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A 1% TBSA Chart Reduces Math Errors While Retaining Acceptable First-Estimate Accuracy

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Life-threatening and treatment-altering errors occur in estimates of the percentage of total body surface area burned (%TBSA burned) with unacceptable frequency. In response, numerous attempts have been made to improve the charts commonly used for %TBSA-burned estimation. Recent research shows that the largest errors in %TBSA-burned estimates probably come from sources other than inaccurate values in the charts. Here, we develop a taxonomy of the possible sources of error and their impact on %TBSA-burned estimates. Also, we observe that different caregivers have different estimation needs: First-responders require a rapid estimate with sufficient accuracy to enable them to begin care and determine patient transport options, while burn surgeons ordering skin grafts desire accuracy to the square centimeter, and can afford considerable time to attain that accuracy. These competing needs suggest that a one-tool-fits-all-caregivers approach is suboptimal. We therefore present a validated, simplified burn chart that minimizes one of the largest sources of random errors in %TBSA-burned estimates—simple calculation errors—while also being quick and requiring little training. NCHart-1 also enables simple consensus estimates, as well as separation of estimation subtasks across caregivers, leading to several potential improvements in mass casualty situations. Our results demonstrate that NCHart-1 possesses the accuracy necessary for first responders, while reliably producing results in less than 2 minutes. Of 76 healthcare professionals surveyed, a large majority indicated a preference for NCHart-1 over their previous methods for ease of both use and training. For clinical or commercial use of NCHart-1, please contact: tech.commercialization@nationwidechildrens.org

An accurate assessment of the percentage of the total body surface area affected by a burn injury in children is essential to provide appropriate burn care. The estimated %TBSA affected by a burn directly affects the calculation of resuscitative fluid, rate of feeding, and resources needed to provide appropriate burn care.^{1–3} Inaccuracy in %TBSA estimates can result in suboptimal care whether it is the first responder who needs to quickly determine whether a burn exceeds the

TBSA threshold requiring initiation of the Parkland fluid resuscitation protocol or other burn-size-dependent protocols such as transport to a specialty burn treatment center, a local trauma facility that needs to validate incoming %TBSA estimates, or a specialty burn center that needs accurately documented burn size for complexity of care.

Large %TBSA burns generally require continuous administration of fluid resuscitation as calculated by the Parkland or other burn formula. Likewise, it is recommended that pediatric patients with burns exceeding 10%TBSA be transported to specialty burn treatment centers.^{4–7} Over-resuscitation can result in compartment syndromes of all of the natural body spaces and pulmonary edema.^{8, 9} Under-resuscitation can result in conversion of the burn to deeper tissues and kidney failure or multiple organ failure.¹⁰ Significant over-resuscitation cannot be simply titrated out by observing urine output and decreasing fluid. Instead, fluid resuscitation must be carefully adjusted over time, often by initially increasing rather than decreasing fluid rate.^{11, 12} These factors and more, along with the simple importance of providing the best possible care at each stage of a patient's treatment, argue for reducing errors in early %TBSA estimates, rather than relying on later, more careful estimates to fix the problem.

In recognition of the importance of accurate %TBSA estimates, the eponymous Lund and Browder (L&B) charts were created to assist with %TBSA estimates at different ages.¹³ Their work in creating tables of relative regional body surface area percentages for individuals at 1, 5, 10, and 15 years of age embodies an implicit understanding that minimizing errors in %TBSA estimation requires use of reference charts that are matched to individuals' body proportions.

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While a customized chart that is specific to a specific individual's personal body measurements would be the "perfect" tool for making %TBSA estimates for that individual, standardized charts are necessarily based on population averages, and so in an effort to decrease errors, there has been a proliferation of L&B-like charts and estimation formulas adapted to specific segments of the population. Of concern, none of these have eliminated the occurrence of %TBSA estimation errors of magnitudes sufficient to negatively affect care and outcomes.^{1, 5, 9, 14, 15}

As portable digital devices have become pervasive, there have been attempts to address the inaccuracy of %TBSA estimates with technology. These attempts are exemplified by the flagship product BurnCase 3D.¹⁶ These attempts generally take the approach of using a digital device—smartphone, tablet, or computer—to present a representation of the patient's body, a representation that we will call a "digital twin." The user is then prompted to indicate burned areas on the digital twin, and the calculation of the affected %TBSA is accomplished from these indicated areas automatically.

While BurnCase 3D has been robustly demonstrated to be capable of exemplary accuracy (with some caveats to this demonstration, discussed below), it has also been robustly demonstrated to be quite slow in application. Estimates that can be created in seconds with L&B-like approaches can take several minutes with BurnCase 3D, even for relatively small burns (approximately 5 minutes with a standard deviation of 4 minutes, for burns averaging less than 15%).¹⁷ Other digital solutions that attempt to simplify the process do not necessarily enjoy the significant accuracy benefit of BurnCase 3D,¹⁸ and based on experience in our burn clinic, sometimes produce estimates that are dramatically worse than even the poorest estimates from L&B-like approaches: We have observed some products counting an entire L&B region such as the 13% torso as burned, if any portion of it is marked as burned.¹⁸ A survey of smartphone apps for calculating fluid resuscitation volumes based on a standardized burn, found applications recommending a first 24-hour volume of anywhere between 600 ml above, and 2700 ml below the appropriate volume. Less than 2/3 of the apps surveyed produced results that correlated with the standard value.¹⁸ Based on these observations, it should not be assumed that "digital" means accurate, or better, in assessments for burn treatment.

It is worth noting that the relative accuracy and magnitude of errors in the various approaches to estimating affected %TBSA say something interesting about how and where errors occur in the estimation process. These data suggest that errors in %TBSA estimates derive from at least seven different sources. Applying the methodology of Viswanathan¹⁹ for error analysis, we have created a taxonomy of these error sources and analyzed their common impacts on %TBSA-burned estimates. This taxonomy and its use to focus effort on specific varieties of error in %TBSA-burned estimates are broken out and discussed more explicitly in [Table 1](#) and the Methods section.

Previous work demonstrates that the persistence of large errors in %TBSA estimates is unlikely to result from a systematic deviation of body morphology (eg, increasing obesity) from that of the population used to create the de facto-standard tables of regional percentages for different areas of the body.²⁰

The L&B table, originally created in the 1940s, appears to remain acceptably faithful to pediatric body regional areas. Both extremely obese and extremely thin individuals have regional body percentage areas that are close to those predicted by L&B, and errors induced by individual-to-individual variation (eg, having proportionally longer or shorter legs) cause much more significant deviations from the L&B predicted values than does obesity or emaciation. Moreover, both the systematic errors and individual morphological variation are small compared to the magnitude of actual errors in %TBSA estimates that are seen by burn care centers for incoming burn victims.^{21–23}

Rumpf et al²⁰ demonstrated that the prevalence of large random errors in %TBSA estimates cannot be explained by systematic error. In this work, we demonstrate that Calculation Error, previously unaddressed, is a significant contributor.

In light of the importance of minimizing calculation errors, we introduce a new chart-based system for assessing %TBSA burned. This chart, named NCHart-1, uses regional percentages from the traditional L&B chart, but reduces the complexity of the calculations required to produce an estimate from the chart.

Because NCHart-1 parcels the opportunity for different errors to enter the estimate into different steps, several additional benefits can also be realized from its approach: It enables easy cross-checking of %TBSA-burned estimates and detection of where errors occurred; it facilitates consensus estimates; and, it enables division of labor so that, for example, highly experienced experts can focus solely on identifying burned/unburned regions, while leaving the other tasks of producing a numeric estimate to other caregivers.

Our data, gathered from 157 individual caregiver assessments of a burn simulation, across a broad swath of experience levels, demonstrate that regardless of experience, users of NCHart-1 produce %TBSA-burned estimates with smaller average error, and also a smaller standard deviation, than users of the L&B chart. NCHart-1 users also produce these estimates consistently faster than users of the L&B chart.

MATERIALS AND METHODS

A Taxonomy of Errors in %TBSA-Burned Estimation

For many years there have been attempts to reduce the effect of errors in %TBSA-burned estimates by creating "L&B-like" regional percentage charts with updated values. Some of these have attempted to address a perceived drift in the average regional %TBSA of the modern population and so have created new charts intended for general use, while others have created new charts adapted for specific (eg, obese) populations.

Despite these efforts, improving the accuracy of %TBSA-burned estimates remains an important topic in the burn community, and so we turn our attention to understanding how errors occur in these estimates.

Critical to this analysis, Redlarski et al²⁴ note that in the large history of attempts to improve body surface area estimates, most produce improved values with the sample population on which they were developed and larger average error when applied to other populations—even other populations with similar height/weight characteristics. This strongly suggests that systematic morphological variation due

Table 1. A taxonomy for error categories occurring in %TBSA-burned estimates

Source of Error	Example	Practical Effect	Mechanism of Impact	Remedies
<p><i>Table Error:</i> Systematic, additive Inaccurate standard values in a chart or process</p>	<p>Mistranscription of the original L&B table values that occurred in the 1950s, resulting in many published tables after that period having incorrect values for the hand, with many having area totals over 100%.</p>	<p>Multiple assessments of an individual produce identical, identically wrong estimates.</p>	<p>Identical, systematic impact on all burns involving the entire affected area, regardless of body morphotype.</p>	<p>Use a table that contains correct values for the population to which the patient belongs.</p>
<p><i>Morphological Error:</i> Random, generic (though possibly systematic, correlated for morphotype “classes”) Differences between an individual’s regional %TBSA contributions and the population averages from which a table or process was made.</p>	<p>Individuals with “long torsos” (regardless of obesity) can have as much as 19% of their TBSA occupied by their anterior trunk, as compared to the L&B population, where only 13% is assigned to the anterior trunk in juveniles.</p>	<p>Multiple assessments of an individual produce identical, potentially identically wrong estimates.</p>	<p>Any given individual will have the contribution of burns affecting some body regions randomly over or underestimated. Systematic over/underestimation may be observed for individuals with shared body morphotypes (eg, comparatively long torsos).</p>	<p>Errors can be reduced by the development of a suite of tables that addresses population morphotype differences with more granularity than provided by L&B.</p>
<p><i>Process Error:</i> Systematic, additive Some assessment approaches can have errors built into the process.</p>	<p>Approaches that break the body into regions and count the entire %TBSA of a region if any area within that region is burned, inherently produce overestimates as a result of the process.</p>	<p>Multiple assessments of an individual produce identical, identically wrong estimates. All other factors being equal, assessments of the same individual with different tools produce different values.</p>	<p>Varies depending on the process, likely systematic, affects identical assessments identically.</p>	<p>Depending on the error, either the process can be corrected, or dependent processes and calculations can be adapted to the presence of the error.</p>
<p><i>Assessment Error:</i> Random, generic, and systematic Inaccuracy in determining burned (second/third degree) vs unburned skin surface</p>	<p>First-degree boundary regions around second- or third-degree burns counted as partial- or full-thickness burns for fluid resuscitation calculations.</p>	<p>Multiple assessments of an individual will produce different values. Assessors with more experience in burn assessment produce smaller errors.</p>	<p>Typically small generic random errors with a (generally) normal distribution around the true %TBSA value. For a given assessor, there is a correlational systematic scaling of the error dependent on the burn perimeter to burn area ratio. Some assessors may systematically “err on the side of caution” when deciding whether a burn is first vs second degree, etc.</p>	<p>Training: Experience with burn assessment reduces error.</p>

Table 1. Continued

Source of Error	Example	Practical Effect	Mechanism of Impact	Remedies
<i>Assignment Error:</i> Random, generic. Systematic cor- relational within assessors	In “sketch the burn” sys- tems, there is a time/ accuracy tradeoff in representing the boundaries of the burn.	Multiple assessments of an individual will produce randomly different values. Assessors with more expe- rience with the tool pro- duce smaller errors.	Typically small random errors with a (generally) normal distribution around the true %TBSA value. For a given assessor, error scales (generally)	Training and as- sessment time: Experience with the tool reduces errors. Realistic expectations re- garding the
Inaccuracy in representing the assessed burn using the %TBSA estimation tool			proportionally with the size of the burn and inversely with the time devoted to representing the burn in the tool.	time required to complete an assessment accu- rately (and appro- priate use of that time) increase accuracy.
<i>Intentional Error:</i> Systematic, corre- lational (?) Inaccuracy in assessing or representing the assessed burn, presumably in- tended as a safety factor.	Intentionally assessing all reddened skin as partial- or full thickness because of a belief that an over- estimate of the %TBSA is erring on the side of caution.	Multiple assessments of an individual will produce randomly different values typically greater than the true %TBSA occupied by the burn.	Random errors on the pos- itive side of the true %TBSA value. Empirical data suggest that these may be neither normally distributed nor small. Smaller burns are more af- fected than larger burns.	Training (?): Inad- equate research has been done on intentional errors in assess- ment; however, the fact that the preponderance of observed errors is positive suggests that this error sig- nificantly affects %TBSA estimates.
<i>Calculation Error:</i> Random, idiosyn- cratic, also pos- sibly systematic, additive Mathematical inaccu- racy in reporting %TBSA estimates as a result of simple calculation errors.	A burn that occupies 2/3 of a 13% frontal torso, and half of a 17% upper leg, might be added as 27% due to difficulty in simultaneously dealing with fractions and percentages, or a mis- taken doubling of the carry digit.	Multiple assessments of an individual will produce randomly different values. Assessors with minimal experience in burn as- sessment and those with significant experience in burn assessment probably produce smaller errors than those with interme- diate experience (due, re- spectively, to uncertainty and more careful addi- tion, and a greater ability to “eyeball” a reasonable %TBSA estimate for cross- checking their answer).	Random errors of unpredict- able size with a complex, nonnormal distribution. Systematic errors can appear if, for example, an assessor consistently “rounds up” to make ad- dition easier.	Assessment experi- ence and human- factors-based modification of the assessment tools to minimize the likelihood of calculation errors. Additionally, tools to automate the calculation.

to factors, such as BMI, plays a smaller role in %TBSA-burned estimates than does idiosyncratic individual variation such as relatively shorter or longer legs. This suggestion is further argued for by Lund and Browder¹³ themselves, who observed that even late-term pregnancy did not affect regional %TBSA contributions as much as an amputation at the knee (5–10% TBSA, depending on age).

At the same time, in our testing of the L&B and other charts, a cohort of clinical care providers assessing a single

(simulated) burn case with the L&B chart produces estimates with a standard deviation of 11.5% and a maximum deviation of 53% TBSA from the true value. About 5% of the respondents (4 of 78) produced an estimate with an error $\geq 35\%$ of the mannequin’s TBSA. These errors *cannot* derive from systematic errors in the values contained in the L&B chart. If the errors were solely in the table values, we would have received 78 identical, systematically incorrect estimates.

These observations suggest that errors in the table values themselves are not the primary source of large errors in %TBSA-burned estimates.

Therefore, following the taxonomy and approach of Viswanathan,¹⁹ we have created a taxonomy of categories for the possible sources of error in burn estimates. These different possible sources of error, presented in Table 1, can be dichotomized into systematic and random errors, and each source has a different impact on %TBSA-burned estimates.

Correcting each possible source of error will require different strategies and will have different impacts on the distribution and magnitude of errors seen in %TBSA-burned estimates. Additionally, careful consideration of the error taxonomy reveals that the NCHart-1 process of %TBSA-burned estimation can be broken down into separate discrete tasks, which in some situations could be assigned to different caregivers. Such a change to the process of %TBSA-burned estimation would enable focusing of different caregivers' expertises on the aspects of an estimate where they are most skillful, further minimizing error.

We note that any estimate contains an error. Our aim is to reduce the frequency of errors in %TBSA estimates that are sufficiently large as to affect care and outcomes. This can be accomplished by reducing the average error and variance in %TBSA estimates, reducing the incidence of large errors in %TBSA estimates, or both.

Errors in estimates arise from everything that is done to produce the estimate, including both the burn-estimation tool and the caregivers using it. In this situation, tradeoffs are inevitable, as a chart that approaches perfection may be so complex as to cause errors in its application, and a method that is so simple as to be universally applied without any mistakes may give up accuracy to attain simplicity.

Broadly, errors in estimates can be random or systematic. Reliable or consistent estimates are low in random error, and valid or accurate measures are low in both random and systematic errors.

Random errors can be further classified as generic, affecting a relatively large proportion of estimates, or idiosyncratic, that is, affecting a small proportion.

Translated to %TBSA estimation, any given individual's thigh may comprise a larger or smaller percentage of their TBSA than the L&B tabular (5- to 9-year old, front plus back) 8%. The affect that this difference has in the estimation of %TBSA burned for that individual will affect any estimate and is therefore best represented as generic random error. On the other hand, there may be idiosyncratic factors such as a high level of distraction that affect a small proportion of estimates and that do not affect other estimates.

Differentiating sources of idiosyncratic versus generic random error is important because the pattern and frequency of such errors affects both the benefit and difficulty of minimizing them in the estimation process.

In contrast to random errors, systematic errors are consistent, but nevertheless inaccurate. The simpler form of systematic errors is called additive—they cause estimates to be incorrect by a fixed value. Systematic errors can also be correlational,¹⁹ where the error in an estimate has a predictable, nonadditive relationship to the magnitude of the estimate. The tendency for larger burns to be more significantly

overestimated than smaller burns²⁵ is a form of correlational systematic error.

Additionally, complex varieties of systematic error can also occur. If the L&B table contained a standard regional %TBSA value for the torso which was not an accurate population average, this would result in additive systematic errors in %TBSA-burned estimates. If, on the other hand, an individual's torso was larger or smaller than the population average regional %TBSA in the table, this would constitute a random error. However, if a burn affected other areas of that individual's body, there would be complex systematically related errors in their %TBSA contributions, because the regional contributions must add up to 100%: A random error in one region forces the areas of other regions to respond in a predictable fashion to maintain the 100% sum.

Inaccurate "standard" regional %TBSA values in the burn chart, such as deviation between the actual average torso and what is in the burn chart, are a form of constant additive systematic error. This form of error is what has been addressed by many attempts to improve the L&B chart.

Morphological differences between the actual regional distribution of an individual's surface area and the standard table values can best be represented as generic random error. These will affect any estimate that operates from population averages, but are unlikely to be large, for reasons identified by Rumpf et al.²⁰

Methodological process errors such as counting an entire region when a part of it is burned can be represented as an additive systematic error (overestimation).

Variation in determining what regions of a body contain second-degree or greater burns can be both random and systematic. Random errors occur in the exact boundaries of burned areas, while intentional overestimation due to caution produces an additive systematic reporting error.

Errors in assigning a burn area to the appropriate anatomic region can be assumed to be random. They may be idiosyncratic due, for example, to distractive settings or generic, for example, where real-world anatomy is difficult to represent on a two-dimensional burn chart.

Variations in assigning a burn area to the appropriate anatomic region on a burn chart can be interpreted as random errors.

Intentional inclusion of fudge factors in order to err on the side of overestimation represents additive systematic error.

Mathematical errors can be both idiosyncratic random (calculation mistakes) and additive systematic, if, for example, a caregiver always rounds up, to make addition easier while assuring an overestimate rather than an underestimate. In our work on NCHart-1, we have traded a small increase in a source of systematic errors, for a large decrease in a source of random errors. Using this approach, we observe a significant decrease in both the variance of %TBSA-burned estimates and in the incidence of large total errors.

Errors that occur in %TBSA-burned estimates are an integration of some amount of all of these types of errors. In considering the most problematic errors—those that are large and unpredictable—we note that they cannot be purely systematic (such as incorrect table values), or else all estimates would be wrong by an easily-correctable constant, or constant correlational factor. They are also quite unlikely to derive solely

from sources of generally small generic random errors (such as individual morphologic differences), or else the errors would be of roughly the same magnitude as the component errors (*or smaller*—random errors being random, their signs tend to be different and their sum tends toward zero). We turn our attention therefore to the largest potential source of idiosyncratic random errors, calculation error.

Simple math mistakes create errors that are not bounded in size or normally distributed. One is as likely, for example, to make a mistake in the tens position as the ones position when adding. As calculator use becomes more prevalent at earlier levels of elementary school, math anxiety is increasing, and simple calculation errors are easy to make under stress.

To investigate whether this simple source of errors significantly affects %TBSA-burned estimates, we developed a version of the canonical L&B chart that eliminates addition, transforming it instead into counting.

Development of NCHart-1

Inspired by the work of Murari and Singh,²⁶ who observed decreased variance in estimates produced with an adult burn chart that divides the body surface into 400 regions, NCHart-1 was created by dividing the model image for a 5 to 9 years of age L&B chart into 100 equal sections as shown in [Figure 1](#). Fifty sections were placed on the anterior surface and 50 on the posterior surface of the body following the L&B chart's distribution of area to each different body region.

Users of NCHart-1 were instructed to simply place a check mark in any region of the chart where a partial- or full-thickness burn existed on the subject and then to count the check marks to produce their final %TBSA-burned estimate.

Further dividing the sections of NCHart-1 into halves (generally vertically, not shown) created NCHart-half (0.5%).

For comparison testing, a traditional L&B chart was provided, with an added calculation area where each regional %TBSA contribution could be written and summed (not shown).

Evaluation of NCHart-1

A three-dimensional burn-simulation test model was created by moulage of a mannequin using commercially prepared silicone moulage burns (Gaumard). These were specified by the manufacturer as covering 36% of the mannequin's surface area. The accuracy of the 36% %TBSA coverage was verified by acquiring a digitally measured 3D scan of the doll and moulage, using the DAVID structured-light scanning system and David SLS-3 program (DAVID Vision Systems) as shown in [Figures 2](#) and [3](#). At the scale of the mannequin, the DAVID SLS system is capable of approximately millimeter accuracy in linear measurements, but the necessity to assemble different views of the mannequin to cover occluded areas can induce somewhat larger errors in surface measurement. The MeshLab²⁷ program was used to clean and quantitate the model. We selected a mannequin representing a 5-year-old child, as this is the median age of patients with large burns at our institution. We measured the mannequin as possessing 0.85 m² surface area and the moulage as possessing 0.28 m² surface area. Thus, the %TBSA measured for the moulage was measured at ~33% of the mannequin TBSA. Accepting that both the manufacturer-claimed

36% and measured 33% values have some level of inaccuracy, we used the manufacturer-claimed 36% coverage as our standard for statistical comparison.

Healthcare (HC) providers with varying levels of experience were tested for accuracy at estimating %TBSA burned, using either NCHart-1, NCHart-half, or the L&B chart. They were timed by the test administrator while making their assessments. Providers included nurses, medical students, surgery physicians (resident, fellow, and attending level), and Emergency Medicine physicians (fellow and attending level). This work was conducted under the auspices of the IRB at Nationwide Children's Hospital, Columbus, Ohio, USA.

Participants were randomly assigned to charts, and more than 1/3 of participants made assessments using two or more different charts (in random order). During the interval between testing with different charts, participants were distracted to reduce memory of details of previous calculations.

A follow-up questionnaire was administered to each participant after completing their assessment(s). It consisted of seven questions:

1. How many years of experience do you have caring for pediatric burn patients?
 - 1: 0
 - 2: 1–2
 - 3: 3–5
 - 4: 5–10
 - 5: 10+
2. How comfortable are you in estimating TBSA burn size for pediatric burn patients?
 - 1: Not comfortable at all
 - 2:
 - 3:
 - 4:
 - 5: Extremely comfortable
3. What is your preferred/usual method of TBSA estimation?
 - 1: The “rule of 9s” method
 - 2: The L&B chart method
 - 3: The palmar surface method
 - 4: Other
4. How difficult was the 1% surface area chart (NCHart-1) to learn?
 - 1: Not difficult at all
 - 2:
 - 3:
 - 4:
 - 5: Extremely difficult
5. Using NCHart-1, how difficult was the TBSA calculation?
 - 1: Not difficult at all
 - 2:
 - 3:
 - 4:
 - 5: Extremely difficult

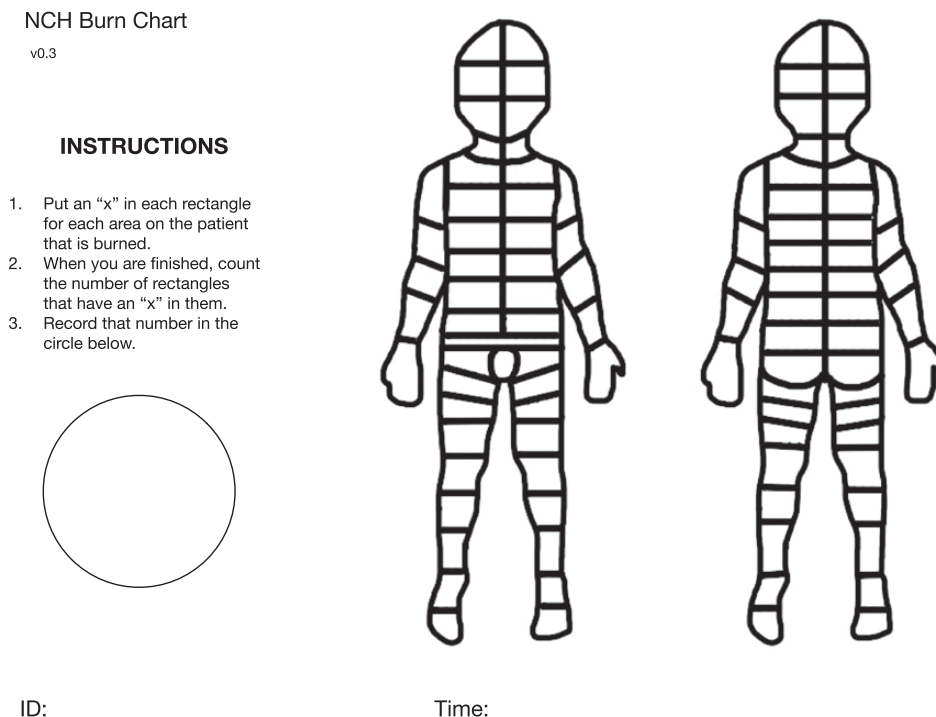


Figure 1. Our survey instrument for testing NCHart-1, including the tested NCHart-1 representation. ©Nationwide Children’s Hospital. For clinical or commercial use permissions, please contact: tech.commercialization@nationwidechildrens.org.

6. How confident were you in accurately identifying the burned surface area on the doll model?
 - 1: Not confident at all
 - 2:
 - 3:
 - 4:
 - 5: Extremely confident
7. Assuming equivalent accuracy, what would be your preferred method of TBSA estimation in future burn cases?
 - 1: Strongly prefer NCHart-1 method
 - 2: Weakly prefer NCHart-1
 - 3: No preference
 - 4: Weakly prefer original preference
 - 5: Strongly prefer previous preference

4. How confident are you with your answer?

A total of 20 HS students created TBSA assessments and participated in the naive-cohort study. All filled out the follow-up questionnaire.

Student’s *t*-test was used to estimate the significance level of differences in accuracy and time of each assessment modality in both the Healthcare professional and HS student cohorts. Spearman’s ρ ranked-correlation coefficient and the associated significance level (*P* value) were used to evaluate the relationships among answers provided on the surveys.

A total of 137 healthcare-professional participants created %TBSA assessments and 76 participants (55%) filled out the follow-up questionnaire.

A similar study was conducted in a completely untrained cohort consisting of High School (HS) students. Because the HS students had no prior experience, a different survey was administered to this cohort subsequent to their estimating the size of the simulated burn on our burn simulator mannequin:

1. What grade are you in?
2. How comfortable are you assessing the area of a burn on a patient?

Items 3 to 5 recorded data on the participant’s performance in the assessment

3. Rate the difficulty of the chart on a scale from 1 to 5

RESULTS AND DISCUSSION

Statistical Accuracy

The most important finding of this study was that users of NCHart-1 produce answers that are, on average, more accurate than users of the L&B chart (among HC professionals, 13% average absolute error for L&B vs 6.4% average absolute error with NCHart-1, $P \approx .00004$, Welch’s *t*-test, two-sided, unequal variance), the answers contain large errors less frequently (standard deviation of 11.4% for L&B vs 6.5% with NCHart-1), and users produce these answers more quickly than users of the L&B chart (2 minutes 7 seconds with a standard deviation of 36 seconds for L&B vs 1:39 with SD of 33 seconds for NCHart-1, $P \approx .0004$).

It is worth noting that we are reporting the average absolute magnitude of the errors, rather than the average of the errors (which contain both positive and negative values). As a result, the average assessed %TBSA for a method will not be equal to the true value plus the average (absolute) error that we report.



Figure 2. The burn-simulator mannequin used for our study, with applied burn moulage.

Error Distribution

Both NCHart-1 and NCHart-half have admittedly increased systematic process error: “Convenient to mark and count” is directly at odds with “accurate 1% body demarcations.” They also probably increase assignment error: Users are asked to mark and count a 1% region as affected if any portion of it is affected, leading to an almost-guaranteed assignment overestimate. Offsetting this, in our study, the reduced magnitude of calculation errors dwarfs the impact of these sources of increased error. Even with admittedly increased process error and increased probability of assignment errors, users produce reliably more accurate estimates of %TBSA with our



Figure 3. The complete 36% burn moulage kit that was applied to our simulator mannequin.

NCHart-1 counting chart, than they do with the L&B chart, which is notorious for significant errors.

Invariance to Training

Surprisingly, the accuracy of answers derived from NCHart-1, and the time taken to produce the answers, is essentially invariant of training. Both HC professionals with burn assessment experience and HS students with no such experience produce answers using NCHart-1 in about 1 minute and 40 seconds (1:39 HC professionals, 1:40 HS students), and both groups produce results with an average of about 6% error (6.4% for HC professionals and 5.4% for HS students). Importantly, the standard deviations of both the estimates, and of the time taken to produce the estimates, are both small and essentially identical between the groups ($SD \approx 6.5\%$ error for HC professionals vs $SD \approx 4.5\%$ for HS students, and $SD \approx 33$ seconds HC professionals vs $SD \approx 34$ seconds HS students).

Neither the small average error, tight standard deviations, nor surprisingly training-invariant performance is shared by the answers produced using the L&B chart. The average error produced using the L&B chart by HC professionals was 13% and by HS students was 17%. The standard deviations in the errors were 11.4% and 12.6%, respectively. When using the L&B chart HC professionals averaged 2 minutes 7 seconds, and HS students averaged 2 minutes 24 seconds, with 36

seconds, and 1 minute 3 seconds, respectively, for standard deviations. It is easy to see that their training benefited the HC professionals in the rapidity of their assessments with L&B; however, their experience surprisingly produced no meaningful benefit to their average accuracy.

Critically, the estimates produced by the HC professionals using the traditional L&B approach, with which they already had at least some familiarity, were slower, numerically worse on average, and had a higher rate of larger errors, than the estimates produced by either HC professionals or completely untrained HS students using NCHart-1.

Mass Casualty Applications

Finally, it is important to note that the change from calculation to counting seems subtle, but it enables important changes to the process of %TBSA-burned estimation itself. The process using the canonical L&B chart requires that an individual caregiver conducts individual %TBSA-burned estimates “start to finish,” while the process using NCHart-1 does not.

Using the L&B chart, it is challenging for a caregiver to perform the assessment task of determining that, for example, 2/3 of the torso is burned, along with similar assessments of other regions, and then to hand that information off to another caregiver to perform the remaining tasks of %TBSA-burned estimation. As a result, estimates using the L&B chart are usually produced in their entirety by an individual caregiver.

In one-caregiver-one-patient situations, this limitation is irrelevant. However, in mass casualty situations, this can lead to caregiver exhaustion, asymmetric distribution of caregiver expertise across cases, suboptimal utilization of resources, and delays and additional complications.²⁸ In a mass casualty situation it is important to rapidly identify those with the worst trauma and to appropriately triage different levels of trauma to facilities that can accommodate them, yet there may be insufficient caregivers present to accurately evaluate each case in a timely fashion.

Even with a good emergency-response plan and experienced first responders conducting triage, in the 2015 “Colored Dust Explosion” incident in New Taipei City, Taiwan, it took over 3 hours (3H 24M) to triage and initiate transport for the almost 500 victims of the conflagration.^{29, 30} Environments with less emergency planning and fewer trained emergency personnel could easily take far longer to appropriately triage or make worse triage decisions if their %TBSA-burned estimation tools are cumbersome and have a significant learning/experience curve.

The World Health Organization Emergency Medical Teams Technical Working Group on Burns recommends that first responders with TBSA experience should assess %TBSA-burned³¹ on-site, but in some situations, un-trained self-organized civilians may be the first responders responsible for triage.³² In such situations, a %TBSA-burned estimation method that reliably produces quick estimates with acceptable accuracy in the hands of the minimally experienced may be preferred to a method that is capable of superior accuracy, but at the cost of either significant expertise or protracted evaluation times.

With the L&B approach, the caregivers with the best skills at determining the precise boundaries of partial- and full-thickness burns must still spend the time to perform the calculation tasks, even though there may be others present who may be less skilled at determining the extent of burns, but just as, or more skilled at numeric calculation.

NCHart-1 enables the separation of these tasks. In a mass casualty situation, expert clinicians using NCHart-1 could focus on the tasks of determining burn boundaries and marking charts, and then hand over marked charts (as our data demonstrate quite literally) to teams with no more experience than HS students, and have the calculation step performed with adequate accuracy. This enables both better record-keeping and record-transfer and also preserves the attention of the expert clinicians for the part of the %TBSA-burned estimation task for which they are uniquely best trained.

In addition, because the assessment and assignment tasks can be separated from the calculation task, it is much easier to cross-check each of these tasks for errors when using NCHart-1 than when using the traditional L&B process. In the NCHart-1 process, after the assignment (marking the chart) stage, the chart is unambiguous: If there is a burn in an area, there should be a check mark, and if there is not, there should not be a check mark.

If two different assessing caregivers produce differently marked charts, it is easy to isolate this difference to assessment (determination of the burn boundaries) or assignment and straightforward to investigate the reason for the difference. If there are discrepancies between the calculations (summation of check marks) of different caregivers working from the same marked chart, it is unambiguous which count is correct.

With the L&B chart and process, however, if one caregiver produces a result of 13% and another produces a result of 25%, it is quite difficult to determine if they differed in their assessment of what was burned, their assignment of the burns to the chart regions, their calculation of the sub-regional percentages, or their overall summation of the results. Disambiguation of the error in this situation becomes challenging and time-consuming.

These challenges can be critical in mass casualty situations where expert caregiver resources are spread thin. In such situations, it may be advantageous to use consensus assessments of %TBSA-burned that are produced by less-expert caregivers. Consensus estimates have long been understood to have smaller errors than individual estimates,^{33,34} conceptually enabling groups of caregivers with less experience to produce reliable estimates despite their limited experience. However, the challenges with identifying the source of errors in estimates produced by the L&B approach limit the possibility of using it in this situation.

NCHart-1, because it enables step-by-step cross-checking of results, can facilitate consensus estimates, potentially enabling faster initial-assessment coverage of mass casualty events.

User Impressions and Preference

Our survey results also demonstrate compelling evidence that NCHart-1 provides user preference and other advantages over the traditional L&B chart, as well as over other common traditional methods. Among our 76 HC professional survey respondents, 32 (42%) had over 10 years, 14 (18%) had 5 to 10 years, 12 (16%) had 3 to 5 years, 7 (9%) 1 to 2 years, and 11 (14%) less than a year or no experience.

Prior to introduction to NCHart-1, only 3 (4%) of HC professionals claimed to be extremely comfortable in estimating TBSA burn size for pediatric patients, 25 (35%) very comfortable, 27 (38%) moderately comfortable, 10 (14%) mildly comfortable, and 3 (4%) not comfortable at all.

Before the introduction of NCHart-1, 40.3% of participants who filled the questionnaire (PQ, participants who filled out the questionnaire, n = 76) preferred the “rule of 9s”, 38.7% favored the “palmar area method,” and 21% called the L&B chart a preferred method.

After the testing, which introduced NCHart-1 for the first time, 79% of PQ participants reported that they preferred NCHart-1 to their previous methods, 16% did not have a preference, and 5% (4 participants) slightly preferred the previous method they used. Only one participant, who reported 10+ years experience in pediatric burn assessment, reported a strong preference for their original method of choice, after using NCHart-1 for our brief study.

About 55 (72%) PQ found it not difficult at all to learn, 16 (21%) slightly difficult, and 5 (7%) moderately difficult; nobody found it very difficult or extremely difficult.

Once they learned NCHart-1 in a short demonstration, 47 (62%) PQ found it not difficult at all to apply, 18 (24%) slightly difficult, 8 (12%) moderately difficult, and 2 (3%) very difficult.

While we initially expected NCHart-half to produce better numerical results than NCHart-1 at the cost of increased time, our expectations were not borne out. NCHart-half has similar accuracy, but slower performance than NCHart-1. When using NCHart-half, the mean estimated TBSA-B was 39.6%, which deviated from the actual value by an average of 7.5%, and the average time spent calculating was 2:07 with a standard deviation of 37 seconds. This is actually slightly worse accuracy than NCHart-1, though the difference was not statistically significant, at ($P \approx .62$). The difference in times between assessments performed with NCHart-1 and NCHart-half also did not attain statistical significance; however, with $P \approx .02$, it is likely that this is solely due to the limited number of participants (20) who used NCHart-half.

In addition, there are interesting patterns in the survey answers that both shed light on the likely acceptance of NCHart-1 for use in practice and that bolster our confidence in the validity of the survey results.

Table 2 presents the (Spearman’s Rank) correlation between the answers provided to each question on the survey, while Table 3 presents the uncorrected significance level (P value) of each of these correlations, with values remaining significant

Table 2. Spearman’s rank correlation between the answers to our survey

	Q1	Q2	Q3	Q4	Q5	Q6
Q1 Preexperience						
Q2 Precomfort	0.40					
Q3 Prepreference	-0.13	-0.21				
Q4 NChart-1 difficulty learning	0.11	0.08	0.02			
Q5 NCHart-1 difficulty using	0.20	0.01	0.01	0.57		
Q6 Confidence	0.16	0.32	-0.09	-0.24	-0.33	
Q7 Postpreference	0.12	0.09	-0.05	0.57	0.31	-0.30

Predictable correlations, such as between experience (Q1) and comfort (Q2), at assessing %TBSA are reasonably strong, suggesting that the weaker correlation seen between experience or prior preference and preference after using NCHart-1 is real. Redundant values excluded.

after multiple-hypothesis correction underlined. As might be expected, there is a fairly strong (Spearman’s rank $\rho \approx 0.40$) and significant (corrected $P \approx .002$) correlation between years of experience in pediatric burn care and comfort in assessing pediatric burns. More detail regarding this relationship can be understood by examining the frequency of pairs for each possible response to Q1 and Q2, as shown in Figure 4. The trend from less comfort with less experience toward more comfort with more experience is clear, although there are additional interesting nuances to the differences in responses at different experience levels that may bear further study.

Similarly, there is little reason to assume that years of experience would bias a participant toward a particular assessment method, and the correlation ($\rho \approx 0.13$) and significance of this relationship ($P \approx .235$) do not bear out any impact of experience on a preference for assessment instrument at the

Table 3. Uncorrected significance (P) values of the Spearman’s rank correlations given in Table 2

	Q1	Q2	Q3	Q4	Q5	Q6
Q1 Preexperience						
Q2 Precomfort	<i>.0001</i>					
Q3 Prepreference	.2346	.0511				
Q4 NChart-1 difficulty learning	.2960	.4513	.8545			
Q5 NCHart-1 difficulty using	.0664	.8948	.9564	.0000		
Q6 Confidence	.1527	.0026	.4242	.0259	.0022	
Q7 Postpreference	.2546	.4321	.6595	.0000	.0032	.0049

Redundant values excluded. Values that remain significant at a level of 0.01 or better after multiple-hypothesis correction are italicized. The actual P values for Q4 ν Q5 and Q4 ν Q7 are 1.102 and 1.129×10^{-8} , respectively.

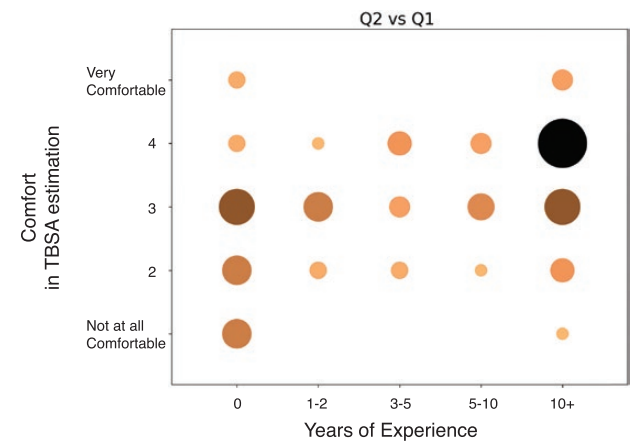


Figure 4. Comparison of survey responses for experience in assessing pediatric burns (Q1) vs comfort in assessing pediatric burns (Q2). Bubble size and darkness correlate with the fraction of respondents reporting that pair of values. As might be expected, respondents with the least experience report the least comfort with the assessment, and those with the most experience report the most comfort. The observation that those with the least and most experience also display the largest range of comfort values was initially surprising, but might be explained by a combination of “beginner’s overconfidence” and the fact that it often requires many years to assess enough cases to become fully aware of the challenges of the task.

beginning of our study. Again, greater detail can be understood by examining Figure 5.

Of note, the strongest and most significant correlations observed between questionnaire answers are Q4 ν Q5 (Difficulty in Learning NCHart-1 predicts difficulty in using NCHart-1, $\rho \approx 0.57$, $P \approx 1.10 \times 10^{-8}$) and Q4 ν Q5 (difficulty in learning NCHart-1 predicts preferred method at the end of the study, $\rho \approx 0.57$, $P \approx 1.12 \times 10^{-8}$). While it may be initially concerning that there is a strong correlation between the reported level of difficulty in learning NCHart-1 and the reported level of difficulty in using it, and similarly with poststudy preferences, looking more closely at the data suggests that this is a positive finding. As shown in Figures 6 and 7, these strong correlations are dominated by the significant population of respondents who found no difficulty in learning or applying NCHart-1 and who preferred NCHart-1 to the other assessment methods after participating in our study. Of note, no respondents indicated anything more than moderate difficulty (on a 5-value scale from no difficulty to extreme difficulty) in learning NCHart-1.

Several of the comparisons for which little to no correlation can be detected are also important to consider. For example, there is no meaningful correlation between the method which participants preferred before they tried NCHart-1 (Q3) and the method they preferred after participating in our study. This lack of correlation is driven by a strong shift away from each of the possible incoming method preferences toward NCHart-1 after participation in our study, as shown in Figure 8.

Also critically, there is little to no correlation between the level of prior experience in assessing burns and method preference after participating in our study. We initially expected to find that users with long experience in a traditional method would be reluctant to adopt the NCHart-1 approach. However, our data do not bear out this expectation. As shown in Figure 9, with the exception of one 10+ year veteran at pediatric burn assessment who maintained a strong preference

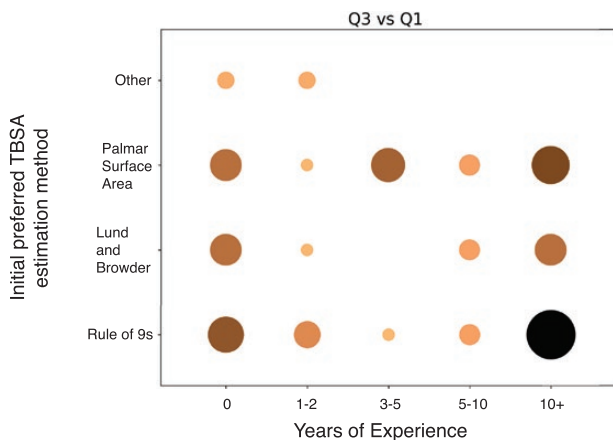


Figure 5. Comparison of survey responses for experience (Q1) vs preferred method of assessment prior to our study (Q3). Bubble size and darkness correlate with the fraction of respondents reporting that pair of values. The data display no strong preferences between the “big 3” methods of the “rule of 9s” (response 1), the Lund and Browder chart (response 2), and the palmar surface area method (response 3), regardless of the experience level of the participant. The preference for “other” expressed by some of the participants with 0, or 1 to 2 years experience, may be due to the recent advent of mobile-device-based methods such as BurnCase 3D.

for using the rule of 9s, across all experience levels, there was a strong shift toward preferring to use NCHart-1 after the experience with it.

Taken together, these data suggest that NCHart-1 is an appropriate tool for first responders and other caregivers who require rapid estimates of affected %TBSA with errors that are reliably constrained to reasonably small magnitudes. NCHart-1 cannot replace the fine-grained documentation and precise estimates created by BurnCase 3D or other similar technological approaches using detailed annotation on digital twins. But, at the same time, it can serve as an important

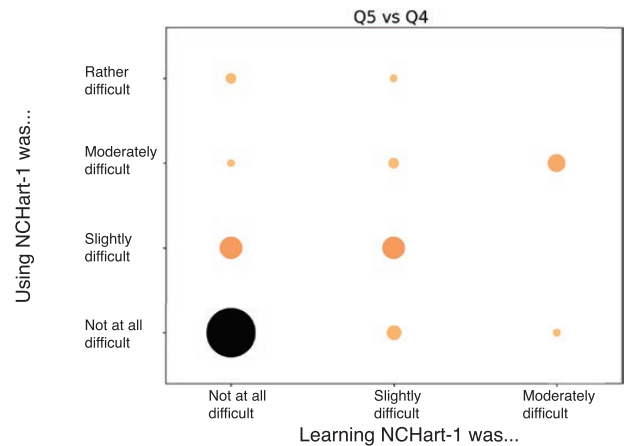


Figure 6. Comparison of survey responses for the difficulty experienced in learning NCHart-1 (Q4) vs difficulty experienced in applying NCHart-1 (Q5). Bubble size and darkness correlate with the fraction of respondents reporting that pair of values. From this data, it is apparent that the strong correlation between the reported difficulty of learning and difficulty of application is dominated by the fact that the large majority of respondents reported no difficulty in learning or applying NCHart-1. No respondents indicated that learning NCHart-1 was either rather or extremely difficult, and none indicated that using NCHart-1 was extremely difficult.

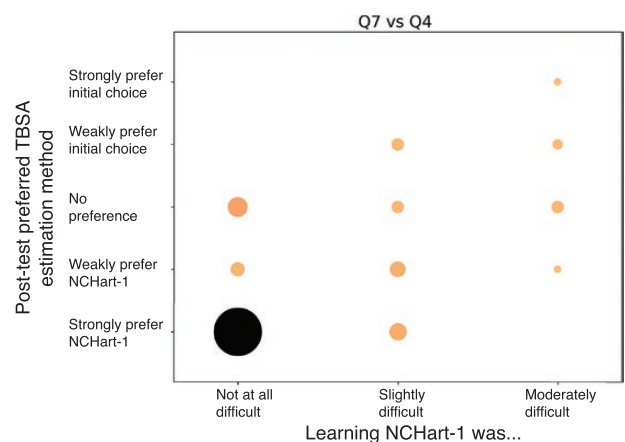


Figure 7. Comparison of survey responses for the difficulty experienced in learning NCHart-1 (Q4) vs poststudy method preference (Q7). Bubble size and darkness correlate with the fraction of respondents reporting that pair of values. As with Q4 ν Q7, the strong correlation observed between the reported difficulty of learning and poststudy method preference is a result of a large number of respondents reporting no difficulty in learning NCHart-1 and expressing a preference for using NCHart-1 poststudy. No respondents indicated that learning NCHart-1 was either rather or extremely difficult.

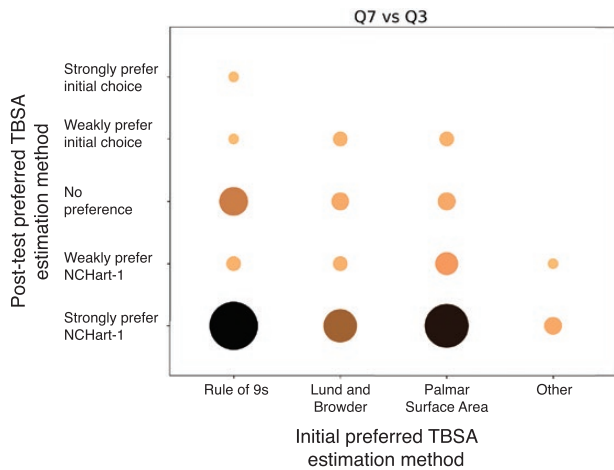


Figure 8. Comparison of survey responses for prestudy %TBSA-assessment method (Q3) vs poststudy method preference (Q7). Bubble size and darkness correlate with the fraction of respondents reporting that pair of values. The results of this comparison show a strong shift in preferences from the user’s originally preferred method toward NCHart-1. Only one respondent (who initially preferred the rule of 9s) maintained a strong preference for their originally preferred method (response level 5, Q7). Regardless of initial preference, at the exit, the majority of participants preferred NCHart-1.

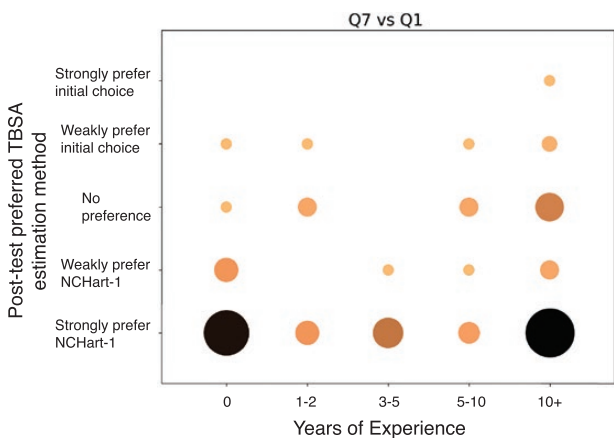


Figure 9. Comparison of survey responses for experience (Q1) vs poststudy method preference (Q7). Bubble size and darkness correlate with the fraction of respondents reporting that pair of values. As with Q7 v Q3, the results of this comparison demonstrate a strong preference for NCHart-1 at the exit from our study, regardless of the user’s level of experience. The single respondent shown in Figure 8 who strongly preferred their original, rule of 9s method, is a highly experienced practitioner with 10+ years of experience.

adjunct to cross-check these methods: It is easily possible to make an annotation error on a digital twin, and because of the considerable time required to create the annotations, finding and correcting such an error is not likely unless caregivers possess an additional, fast, and easy approach that can signal the reasonableness of, or probable error in, a technologically produced estimate.

Limitations

While this study provides strong evidence that using NCHart-1 reduces the frequency of large errors in %TBSA

estimates while enabling consistently faster estimates, and that NCHart-1 levels the playing field between estimates produced by highly experienced and less-experienced practitioners, there remain limitations to our study that warrant additional work to expand the scope of application. There are also several remaining questions regarding the application of charts to creating %TBSA estimates.

The two largest issues, which we would like to address in the future, are the generalizability of these results to burns of different sizes and distributions and across patients of different body morphotypes. NCHart-1 appears to reliably produce estimates that are a few percent over the actual burned percentage, with the specific burn moulage and burn simulator mannequin that we used. It seems likely that different burn sizes and different patient body sizes would produce different results. Nothing about NCHart-1 was designed to optimize the estimates for our purchased burn moulage or for the burn simulator mannequin, so we have no reason to assume that other burn sizes or mannequins would produce dramatically different results. However, there are predictable effects—such as the magnitude of the process and assessment errors increasing in burns consisting of more scattered patches, compared to burns of equal area that are in few consolidated patches—that we cannot estimate from our current data. At the same time, it seems likely that, while the regional area data in the L&B chart are surprisingly robust to differences in body morphology,²⁰ the similarity or dissimilarity between a patient’s body, and the schematic used in a burn-estimation chart, would affect the assignment error. Likewise, we expect that the assessment time using NCHart-1 scales approximately linearly, or perhaps even sublinearly, with the size of the burn: There are only 100 1% regions on the chart to consider, regardless of the burn’s distribution. As the only extant “counting” approach to estimating burn %TBSA, we suspect that this linear or better performance with increasing burn size and complexity is a feature enjoyed only by NCHart-1.

While not directly affecting the validity of our results, there are also limitations to the interpretation of our data that leave important questions unanswered. Because our surveys were not paired with assessments, and because assessments in multiple modalities by the same participant were not tracked, we can make only the most mild comments regarding the effect of experience on the accuracy of the assessment. While our ability to compare the completely inexperienced HS cohort with the health professional cohort suggests that NCHart-1 has a nearly imperceptible learning curve, it seems probable that those with more experience with the L&B chart produce results more quickly and possibly more accurately (the accuracy of highly experienced practitioners is in some question, as there are conflicting results from studies of BurnCase 3D that demonstrate that experienced practitioners are both essentially error-free^{35, 36} and that they are worse at burn estimation than inexperienced users of BurnCase³⁷). This detail is not purely of academic interest, as it is probable that highly experienced practitioners transition from a process of using %TBSA-estimation tools to actually produce their estimates, to one of using them to confirm the estimates that they make essentially instantly on seeing the burn. There is no evidence that the best tool for producing estimates is also the best tool for confirming estimates.

Future Work

Our primary focus going forward is the optimization of NCHart-1 to different body morphologies (age and morphotype) as necessary to maintain an acceptably small average and maximum error. Both recent work,²⁰ the original L&B work,¹³ and a careful consideration of their underlying data³⁸ demonstrate that morphotype (long vs short torso, etc.) differences in physical proportions produce a significantly larger impact on %TBSA regional contributions than does obesity, and L&B's original age-based tables were produced in recognition of this fact. We are therefore working to develop and verify a suite of NCHart-1 versions to address these needs.

We are further working to validate the application of NCHart-1 and characterize its error performance in separated tasks and consensus modes where different caregivers are responsible for different subtasks within the %TBSA-burned estimation, or where teams of caregivers collaborate to produce %TBSA-burned estimates.

A mobile-device app to automate the calculation (counting) task directly from a marked NCHart-1 chart is under development.

Finally, we are also working to develop an error-correction term that could be applied to further improve NCHart-1's accuracy. NCHart-1's total error includes a systematic overestimation term. As a systematic component, this portion of the error can be at least partially corrected.

CONCLUSION

Despite these limitations and recognizing that additional work is necessary to produce and validate NCHart-1 versions for other age groups and possibly other body morphologies, we propose that our current results—both in demonstrably reduced error magnitude and reduced learning curve, as well as the overwhelming consensus among our cohort of surveyed HC providers that NCHart-1 is preferable to the current L&B standard of care—demonstrate that NCHart-1 should be deployed now for the 5 to 9 age range.

Nationwide Children's Hospital will cooperate with regional and national burn communities to disseminate NCHart-1. The most current version of the chart is available for immediate deployment from the Nationwide Children's Hospital Office of Technology Commercialization. For clinical or commercial use, please contact: tech.commercialization@nationwidechildrens.org

Nationwide Children's Hospital will be promoting the availability of NCHart-1 via our Marketing/Public Relations department, and we will be conducting local in-person and global online trainings for NCHart-1 as part of the roll-out. Please contact our Office of Technology Commercialization to know about training dates and opportunities.

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