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Original Contribution

ABC/2 estimation in intracerebral hemorrhage: A comparison study between emergency radiologists and emergency physicians

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ABSTRACT

Objectives: We aimed to define levels of agreement (LOA) between emergency radiologists (RAD) and emergency medicine (EM) physicians for estimating bleed volume in intracranial hemorrhages (ICH) using ABC/2 formula.
Methods: A prospective study of a curated sample of head CT's were performed in an emergency department. Raters independently reviewed the scans. Perpendicular maximal dimensions (A and B) were measured on an axial CT image. The 'C' dimension was a product of slice thickness and number of slices with visible bleed.
Results: A hundred CT head examinations were included with a median age of 50 years (IQR 43 to 57). The median bleed volume was 11.2 mL (IQR 6.6–18.6) per the index radiologist estimations. The overall mean of differences between the RAD mean and the EM mean estimated bleed volume was 0.3 (95% CI -1.5 to +1.7) in milliliters. The percentage difference between EM and RAD expressed as median was 1.9% (IQR -13.4% to +14.1%). Compared to the index RAD the mean of differences for bleed volume [rater, mean (95% CI) in milliliters] were: second RAD, 1.19 (1.14 to 1.24); EM attending, 1.05 (0.98 to 1.13); senior fellow, 1.05 (1.00 to 1.10); junior fellow, 1.19 (1.06 to 1.33); senior resident, 1.29 (1.19 to 1.39); junior resident, 1.11 (1.03 to 1.20). The difference between EM *versus* radiologist, junior *versus* senior EM physician estimation of bleed size was clinically insignificant.
Conclusions: Excellent level of agreement was found between emergency physicians and emergency radiologists for estimating ICH bleed volumes using ABC/2 formula.

1. Introduction

Intracerebral hemorrhage (ICH) accounts for 10–15% of all strokes. Even with improvement in the overall management and quality of care provided to ICH patients, it remains the type of stroke that carries a high mortality and morbidity [1,2]. Estimation of intracerebral bleed volume is shown to be a useful predictor of mortality and clinical outcomes in patients with ICH [3,4]. There are several methods to estimate hematoma volume. Of those, CT planimetric method for volume measurement is considered to be most accurate; however, it is time consuming. A quick method to estimate hematoma volume is by using ABC/2 formula [5-8]. The use of ABC/2 in estimating volume was shown to be accurate for small size, ellipsoid or round shape, ICH bleeds and was less accurate for irregular shape or larger ICH bleeds [9]. Previous studies have described ABC/2 to overestimate the volume by 5 to 10% in comparison with planimetric analyses even in regular shape ICH bleeds [20].

In a significant proportion of ICH cases, emergency physicians (EM) are the first to be involved in the management of patients in a hospital setting. Therefore, an area of interest is to assess the EM capability to estimate hemorrhage volume using the ABC/2 formula. We aimed to determine the level of agreement between the

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EM raters with various level of EM experience to estimate bleed volume by using ABC/2. We aimed to assess: 1) Sources of bleed-volume disagreement in ABC/2 formula (*e.g.* bleed diameter, slice-count), and 2) Agreement on dichotomous bleed categorization as ellipsoid.

2. Methods

2.1. Design, setting and participants

This was a prospectively designed interpretation of a curated sample of head CT scan examinations from a single study center. Institutional ethics approval was obtained from the study medical center. The study was conducted at the major teaching hospital and only tertiary care center in the country. At the study center, real-time reporting of all ED cranial computed tomography (CT) images was executed by general radiologists who were board-certified attending physicians. The study-center used a 64-slice helical CT scanner (Somatom Sensation 64, Siemens, Munich, Germany) for emergency cranial imaging, with default slice-thickness set at 5 mm.

Participants were two attending emergency radiologists (denoted herein as RAD) and an attending EM, a senior EM Fellow (EMF), a junior EMF, a senior EM resident (EMR), and a junior EMR. Both radiologists had a decade of experience assessing head CTs.

2.2. Obtaining and defining the image-set

A set of cranial computed tomography (CT) scans was drawn from the study center's electronic medical records review for patients with a diagnosis of intracranial hemorrhage (ICH). Based on an initial assessment by EM and radiology study-image viewers, cases were added to the dataset until a case *n* of 100 was reached. Images were included in the study if they were coded as indicating intracranial hemorrhage (ICH) within the brain parenchyma. The set of 100 cases and CT images was collected into a single digital folder for dissemination to the study's raters.

2.3. Image review, measurement acquisition, & volume calculations

The 100 CTs identified for study were reviewed by all raters using a standard image-viewer (Sante Dicom Viewer 64-bit version, Santesoft, Athens, Greece). The review software included capability for measurements of distance. All reviewers assessed the images separately blinded to the patient details and recorded their measurements for maximal ICH diameters (*i.e.* values for *AB*) as well as slice-numbers (*C* slice-counting), as per the method originally described by Kothari *et al* [7].

The final indication from each rater, was a dichotomous categorization as to whether a given case's geometry was judged as "ellipsoidal" or "non-ellipsoidal." The latter was defined as being present if the geometry of a given case's ICH was judged by the rater to be sufficiently off ellipsoid geometry to render use of the *ABC*/2 method. The *ABC2* method is used regularly by the radiologists and most of the practicing EM physicians in this study, but all physicians underwent a 5-minute refresher training session on *ABC2* scoring and the above-outlined steps as well as generating dichotomous ratings of ellipsoid geometry.

In order to provide description of the cases comprising the study's image set, one of the radiologists categorized each ICH into three categories often seen in the ICH evidence base: lobar, deep, or infratentorial [10]. A cross-check of 10% of overall cases (for categorization validation) executed by the other study radiologist identified 100% agreement.

2.4. Defining agreement and disagreement

The study purpose was directed at quantifying agreement between the index radiologist and the second radiologist, as well as between the index radiologist and five EM raters with varying levels of experience and training on *ABC*/2 scoring, with a secondary goal of characterizing the basis (*i.e.* which parts of the *ABC*/2 formula) for disagreement in volume calculations. The study was not intended to assess the utility of *ABC*/2 scoring as compared to gold-standard measurements of ICH volume (*e.g.* by use of planimetric software).

To evaluate whether two evaluators agreed with respect to ICH volume estimates using *ABC*/2, an *a priori* definition was set to follow systematic literature reviews of ICH bleed volume estimation [9]. Volumes were deemed to be in clinical agreement if they were within 6 mL or 20% of each other (whichever rule was more restrictive was applied), which is minimal detectable difference for multiple raters of the same image [11]. The 20% cutoff allows for more conservative estimates of clinical agreement in small ICH, where a difference in ICH volume estimates <6 mL could still be proportionally large and clinically significant.

While other studies have broken ICH bleeds into multiple categories based on volume, the current study chose to simplify bleed volumes to separate the highest volumes (as the ones previous analyses suggest are most prone to *ABC*/2 error) [10]. The approach used in this analysis was to analyze both the overall levels of agreement (for all bleed sizes) and then to execute follow-up assessments for both the largest bleeds – defined as those in the top quartile of size – and the other-size bleeds (first three quartiles of volume) combined into one group. The aim was to determine if the larger magnitudes of disagreement tended to occur on the larger bleed volumes. The combining of the lower three quartiles into one group was taken both for clinical practicality and because of the wish to optimize width of CIs in this relatively small-*n* study.

2.5. Data and analyses plan

All data were entered into an Excel spreadsheet (Office 2010, Microsoft, Redmond, Washington) and imported directly into the statistical software. Statistical analysis and graphing were executed with Stata software. Statistical significance was set at the $p < .05$ level; confidence intervals (CIs) as well as limits of agreement (LOAs) were calculated at the 95% level. Initial descriptive evaluation included use of the Shapiro-Wilk test for assessment for normality of the main continuous variable *ABC*/2. When normality testing revealed non-normal distribution ($p < .001$ for all raters and for both *AB* and *ABC*/2), the decision was made to describe all data's central tendency and dispersion with median and interquartile range (IQR).

The first step toward assessing degree of agreement was determining whether the data were appropriate for standard 95% LOA analysis by using the two-part approach described in detail by Bland and Altman [12-14]. For the first part of the evaluation to assess normal distribution of data, visualization *via* histograms is recommended; for the second assumption that is the magnitude of difference between two ratings will be unrelated to their average, Bland and Altman recommend a Pitman's test for homogeneity of variance [12-15].

In the current study, the evaluation of appropriateness for LOA analysis focused on the main study measurement of ICH bleed volume as measured by *ABC*/2. The secondary assessments (*AB* and *C*) were also evaluated with Bland-Altman LOA assessment in order to address the study's secondary goal of determining which (if either) component had more responsibility for disagreement in the *ABC*/2 estimate. For the LOA estimates, 95% CIs were generated as recommended by Bland and Altman [16], using the following formula for standard error (SE) of the limits: $SE = \sqrt{3s^2/n}$.

By *a priori* plan, if the data in the current study were found (as they ultimately were) to not meet requirements of histogram normality and non-significant Pitman's variance testing, the estimates would be log-transformed as per the Bland-Altman recommendations [12,13].

The final analytic aspect of the study was the assessment of agreement with standard *kappa* (κ) methodology on the question as to whether a given case's ICH was ellipsoid.

3. Results

The 100 cases comprising the study set reflected the population of the study center ED in that they were relatively young and 90% of the occupants in the study were male (median age 50 with IQR 43 to 57). The cases' other basic information is provided in the Table 1.

The bleed volumes (by the index radiologist-calculated *ABC*/2) ranged from 1 to 59 mL. The median bleed volume was 11.2 mL (IQR 6.6–18.6) per the index radiologist estimations. The mean of differences for estimated volume, between the index radiologist and the raters, were [rater, mean (95%CI) in milliliters]: second radiologist, 1.19 (1.14 to 1.24); EM attending, 1.05 (0.98 to 1.13); senior EMF, 1.05 (1.00 to 1.10); junior EMF, 1.19 (1.06 to 1.33); senior EMR, 1.29 (1.19 to 1.39); junior EMR, 1.11 (1.03 to 1.20). Other descriptive results are shown in Table 2.

For *ABC*/2 (in milliliters) as well as its components *AB (in centimeters^2)* and *C (in centimeters)*, the final (*i.e.* after back-transformation) estimates for the degree of agreement between index radiologist and the other raters are shown in Table 3. The table indicates the mean difference (with 95% CI) for the value "Index radiologist minus other rater" (positive numbers correlate to the index radiologist estimate being higher) with upper and lower limits of CI. The table also reports the upper LOA and lower LOA (with 95% Cis) for each of these limits.

Visual depiction of the estimates for the degree of agreement information is provided in Fig. 1 in order to depict the relative mean differences and LOAs for the various raters and parameters (*AB*, *C*, *ABC*/2). Fig. 1 shows the levels of maximum disagreement were in calculating the maximum single-slice bleed area (*i.e.* the *AB* term). Fig. 2 provides similar visualization as that of Fig. 1,

Table 1
Study-case basic characteristics for 100 intracranial hemorrhage patients (all *n* are also %)

Age (median, interquartile range)	50 (43 to 57)
Male	90
Female	10
Outpatient anticoagulation therapy	3
Hemorrhage location	
Lobar	49
Deep	43
Infratentorial	8

Table 2
Radiologist & Emergency Medicine (EM) volume estimates: median & interquartile range (IQR) for each calculation step

	Maximum single-slice area (*AB*), cm^2 median (IQR)	Adjusted vertical dimension (*C*), cm median (IQR)	Volume (*ABC*/2), mL median (IQR)
Index radiologist	10.3 (7.2 to 15.7)	2.3 (1.8 to 3.0)	11.2 (6.6 to 18.6)
Second radiologist	10.1 (7.2 to 15.1)	2 (1.5 to 2.5)	9.4 (6.0 to 15.5)
EM Attending	9.1 (5.0 to 14.3)	2.5 (2.0 to 3.0)	11.3 (5.8 to 18.9)
EM Senior Fellow	10.3 (6.1 to 14.8)	2.3 (1.8 to 3.0)	11.4 (6.0 to 18.4)
EM Junior Fellow	8.3 (5.1 to 12.0)	2.5 (1.8 to 3)	10.4 (5.3 to 15.1)
EM Senior Resident	9.1 (5.1 to 15.4)	2.1 (1.6 to 2.6)	9.2 (5.1 to 16.8)
EM Intern	8.9 (5.0 to 14.5)	2.5 (1.8 to 3.0)	11.2 (5.2 to 19.0)

IQR: Interquartile Range; EM: Emergency Medicine.

Table 3
Estimates for *A* (in cm)^2, *B* (in cm), & *ABC*/2 (in mL): Mean differences & limits of agreement (LOA) with 95% confidence intervals (CIs)

	Mean difference in mL between Index radiologist and other raters (mean and 95% CI)	Lower bound, 95% LOA (with 95% CI)	Upper bound, 95% LOA (with 95% CI)
AB in centimeters^2: Index radiologist compared to:			
Second radiologist	1.00 (0.97 to 1.04)	0.74 (0.70 to 0.78)	1.37 (1.30 to 1.44)
Emergency Medicine Attending	1.15 (1.07 to 1.22)	0.59 (0.53 to 0.66)	2.21 (1.98 to 2.47)
Emergency Medicine Senior Fellow	1.06 (1.03 to 1.10)	0.76 (0.72 to 0.81)	1.48 (1.40 to 1.56)
Emergency Medicine Junior Fellow	1.26 (1.11 to 1.41)	0.38 (0.31 to 0.46)	4.19 (3.42 to 5.14)
Emergency Medicine Senior Resident	1.15 (1.07 to 1.23)	0.56 (0.49 to 0.63)	2.35 (2.08 to 2.65)
Emergency Medicine Intern	1.15 (1.07 to 1.23)	0.57 (0.51 to 0.65)	2.28 (2.03 to 2.57)
C in centimeters: Index radiologist compared to:			
Second radiologist	1.18 (1.15 to 1.22)	0.87 (0.83 to 0.92)	1.61 (1.53 to 1.69)
Emergency Medicine Attending	0.92 (0.89 to 0.95)	0.67 (0.63 to 0.71)	1.26 (1.19 to 1.33)
Emergency Medicine Senior Fellow	0.99 (0.96 to 1.02)	0.73 (0.70 to 0.77)	1.34 (1.27 to 1.41)
Emergency Medicine Junior Fellow	0.95 (0.91 to 0.99)	0.65 (0.61 to 0.69)	1.39 (1.30 to 1.49)
Emergency Medicine Senior Resident	1.12 (1.08 to 1.17)	0.76 (0.72 to 0.81)	1.65 (1.54 to 1.76)
Emergency Medicine Intern	0.97 (0.93 to 1.01)	0.64 (0.59 to 0.68)	1.49 (1.38 to 1.60)
ABC/2 in milliliters: Index radiologist compared to:			
Second radiologist	1.19 (1.14 to 1.24)	0.80 (0.75 to 0.86)	1.76 (1.65 to 1.88)
Emergency Medicine Attending	1.05 (0.98 to 1.13)	0.51 (0.45 to 0.58)	2.16 (1.91 to 2.44)
Emergency Medicine Senior Fellow	1.05 (1.00 to 1.10)	0.66 (0.61 to 0.71)	1.68 (1.55 to 1.82)
Emergency Medicine Junior Fellow	1.19 (1.06 to 1.33)	0.38 (0.31 to 0.46)	3.74 (3.08 to 4.54)
Emergency Medicine Senior Resident	1.29 (1.19 to 1.39)	0.59 (0.51 to 0.67)	2.82 (2.47 to 3.22)
Emergency Medicine Intern	1.11 (1.03 to 1.20)	0.51 (0.45 to 0.58)	2.44 (2.13 to 2.78)

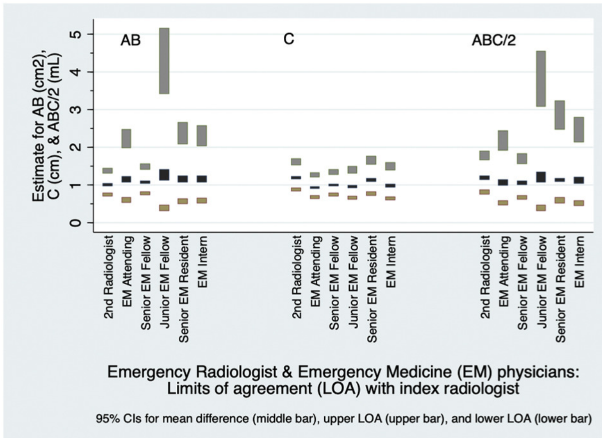

Fig. 1. *AB* (in cm^2), *C* (in cm), & *ABC*/2 (in mL): 95% confidence intervals (CIs) for mean difference & limits of agreement for 6 raters *vs.* index radiologist.

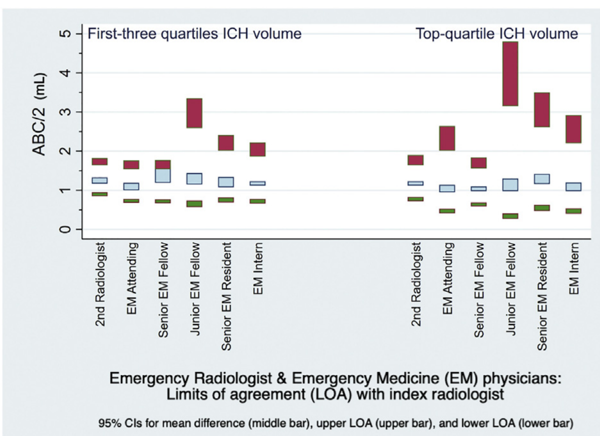

Fig. 2. *ABC*/2 (in mL): 95% confidence intervals (CIs) for mean difference & limits of agreement for 6 raters *vs.* index radiologist, comparing limits of agreement by bleed volume (top-quartile *versus* lower-three quartiles).

but with focus on the main endpoint (*ABC*/2) and its different LOAs for top-quartile *versus* lower-three quartiles of ICH size.

The bleeds were categorized as ellipsoidal in 37 out of 100 CT scans by the index radiologist. The inter-observer agreement for categorizing bleed shapes compared with index-radiologist were [rater, κ (95% CI)]: second RAD, 0.28 (0.12 to 0.44); EM attending, 0.33 (0.19 to 0.49); senior EMF, 0.61 (0.44 to 0.77); junior EMF, 0.19 (0.07 to 0.32); senior EMR, 0.24 (0.11 to 0.39); junior EMR: 0.35 (0.21 to 0.5). The *κ* results on ellipsoidality categorization for the entire set of 100 cases are shown in *(Appendix)*. Overall, the agreement levels were only fair.

4. Discussion

This study aimed to define levels of agreement between radiologist and EM readers' estimates of ICH bleed volume using *ABC*/2 in non-contrast head CT. We found the difference between 'EM versus radiologist' and the difference between 'junior versus senior EM physician' for estimation of bleed size using *ABC*/2 score was clinically insignificant. An excellent level of agreement was found between emergency physicians and emergency radiologists for estimating the ICH bleed volumes using ABC/2 formula.

While the original *ABC*/2 formula was described by well-known academic EM group from Cincinnati [7], most subsequent analyses have assessed *ABC*/2 calculation by radiologists, neurology/neurosurgery clinicians, or researchers in the neurosciences [6,9-11,17-24]. Furthermore, much of the existing literature reports on *ABC*/2 calculations using software that is either unavailable or impractical (taking 2–3× longer time than *ABC*/2) for application by busy ED physicians (and perhaps even ED radiologists) [7,11].

The *ABC*/2 score is widely used in EDs. It takes just minutes to perform and it is commonly employed as a matter of practicality and ease of application (*e.g.* no software training is required) [7,11] In fact, for both EM clinicians and radiologists at the study center, the daily practice is to use *only* the *ABC*/2 methodology for volume estimation. Neither the study center radiologists nor this investigative group aver that *ABC*/2 is as accurate as software-driven geometric evaluation, but *ABC*/2 has a place in emergency care if its bias issues are understood. Those bias issues are considered next.

The *ABC*/2 bias concerns are primarily related to overestimation of ICH size, with *ABC*/2 calculations exceeding the gold-standard planimetric determinations in large bleeds as well as those with non-ellipsoid geometries [25]. The *ABC*/2 technique also tends to overestimate volume in anticoagulation-associated ICH. Such overestimation may be simply due to propensity of anticoagulation-associated ICH to be large and non-ellipsoid; in fact, many studies of anticoagulation-associated ICH use *ABC*/2 [20,26,27].

Despite its bias toward overestimation, *ABC*/2 has utility in volume estimation for many types of ICH in adult [6,7,9,17,21,23,28] and pediatric [18,29] patients, and even for some types of ischemic stroke [30] Attempts at simplification (by eliminating slice-correction) or bias reduction (by changing the denominator to 3 for non-ellipsoid ICH) have been proposed, but these alterations appear to risk over- or underestimation of ICH size [10,20].

The current study is characterized by a set of physician raters with important differences from those represented in the preponderance of the *ABC*/2 literature. The fact that the study center is home to a large ACGME-I accredited EM residency training program and a large fellowship for post-residency training; the finding from present study can be externally considered in similar academic settings.

A limitation to consider, the current study provides information on *ABC*/2 evaluation at a busy academic ED that sees a broad scope of nationalities, with demographics that are dissimilar to those of cases reported in existing studies. As compared to the cases comprising much of the *ABC*/2 evidence base, the patients in the current study are younger, far less likely to be anticoagulated (3 of 100 cases in the current study as compared to nearly 1 in 5 in a Cincinnati *ABC*/2 study) [19], and have smaller ICH volumes (likely due to lower rates of anticoagulation) [10,20,23,25].

In sum, the study center for the current investigation had characteristics that were unusual compared to the preponderance of the *ABC*/2 evidence base. As an extremely busy ED (with nearly a half-million visits annually) with a large academic EM presence, no 24-h neuroradiology coverage, and frequent execution of *ABC*/2 by EM and radiology personnel, the study site seems an appropriate setting for further validation of *ABC*/2 agreement between EM and radiology CT evaluators.

5. Conclusion

In a busy academic ED, studying a population that was both younger and less likely anticoagulated than the cases of most other ICH studies, the current analysis identified excellent levels of agreement in *ABC*/2-calculated bleed volumes. From EM interns to EM Attending physicians, the mean difference in all-case ICH volume estimate was approximately 1 mL. The levels of disagreement that were identified, were mostly due to differences in calculating the maximum single-slice bleed area (*i.e.* the *AB* term) rather than the vertical bleed dimension (*C*). Other than the finding that dichotomous assessments of ellipsoidality showed unacceptable levels of agreement, the study results strongly support the employment of *ABC*/2 in an academic ED setting for use by EM raters of a variety of training and experience levels. Further investigation is indicated to elucidate methods for minimizing the 95% limits of *ABC*/2 agreement, to improve *ABC*/2 clinical applicability even more.

Conflicts of interest

None.

Disclaimer

The views expressed in this paper are attributed to the authors alone and is not an official position of the institution.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2018.12.036.

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