Journal of Clinical Neuroscience 40 (2017) 39–43

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Clinical commentary

Mathematical formulae to estimate chronic subdural haematoma volume. Flawed assumption regarding ellipsoid morphology

Appukutty Manickam [a], Laurence A.G. Marshman [a,b,*], Ross Johnston [c], Piers A.W. Thomas [a,b]

[a] Department of Neurosurgery, The Townsville Hospital, Douglas, Townsville 4810, Queensland, Australia
[b] School of Medicine and Dentistry, James Cook University, Douglas, Townsville 4810, Queensland, Australia
[c] Department of Marine & Tropical Biology, James Cook University, Douglas, Townsville 4810, Queensland, Australia

ARTICLE INFO

Article history:
Received 8 October 2016
Accepted 27 December 2016

Keywords:
Mathematical formula
Chronic
Subdural haematoma

ABSTRACT

Mathematical formulae are commonly used to estimate intra-cranial haematoma volume. Such formulae tacitly assume an ellipsoid geometrical morphology. Recently, the '*XYZ*/2' formula has been validated and recommended for chronic subdural haematoma (CSDH) volumetric estimation. We aimed to assess the precision and accuracy of mathematical formulae specifically in estimating CSDH volume, and to determine typical CSDH 3-D morphology. Three extant formulae ('*XYZ*/2', '$\pi/6\cdot XYZ$' and '$2/3S\cdot h$') were compared against computer-assisted 3D volumetric analysis as Gold standard in CTs where CSDH sufficiently contrasted with brain. Scatter-plots ($n = 45$) indicated that, in contrast to prior reports, all formulae most commonly over-estimated CSDH volume against 3-D Gold standard ('$2/3S\cdot h$': 44.4%, '*XYZ*/2': 48.84% and '$\pi/6\cdot XYZ$': 55.6%). With all formulae, imprecision increased with increased CSDH volume: in particular, with clinically-relevant CSDH volumes (i.e. >50 ml). Deviations >10% of equivalence were observed in 60% of estimates for $2/3S\cdot h$, 77.8% for '*XYZ*/2' and 84.4% for '$\pi/6\cdot XYZ$'. The maximum error for '*XYZ*/2' was 142.3% of a clinically-relevant volume. Three-D simulations revealed that only 4/45 (9%) CSDH remotely conformed to ellipsoid geometrical morphology. Most (41/45, 91%) demonstrated highly irregular morphology neither recognisable as ellipsoid, nor as any other regular/non-regular geometric solid. *Conclusions:* Mathematical formulae, including '*XYZ*/2', most commonly proved inaccurate and imprecise when applied to CSDH. In contrast to prior studies, all most commonly over-estimated CSDH volume. Imprecision increased with CSDH volume, and was maximal with clinically-relevant CSDH volumes. Errors most commonly related to a flawed assumption regarding ellipsoid 3-D CSDH morphology. The validity of mean comparisons, or correlation analyses, used in prior studies is questioned.

1. Introduction

Assessment of chronic subdural haematoma (CSDH) volume is of both academic and clinical significance. For example, evacuation of even 20% of CSDH volume may suffice to induce spontaneous CSDH resolution [1].

Mathematical formulae are commonly used to assess the volume of any intracranial haematoma (ICH). All such formulae tacitly assume a spherical or ellipsoid geometric morphology for the ICH [2]. Since ellipsoid volume ($4/3\cdot\pi\cdot r_1\cdot r_2\cdot r_3$, where r represents each radius) approximates to $4\cdot d_1/2\cdot d_2/2\cdot d_3/2$ (where d represents each diameter), the ellipsoid formula reduces to $(d_1\cdot d_2\cdot d_3)/2$, or '*XYZ*/2'. Over time, the ellipsoid '*XYZ*/2' formula has become popular for assessing ICH volume [3–6]. Sucu et al. recently validated and formally recommended the '*XYZ*/2' formula for use *specifically* in CSDH volumetric analysis [7]. However, validation in that study [7] largely consisted of correlation analysis, which is not ideal for comparing measurement techniques of the same parameter [8]. Other ICH formulae, such as '$\pi/6\cdot XYZ$' [9] and '$2/3S\cdot h$' [10] (where S represents the surface area of the largest axial CSDH slice, and h the CSDH depth) have also been used to estimate CSDH volume.

We set out to validate ellipsoid-based mathematical formulae, including '*XYZ*/2', for use *specifically* in CSDH volumetric estimation. Computer-generated 3D volumetric analysis was used as 'Gold standard', and to graphically depict 3D CSDH morphology.

2. Methods

Adult patients with symptoms and signs requiring admission to the neurosurgical unit were initially considered. Children less than

* Corresponding author at: Department of Neurosurgery, The Townsville Hospital, Douglas, Townsville 4810, Queensland, Australia. Fax: +61 4433 1431.
E-mail address: l.a.g.marshman@btinternet.com (L.A.G. Marshman).

http://dx.doi.org/10.1016/j.jocn.2016.12.043
0967-5868/

18 yrs old were excluded because chronic subdural collections in this age group potentially represent a distinct pathological entity [11].

All patients had CSDH causing symptoms and signs that indicated neurosurgical admission. Patients were included where CTs demonstrated a convexity CSDH of suitable hypo-density, such that the CSDH sufficiently contrasted with brain to permit accurate estimation. Patients were excluded where CTs had demonstrated significant iso-dense CSDH which rendered estimation inaccurate. All tentorial and inter-hemispheric CSDH were also excluded.

One observer (AM) performed all radiological measurements from individual patient CTs. OsiriX™ software was used on images obtained from a Philips 64-slice MX8000 CT scanner to obtain 3-D estimates of CSDH volumes ('Gold Standard'). 'Gold Standard' CSDH volume was calculated using volume rendering based on: (slice cross-sectional area) × (No. slices) × (slice thickness [0.75 mm]) (Fig. 1a). CSDH volumes were also estimated using 3 different formulae, as previously described: '$XYZ/2$' [7] (Fig. 1b), '$\pi/6{\cdot}XYZ$' [9] and '$2/3S{\cdot}h$' [10]. Formulaic volumes were then compared against 3-D estimates as 'Gold standard' graphically (Figs. 2a–c). CSDH were also subjectively classified by inspection of 3-D computer simulations (by AM, blinded to associated formulaic data) into 'ellipsoid' and 'non-ellipsoid' (Fig. 3) geometrical morphological groups.

In any XYZ estimation, the largest volume slice (typically at the centre of the CSDH) was selected, and the linear distance between each corner of the CSDH 'crescent' was used to determine Y (cm) (Fig. 1b) [7,10]. The depth Z (cm) of the idealised ellipsoid was determined by multiplying the number of slices on which the CSDH was visible by the CT slice thicknesses (0.75 mm) [7,9,10]. The width X (cm) was measured using the maximum thickness of CSDH from the inner table of the skull perpendicular to X [7,10]. Because CSDH volume is the volume of the outer hemi-ellipsoid minus the volume of the inner hemi-ellipsoid, CSDH volume is $(Xa{\cdot}Y{\cdot}Z/2) - (Xb{\cdot}Y{\cdot}Z/2)$, or $(Xa - Xb){\cdot}Y{\cdot}Z/2$. This yields $X{\cdot}Y{\cdot}Z/2$ (since $X = Xa - Xb$) (Fig. 1b). In '$2/3S{\cdot}h$' estimation, 'S'(cm^2) represented the area of the largest axial CSDH slice (Fig. 1a), whilst 'h' was the depth of the CSDH: i.e. 'h' = 'Z' in 'XYZ' estimates [10].

Local Institutional Review Board (IRB) approval was obtained for the study who agreed to waive individual consent.

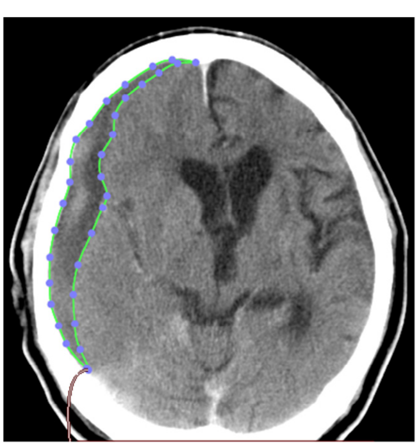

Fig. 1a. 'Gold standard' computerised 3-D volumetric analysis of chronic subdural haematoma (CSDH). Each CSDH was manually traced using the computer software. In '$2/3S{\cdot}h$' estimation, 'S' (cm^2) was the area of the largest axial CSDH slice, whilst 'h' was the depth of the CSDH: i.e. 'h' = 'Z' in 'XYZ' estimates.

2.1. Statistical analysis

Non-parametric Kruskal–Wallis (K–W) tests for differences in mean ranks. Graphical displays demonstrating scatter-plots with appropriate 'equivalence line' and 'error' estimates for quantification. Observer agreement was measured using intra-class correlation (ICC).

3. Results

CTs suitable for analysis were obtained in 45 patients from a total of 155: a larger number than in prior reports [7]. ICC for '$XYZ/2$' and 3-D Gold-standard estimates were 0.92 (CI 0.89–0.95) and 0.87 (CI 0.85–0.94) respectively. Gold standard mean CSDH volume was 92.87 ± 46.67 ml. The closest formulaic approximation to 3-D Gold standard was $2/3S{\cdot}h$ (mean: 101.98 ± 56.39 ml). As expected, CSDH volume estimates for '$XYZ/2$' (mean: 105.86 ± 57.72 ml) were similar to '$\pi/6{\cdot}XYZ$' (mean: 108.36 ± 59.05 ml).

Non-parametric K–W tests, used because of failed normality assumptions which had precluded ANOVA, did not detect significant between-groups volume differences (χ^2 1.5, $p = 0.688$). Graphical displays, however, demonstrated that between-groups data analysis with any attempted 'central tendency' measure approach, or with simple correlation/regression approaches, would mask otherwise explicit underlying patterns (Figs. 2a–c). Consistency between formulaic estimates, and gold standard, was therefore demonstrated graphically using scatter-plots, with appropriate 'equivalence line' and 'error' estimates for quantification (Figs. 2a–c). The failure of K–W analysis to detect significant volume differences questions the validity of standard mean comparisons, and of standard correlation analyses [8], used in prior studies [7].

Scatter-plots explicitly showed that all formulae most commonly over-estimated CSDH volume against 3-D Gold standard (Figs. 2a–c). With all formulae, imprecision (scatter) increased with increased CSDH volume: in particular, with increasingly clinically-relevant CSDH volumes (i.e. >50 ml) [12]. Deviations >10% of equivalence was observed in 60% of estimates for $2/3S{\cdot}h$, and in 84.4% for both '$XYZ/2$' and '$\pi/6{\cdot}XYZ$'. The maximum error for '$XYZ/2$' was 142.3% of a clinically-relevant volume (Figs. 2a–c). On inspection, 3-D simulations revealed that only 4/45 (9%) CSDH remotely conformed to an ellipsoid geometrical morphology. Instead, most CSDH (41/45, 91%) demonstrated highly irregular morphology neither recognisable as 'ellipsoid', nor as any other regular/non-regular geometric solid, readily amenable to simple mathematical modelling (Fig. 3).

4. Discussion

Assessment of CSDH volume is of both academic and clinical significance. A recent study purportedly validated and recommended the use of the '$XYZ/2$' formula to estimate CSDH volumes [7]. This study, as in ours, assessed '$XYZ/2$' against a computer-assisted 3-D Gold standard: however, CT slice thicknesses were not quoted. Further, validation largely consisted of correlation analysis, which is not ideal for comparing measurement techniques of the same parameter [8]. As our study demonstrated, mathematical formulae for ICH volume estimation [7,9,10], including '$XYZ/2$', are most commonly inaccurate and imprecise when applied to CSDH. In particular, all formulae most commonly over-estimated CSDH volume (Figs. 2a–c).

Criticisms regarding '$XYZ/2$' have been previously applied towards geometrically simpler shapes associated with intracerebral ICH. However, results have varied. Diavani et al., using both