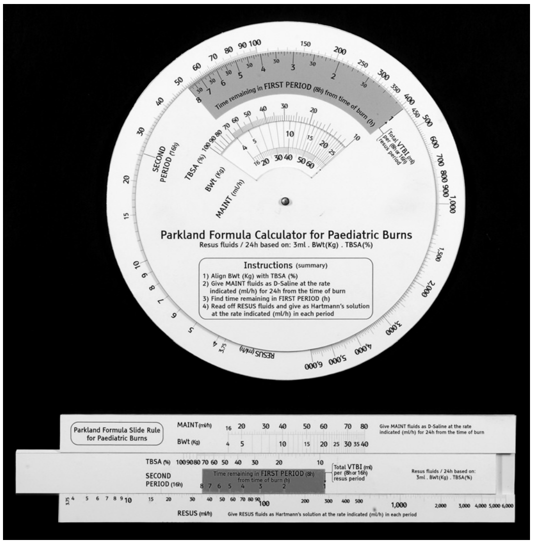

FIGURE 2. Parkland formula slide rule and disc calculator for resuscitation of pediatric burns.

disc calculator was constructed from a 168-mm diameter, 0.5-mm-thick disc with a sector cut away to allow the underlying fixed scale to be read. The fixed component was made from a 200-mm diameter, 2-mm-thick disc, and the 2 components were joined with a central 5-mm rivet, spacer and washer. The longest scale length (“RESUS,” mL/h) was arranged on the periphery of the disc. This allowed for wider spacing of the scale graduations, which improved accuracy; and a larger font size, which improved legibility.

Procedures

Nomogram

The user locates the patient’s BWt (kg) on the left hand scale, and reads the rate of administration of maintenance fluid (MAINT, mL/h) from the adjacent conversion scale. This is given as Hartmann solution or D-Saline and continued for the first 24 hours from the time of the burn injury. The user then aligns a straight edge (“isopleth”) between the BWt (kg) scale and appropriate point on the TBSA (%) scale, and reads the volume of resuscitation fluid, given as Hartmann solution, to be infused in each (8 or 16 hours) period (VTBI, mL). A second placement of the isopleth between the VTBI (mL) and time remaining in the first (8 hours) period scales indicates the correct rate of resuscitation fluid administration (RESUS, mL/h) for the remainder of the first period. A third placement of the isopleth from the VTBI (mL) scale to the cross at the bottom right indicates the subsequent rate of resuscitation fluid (RESUS, mL/h) for the second (16 hours) period.

If additional resuscitation fluid has been given to the patient during the first period, before admission to the receiving hospital, this volume is subtracted from the VTBI per period (mL). The isopleth is then placed between this new point and the number of hours remaining in the first period to give the corrected infusion rate for the first period. The original VTBI and infusion rate for the second period remain unaltered (Fig. 3).

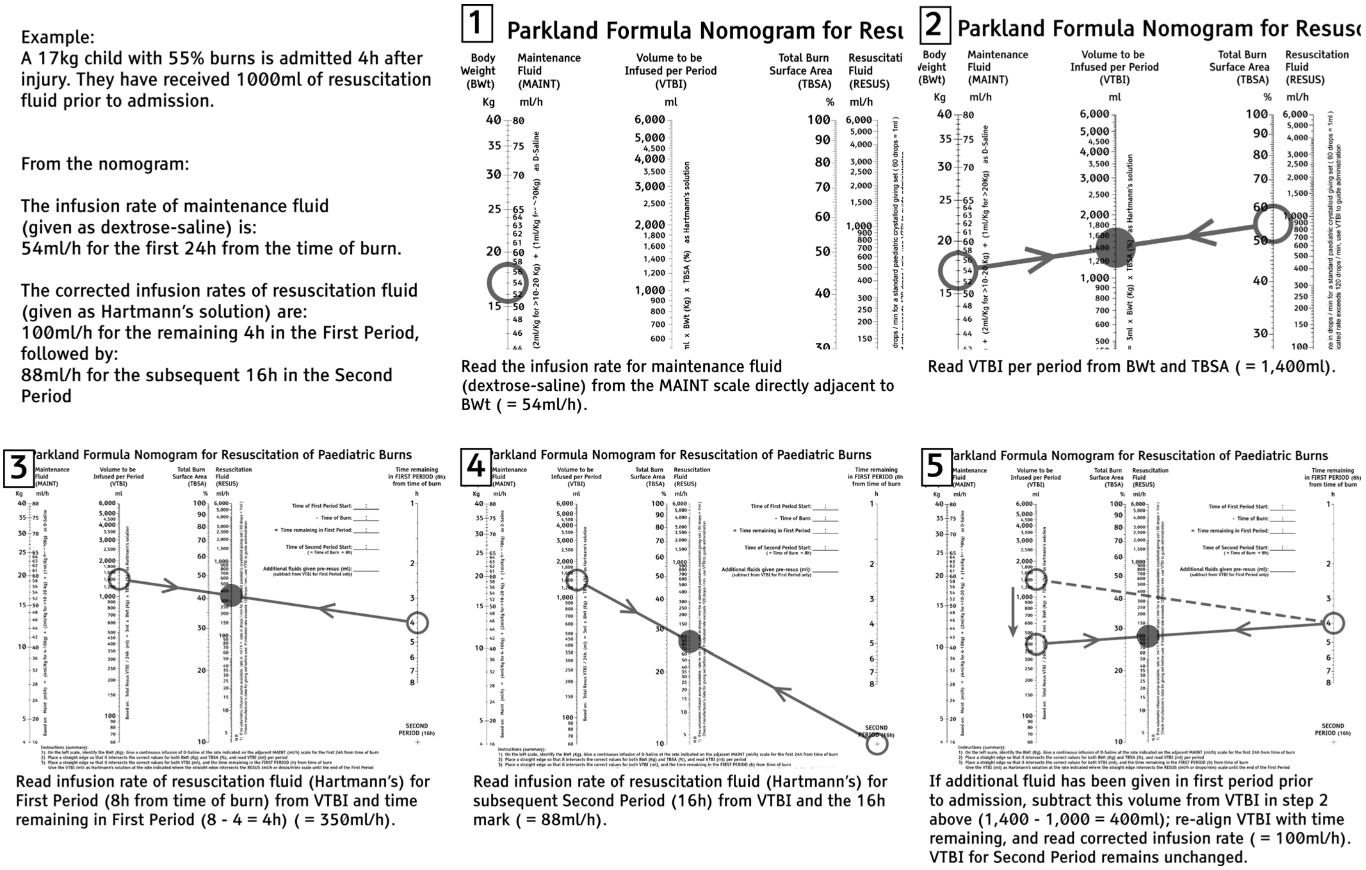

FIGURE 3. An example calculation using the Parkland formula nomogram for pediatric burns.

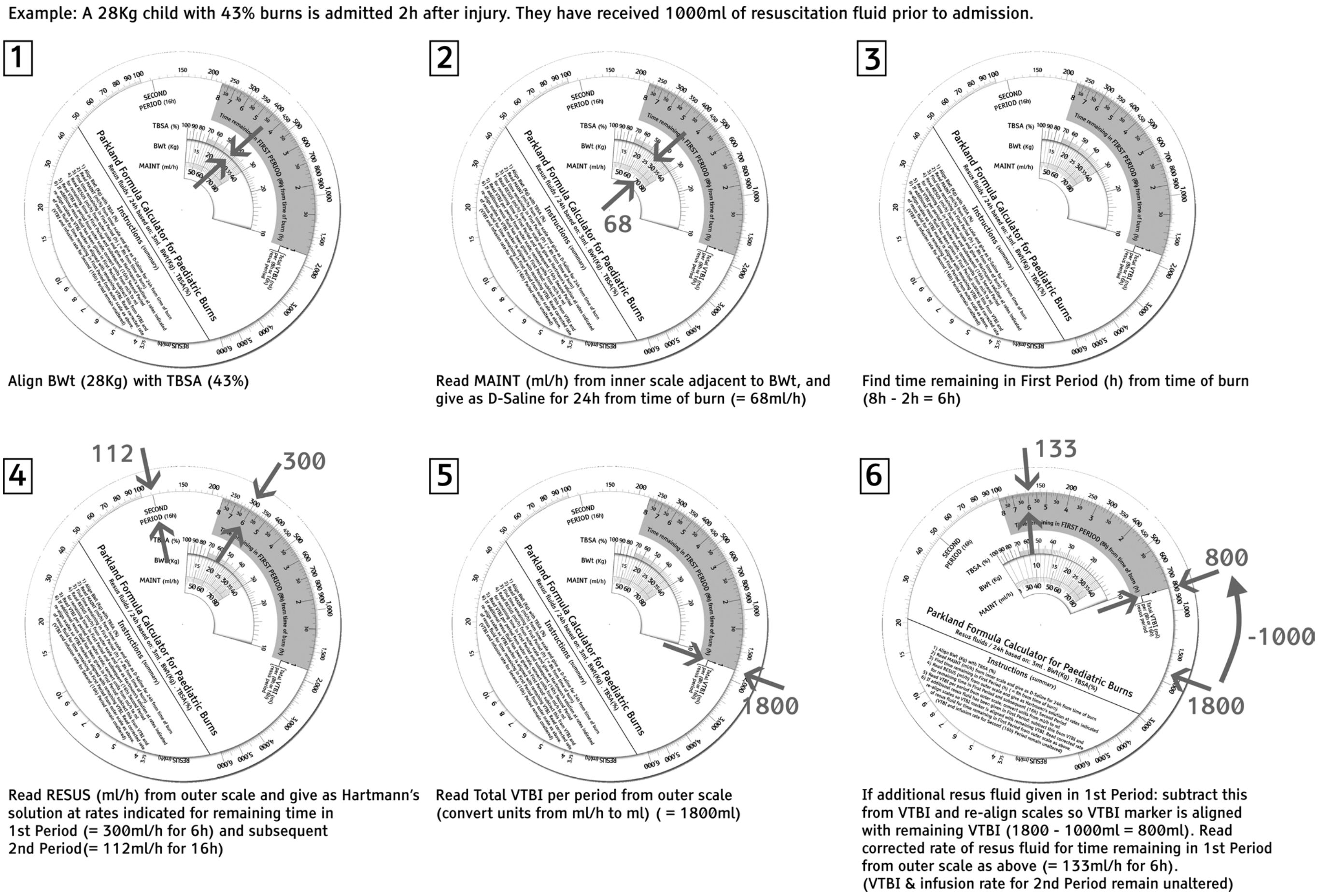

FIGURE 4. An example calculation using the Parkland formula disc calculator for pediatric burns.

The nomogram is constructed so that users work from left to right. Before reading the result from the intervening scale, users should double check that the position of the isopleth against the left-hand scale has not inadvertently moved during the process of aligning the isopleth with the right-hand scale. It is recommended that a transparent isopleth with a central hairline graticule is used to avoid parallax error and allow accurate reading of the scale markings.

Slide Rule and Disc Calculator

The user moves the slide or rotating disc so that the BWt (kg) aligns with the appropriate TBSA (%) and reads the appropriate rate of maintenance fluid (MAINT, mL/h) from the adjacent BWt (kg) scale on the upper scale of the slide rule or innermost scale of the disc calculator. The rate of resuscitation fluid administration (RESUS, mL/h) for the first (8 hours) period is then read from the appropriate point on the "Time remaining" scale, and the rate for the second (16 hours) period is read from the marker, against the lower scale of the slide rule or outermost scale of the disc calculator.

The total VTBI for each (8 or 16 hours) period may be found by keeping the scales in position, reading what the RESUS infusion rate (mL/h) would be if the VTBI were to be given over 1 hour, then changing the units from milliliter per hour to milliliter. If additional resuscitation fluid has been given to the patient during the first period, before admission to the receiving hospital, this volume is subtracted from the indicated VTBI per period (mL). The slide or disc is then moved so that the "1 Hour" marker is aligned with the remaining VTBI (mL). The corrected rate of resuscitation fluid administration (mL/h) in the first (8 hours) period is then read from the appropriate point on the "Time Remaining" scale as previously mentioned. The original VTBI and infusion rate for the second (16 hours) period remain unaltered (Fig. 4).

For all 3 devices, if an indicated value falls between 2 of the numbered scale markings, users should interpolate the value based on their estimation of a logarithmic scale rather than a linear scale. If no volumetric infusion pump is available, the rates indicated by the RESUS (mL/h) and MAINT (mL/h) scales are equivalent to the drip rates in drops per minute if the fluid is given via a standard pediatric crystalloid giving set (60 drops per mL). However, users should check the drip set specification carefully and use the VTBI as an additional guide to administration of resuscitation fluid, especially at high flow rates where it may be difficult to accurately count the number of drops per minute.

DISCUSSION

A pilot study showed that all 3 graphical devices were easy and intuitive to use, and gave results to a clinically acceptable degree of accuracy (error, <1%). The speed of calculation was the same as or faster than that achieved using an electronic calculator.

Compared to the slide rule and disc calculator, the nomogram has no moving parts, is extremely cheap to produce (by printing or photocopying); and is very robust if printed on plastic slates or waterproof paper. Paper copies of the nomogram may be annotated and incorporated into patient notes to provide a written record of the calculations. An advantage of the slide rule and disc calculator over the nomogram is that user only has to align the scales once to find the VTBI and infusion rates of maintenance and resuscitation fluids for both first and second periods: with the nomogram, 3 placements of the isopleth are required, each of which could potentially incur an error. Both the slide rule and disc calculator have only 1 moving and 1 fixed component. The mechanism of the slide rule was more robust; however, many users found the format of the disc calculator to be more intuitive.

Graphical methods for calculation of the pediatric Parkland formula have potential advantages over existing graphic and electronic techniques, including low cost, robust design, and speed of calculation.

Although particularly suited for use in difficult environments and developing countries, these devices could be used in any emergency department or burns unit as the primary method of calculation. The graphical devices may also be used with existing technologies (calculators, computers, and smart phones) as a means of rapidly confirming that a calculation error has not inadvertently occurred because of miskeying of data or incorrect application of the formulae.

Our methodology could be readily adapted to design graphic devices, which are based on other protocols for burns fluid resuscitation (eg, Mount Vernon, Evans, and Brooke[11,28]). However, it is important to remember that all formula-based resuscitation protocols only represent a starting point, and that ultimately resuscitation fluids should be titrated according to clinical response; which in children includes hemodynamic stability and a urine output of 1 to 1.5 mL/kg/h.[6,11]

ACKNOWLEDGMENTS

The authors thank Leif Roschier for developing the PyNomo software that was used to aid calculation of the slide rule scales; and Lincoln Grove for construction of the plastic blanks.

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