An Investigation of juvenile cranial thickness-analysis of skull morphometrics across the complete developmental age range.

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Conflict of interest

None

Keywords

Forensic, Post-mortem computed tomography, Skull thickness, Juvenile.

Abstract

Current methods for measuring skull thickness in adults involve taking measurements from the skull at set points during autopsy. The aim of this study was to develop a reproducible method for measuring skull thickness in juveniles using Post-mortem Computed Tomography (PMCT). Thirty-nine juveniles underwent computed tomography scans as part of the autopsy examination. In those cases where the head scans showed no skull pathology they were made anonymous and entered into this study. One of the methods used at autopsy which is reported to yield the most consistent results was replicated using PMCT. A novel PMCT method was also developed using multi-plane reconstructions (MPR). Each PMCT method produced a set of results that showed a statistically significant positive correlation between age and the average skull thickness. This study shows that PMCT can be used to produce a standardised method for measuring juvenile skull thickness and could form an important component of forensic examinations in children.

Introduction

At present, there is little published data on juvenile skull thickness and its changes during growth and development of an infant's skull. Variations in skull thickness are important as they may relate to susceptibility to fracture. Current methods for measuring skull thickness were developed in adults (1-8) and may not be accurate in paediatric cases. Changes in skull height, bone thickness and skull plate composition differ in children, so simple scaling of adult head models is inappropriate. A method to accurately measure juvenile skull thickness is therefore required.

The most common method of measuring adult skull thickness at autopsy is to measure the thickness of the frontal, temporal and occipital bones at the level where the top of the cranium is removed, using a saw. However, this level is highly variable and may not give a true indication of overall skull thickness. Child bone thickness is rarely measured due to the lack of comparative data. In 1975, Ross *et al.,* (9) suggested a method of measuring the physical skullcap of adults at autopsy using standardized anatomical points. This involves making a horizontal saw cut of the skull (at roughly the same level all the way round) and using vernier calipers to measure parietal and frontal bone thickness, at four different points. Bilateral bony windows are removed from the parietal and frontal bones, 4 cm postero-laterally and antero-laterally respectively from the Bregma and the thickness of these bone windows measured (figure 1). These are the sites of the skull that are considered to be least affected by structural variations such as ectocranial muscle attachments, sinus sites or age related bone change. The measurements are then used to produce an index of skull thickness.

Later Smith *et al.,* (10) presented an automated approach using computed tomography (CT) images and identified soft tissue landmarks. Although this method was more accurate and repeatable than Ross *et al.*, it is extremely complex and requires specific software.

PMCT has been successfully used in the field of anthropology to produce accurate measurements for biological profiling (11-13). We therefore considered that the method of Ross *et al*., (figure 1) could be adapted to post-mortem computed tomography (PMCT) scans, and would be less invasive, faster and more reproducible..

We also developed a novel method for measuring the skull thickness on PMCT. The difficulties in developing a new method were that in juvenile populations the growth rate is extremely variable and so it was difficult to establish a standardised point to begin measurements. We settled upon measuring the average thickness at the image slice where the skull was at the maximum bi-parietal diameter. This is a measurement commonly carried out clinically to measure fetal gestational age (14).

Materials and Methods

Thirty-nine cases from 0-18 years were selected retrospectively where a PMCT scan had been performed as part of the autopsy examination undertaken by the East Midlands Forensic Pathology Unit. The scans had a slice thickness of 1mm and a bone reconstruction algorithm and window was used. Any scans with skull pathology, trauma or that used a significant tilt of the scanner gantry, which alters the proportions of the images, were excluded. For each scan the anonymized DICOM image-set was transferred to an Apple Mac Pro workstation, and the radiograph data was processed for analysis using OsiriX 3D imaging software (version 3.7.1; distributed freely as open-source software under the GNU licensing scheme at the following Web site: http://homepage.mac.com/rossetantoine/osirix. Pixie: Switzerland).

Method 1 - Replication of Ross et al

The scans were viewed as a 3D-MPR. A step-by-step guide of the measurement protocol is shown in figure 2. The skull thickness was then calculated, with a line that is normal to the skull table. The mathematical theory is given in figure 3. This method is repeated 4 times to produce the average of 4 thickness measurements at four different locations.

Method 2 - Bi-parietal diameter (BPD)

To undertake Method 2 the images were aligned into the correct anatomical position using the 3D-MPR setting, as with Method 1 (figure 2A). Then a new set of 2D images (DICOM files) were created in the correct alignment to allow accurate measurement of BPD. The measurement protocol used for Method 2 is illustrated in figure 4. The area between the two Regions of Interest was found (by subtracting the smaller from the larger area). The average thickness is the distance between the two circles, which is calculated by assuming that if the area were made straight, it would resemble a trapezium. Using the area and the two distances (circumferences), the height (average skull thickness) can be found, by dividing the area of the trapezium by half of the sum of the two circumferences (figure 5).

In order for these methods to be useful in juvenile anthropological examination, the data collected was compared with the age of the individual scans in order to assess any correlation (figure 6). Data were tested for normalcy and Pearson Correlation coefficients calculated for normal data and Spearman Rank Correlation coefficients where normalcy was not achieved.

Results

Of the original 39 cases, 7 were excluded due to trauma and 2 due to significant gantry tilt. Age range was 0.8 to 216 months (18 years old). The number varied depending on the method, as Method 1 could not be completed on 2 scans, due to difficulties locating measurement landmarks, leaving 28 cases for Method 1 and 30 cases for Method 2.

Normalcy was shown for Method 1 data, but Method 2 showed more variation from the normal distribution plot and normalcy was not confirmed. Both methods showed a strong correlation of measurement with age (Pearson correlation co-efficient $r=0.833$, ($p<0.0001$) for Method 1 and Spearman's rank correlation co-efficient $r = 0.896$ ($p<0.0001$) for Method 2. Figure 6 shows a potential positive correlation between age and average cranial thickness. It also shows a variable region between the ages of 0-5 years.

Two different individuals carried out each method. The results from each individual were compared using a Bland-Altman plot. Figure 7 shows the Bland-Altman plot for each method. The plots show that in Method 2, there were smaller deviations from the mean value, compared to Method 1.

Discussion

We have shown that PMCT images can be used to measure mean skull thicknesses in a rapid and non-invasive way (15). We propose this is also a more reliable method than autopsy derived bone measurements, however this would need to be evaluated scientifically in another study. We have shown that there is a positive correlation between age and mean skull thickness using PMCT to replicate this method.

We also set out to compare methods of measuring the mean skull thickness at CT. The results from the Bland-Altman comparison show that there is less inter-observer variation with the bi-parietal diameter method, as opposed to the method adapted from Ross *et al.* This implies that the method using bi-parietal diameter might produce more reproducible results if applied to other cases.

We acknowledge that our sample size is small and that a larger sample size is needed to develop the PMCT method to establish a range of normal measurements for thicknesses at different landmarks across the age range. This future work may be of particular use to forensic pathologists examining head trauma in children. The ideal output would be to develop a mathematical rule to predict age from mean skull thickness. This would allow a simple calculation of the approximate age range of a particular specimen. This would be particularly useful from ages 0-4 years, because this was the range that showed the most variability in the results. This would be important as a large majority of child head trauma cases fall within this age category.

Summary

This study provides evidence that traditional anthropometric methods can be replicated using PMCT to provide a fast, non-invasive method to measure juvenile skull thickness. Given further investigation, this approach may begin to assist those investigating accidental and non-accidental head injuries in the paediatric population.

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Figures

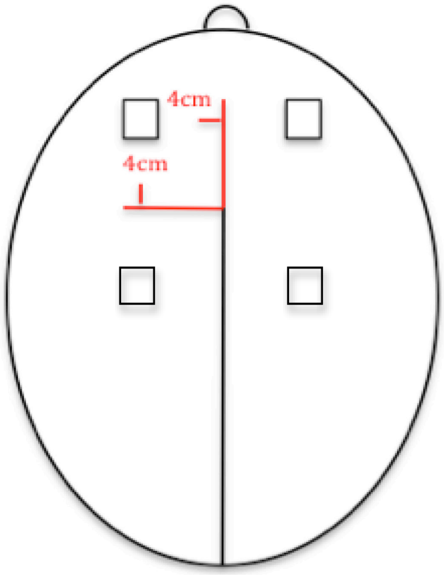


Figure 1. The location of the bone windows used to measure the thickness of the frontal and parietal bones of the skull. Ross A.H, Jantz R.L, McCormick W.F (1998).

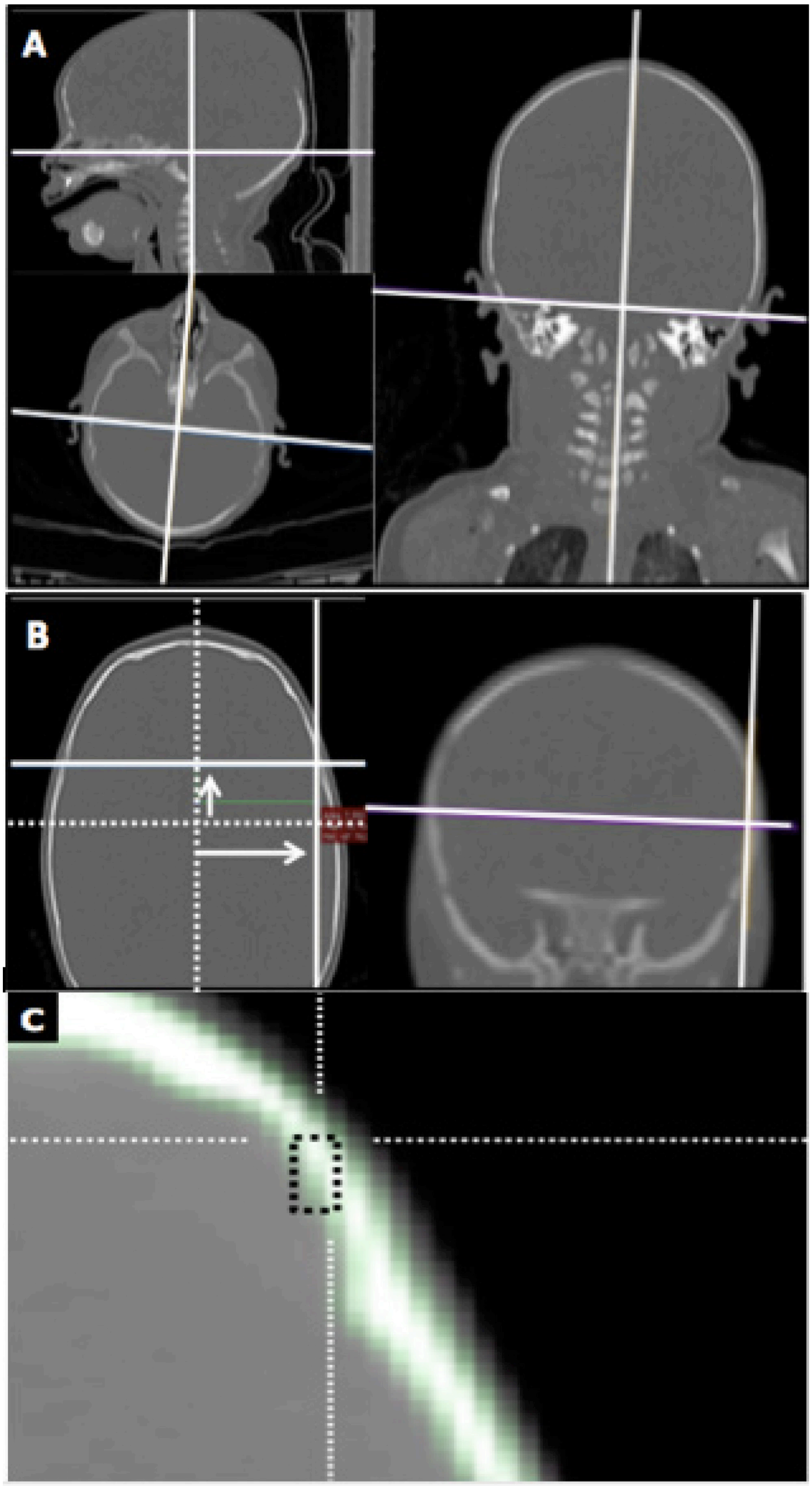


Figure 2. Step-by-step measurement protocol for Method 1. A) Align the head to the correct anatomical position, 1) by using the sagittal view to locate the axial plane in the anthropological baseline (inferior orbital margin to external auditory meatus), and 2) using the axial view align the sagittal axis centrally using the nasal cavity, ethmoid sinuses and falx cerebri as a guide. Scroll the coronal images assisted by

the sagittal view to identify the bregma (“bregma line”). The coronal view should now show the bregma superiorly and the posterior edge of the first three cervical vertebrae inferiorly.

B) In the axial plane using the axis tool, the sagittal plane can be adjusted to 4cm from the midline (each side) and the coronal plane 1cm from the “bregma line” (anterior and posterior). The axial plane can then be scrolled until the bisection of the sagittal and coronal lines crosses the skull. This defines 4 measurement points. This can be assisted by creating a rectangular region on interest of 4 x 1 cm.

C) The thickness measurement could be measured directly at this point but greater consistency is achieved if the rectangle measurement tool is used, starting at the point of the coronal section intersecting the outer skull table, placing one corner on the outer edge and two corners on the inner edge.

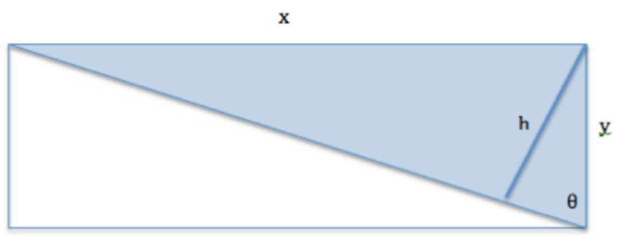


Figure 3. Illustrates the results of the measurement method (shaded area represents the cranium). The length ‘y’ is the line that tracks along the vertical axis. Given that the two lengths ‘x’ and ‘y’ are given as part of the rectangle ROI function, θ’and therefore ‘h’ (the skull table thickness) can be calculated.

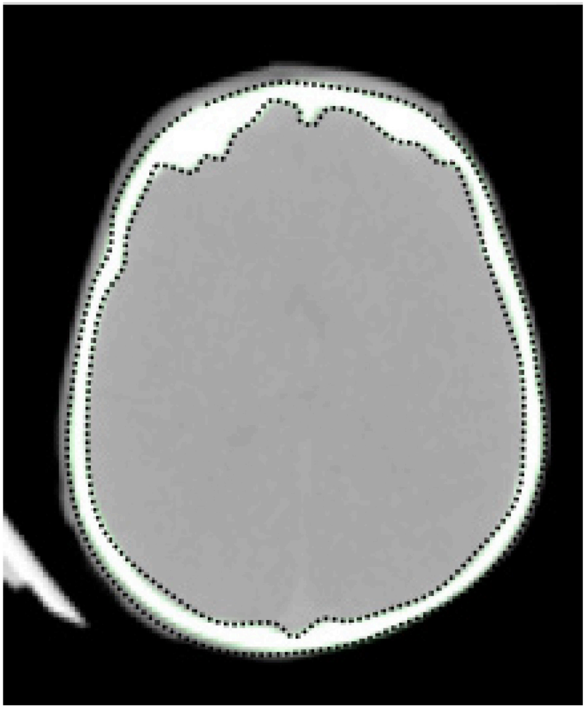


Figure 4. Measurement protocol for Method 2. A) Find the axial slice that has the maximum bi-parietal diameter (routinely measured outer edge to inner edge of the other side)

B) Trace around the outer and inner border of the skull (dashed lines). Record the circumference and the area of each region.

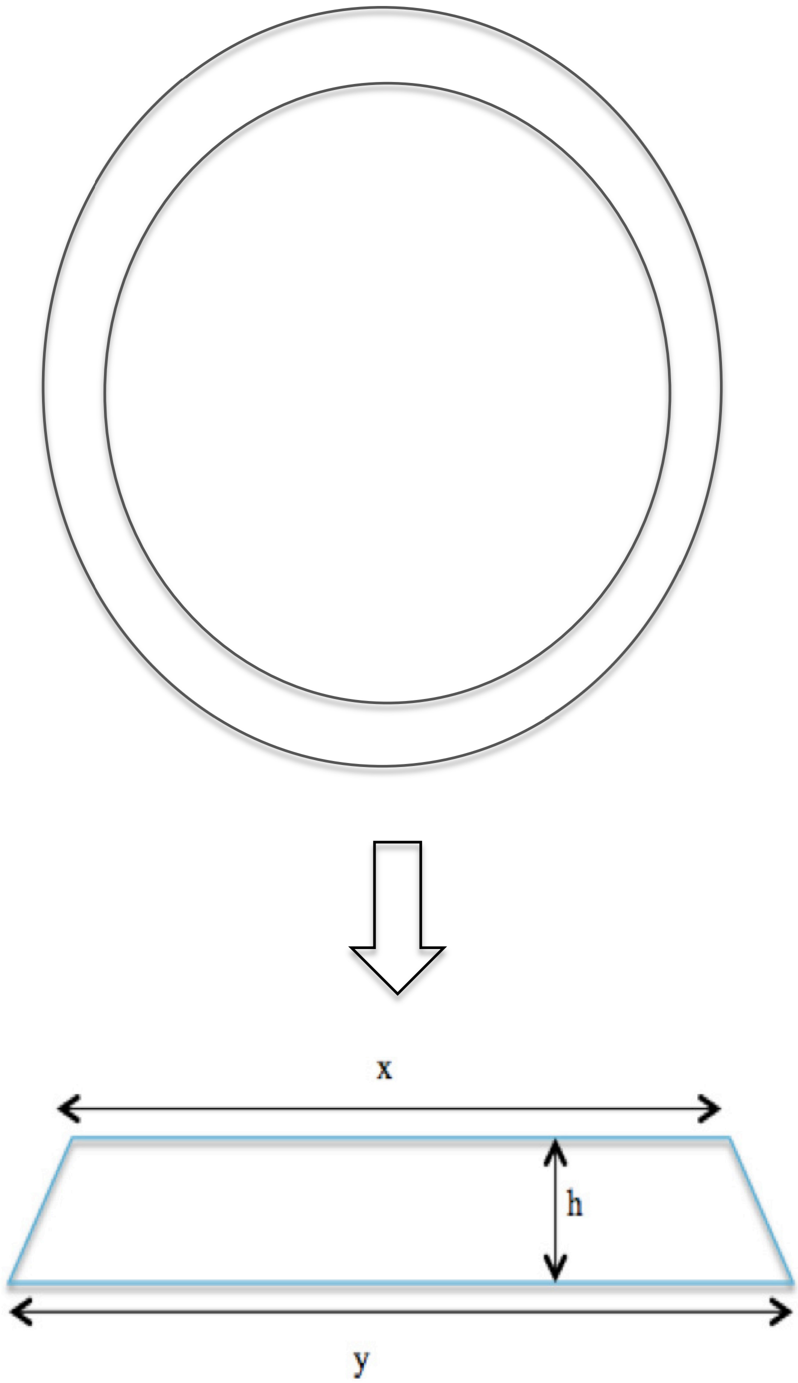


Figure 5. The space between the inner and outer boundary can be approximated to a trapezium with area (A) = outer – inner area, and long axes (x and y) the two measured circumferences. For a trapezium area = ½ (x+y)h, therefore skull thickness (h)=2A/(x+y)

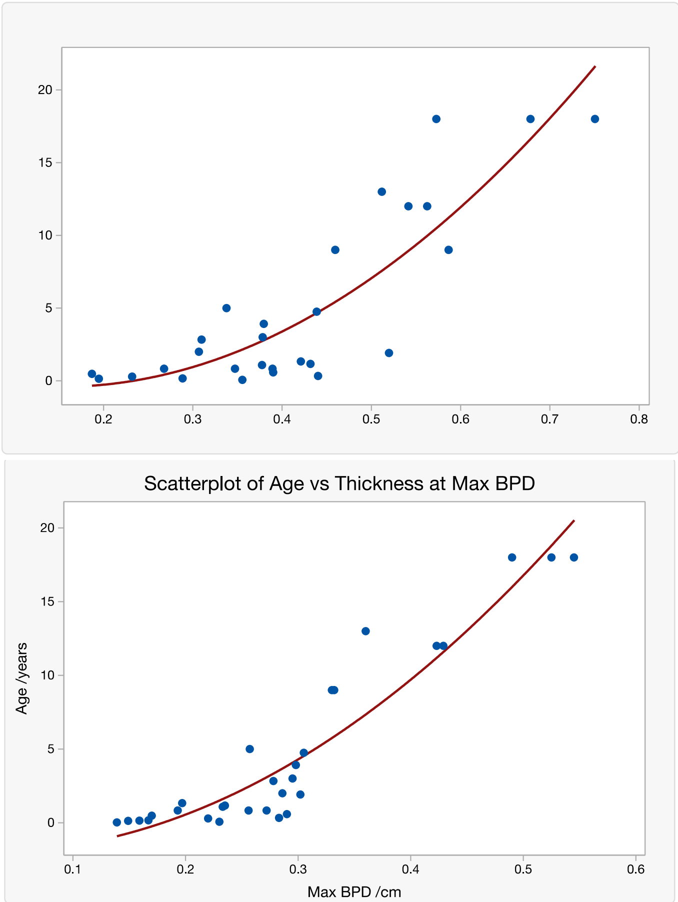
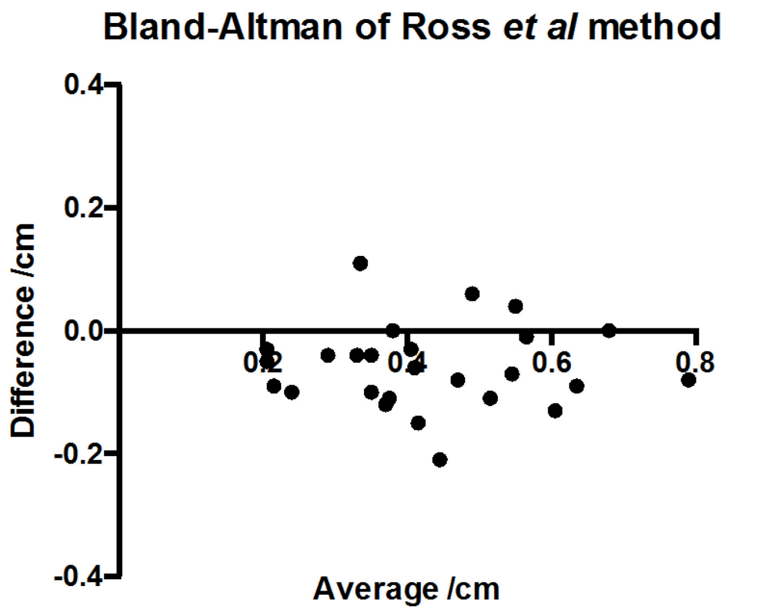


Figure 6. A) Age vs mean skull thickness Method 1. There is a positive correlation between the two variables; thickness of the cranium increases with age. B) age vs mean skull thickness at maximum BPD (method 2).



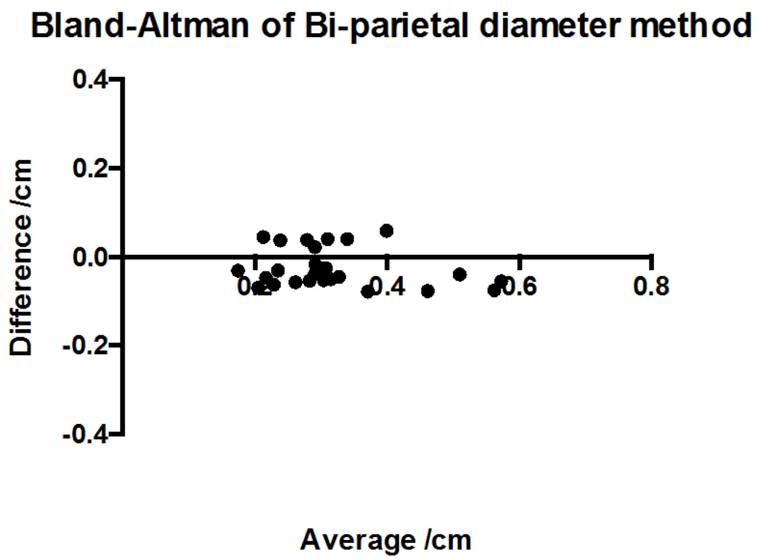


Figure 7. A) Bland Altman plot for Ross *et al* method.B) Bland Altman plot for bi-parietal diameter method.