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ASSESSMENT OF INTRACRANIAL VOLUME PRIOR AND AFTER SURGICAL CORRECTION IN PATIENTS WITH CRANIOSYNOSTOSIS

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Abstract

Background: Craniosynostosis (Craniostosis) is a congenital defect that causes ≥1 suture to fuse prematurely. Cranial expansion surgery is done to correct the skull to a more normal shape of the head as well as to increase the intracranial volume (ICV).
Aim and Objectives: To assess the intracranial volume (ICV) in craniosynostosis patients after the cranial reshaping surgeries and comparing the preoperative values with the postoperative and normal values.

Patients and Methods: This study included a list of all 130 patients who underwent craniosynostosis corrective surgeries and identified retrospectively and prospectively at Abu El-Rish Hospital during a 4-year window from 2017 to 2021.

Results:- There is a highly significant difference between the variables Pre and Post ICV, where $p=0.002$, $p<0.01$. for Males, ICV was 850, 1150, 1250 and 1350 cm3 at age of <12 months, 12 to 24, 24 to 36 and > 36 months respectively. For females, ICV was at lower values being at 790, 1000, 1200 and 1230 cm3 respecting the same age groups. “Pre ICV, Post ICV” are not significant, where ($p = 0.990$, $p = 0.153$) > 0.05, “Normal volume” is significant, where ($p = 0.003$).

Conclusions:- Measuring intracranial volume in early-presenting cases of craniosynostosis would be the cornerstone in determining the optimal time for surgery on clinical terms. Also, in late-presenting cases, recurrence would be predicted. Increased ICV allows better neurodevelopment and denies any delay.

Keywords: Craniosynostosis, Intracranial Volume, Surgical Correction, CT with 3D construction

BACKGROUND

Craniosynostosis occurs when an infant's skull growth plates (also called sutures) close too soon. Non-syndromic craniosynostosis describes the disorder when it only affects the skull's growth plates and not any other tissues. Craniosynostosis may run in families, although it usually develops on its own for unknown reasons, including a growth restriction in the womb. Conditions such as a shallow pelvis, insufficient amniotic fluid, huge birth weights, and multiple births are all examples.

The brain triples its volume in the first life ad reaches its adult size by the age of 6 to 10 years old. Cranial sutures can accommodate brain growth (1).

When a suture closes prematurely, increased intracranial pressure (ICP) occurs with abnormal head shape because of compensatory expansion required by the growing brain. ICP which Defines as 15 mm Hg in slow-wave sleep, classically presents with headache, nausea and vomiting. Clinical identification of the predicted skull deformations brought on by compensatory growth is common, however a CT scan may be acquired to be sure. Delayed diagnosis would lead to neurodevelopmental delay in children (2,3).

Metopic and sagittal sutures divide the parietal bones, whereas coronal & lambdoid sutures divide the frontal & parietal bones, and the occipital bones are separated by the sagittal and coronal sutures. Depending on the abnormalities of the suture, the skull may take on an irregular form as a result of the cranial anomaly (4).

The treatment of craniosynostosis is surgical which and most is performed between 6 months and 2 years. An increase in intracranial pressure caused by alterations in head shape, configuration, or volume might necessitate surgery in a limited number of patients (10-15%). The craniofacial team's efforts, however, can maximize the results because most instances are addressed due to the ensuing cosmetic skull defects. Yet, the connection between ICV as well as elevated ICP signs and the impact of surgery on ICV are still up for discussion. This is a volumetric research that uses 3D CT scans to quantify the intracranial volume (ICV) changes in children with craniosynostosis following surgery, comparing the ICV to the ICV before surgery and to the normal ICV for the individual's age & gender (5).

The aim of the work was to assess the intracranial volume (ICV) in craniosynostosis individuals after the cranial reshaping surgeries and comparing the preoperative values with the postoperative and normal values. This determines the changes occurred postoperatively and will allow us to define the best timing to operate in craniosynostosis.

PATIENTS AND METHODS

This research involved a list of all 130 cases who underwent craniosynostosis corrective surgeries and identified retrospectively and prospectively at Abu El-Rish Hospital during a 4-year window from 2017 to 2021.

In 42 cases out of 130, we managed to find pre-operative and post-operative 3D CT scans fully documented and charted. The rest had either no compact discs (CDs) documenting the imaging outcomes, had less than 200-250 images needed for creating the 3D model, or only had paper reports which did not allow the measurement of intracranial volume.

Out of those 42 cases, only seven had full imaging studies (i.e., complete DICOM data) that allowed for the ICV measurement. As for the software used, a program called Medical Imaging Interaction Toolkit (MITK) was used to assess the seven cases recruited retrospectively.

The sample size was deemed small and a prospective approach was adopted to increase the number of included patients. Therefore, 8 additional cases were recruited consecutively from our clinic at Abu El-Rish Neurosurgery Clinic. The recruitment extended from September 2019 to November 2021.

The follow-up of cases using 3D CT brain scans varied but mostly ranged between 2 and 6 months. For cases where follow up was more or less than six months, it was decided upon consulting our chief supervisor at the department. Measurements were done at Misr Scan Radiology Center as it is one of

only two centers in town that have the technical abilities to measure ICV.

Inclusion criteria: Age: till age of 5 years (60 months old), Sex: No restrictions, Craniosynostosis type: Any and Imaging: CT 3D on CD with an acceptable DICOM data (250-300 slice cuts) .

Exclusion Criteria: Age: more than 5 years and Imaging: CT 3D on a printed paper or on CDs with DICOM data less than 250 slice cuts.

ICV Measurement: ICV can be indirectly measured by capturing images inside of the human skull using radiologic techniques such as computed tomography (CT) scan. There are several methods for estimating ICV using these radiologic techniques, for instance, the Cavalieri method, named after Bonaventura Francesco Cavalieri (1598-1647), Italian Mathematician, a disciple of Galileo.

The algorithm reconstructs the 3D object from a group of 2D sets representing sections of that object. The one-mm slice thickness of CT images is good for evaluation and 3D reconstruction. However, about 200 CT slices are needed to determine ICV for manual slice by slice method-tedious and time consuming. Therefore, we are applying shape-based interpolation method (6) utelizing open-source MITK software (7). That is also why we excluded cases where we could not obtain more than 200-250 CT scan slices to reconstruct a 3D model.

Statistical Analysis

Abstracted data were compiled & analyzed utelizing SPSS version 18 (SPSS Inc., Chicago, IL) with statistical significance established at $p \leq 0.05$. Continuous variables are presented as means (± standard deviation [SD]), & categorical variables are presented utelizing relative frequency distributions & percentages. Time intervals are presented as means (±SD). Continuous variables were compared utelizing Student's t-test or the Mann-Whitney test, & categorical data were analyzed utelizing the chi-square test, Yates' continuity correction, Fisher's exact test, &/or unadjusted odds ratios (ORs) as appropriate. Statistical significance established at $p \leq 0.05$.

RESULTS

Table (1): Mean values of Age, Pre and Postoperative ICV, Imagine Interval and ICV difference

	N	Minimum	Maximum	Mean	SD
Age in months	15	5.00	50.00	21.07	16.28
Pre ICV in cm3	15	510.20	1231.60	862.18	206.70
Post ICV in cm3	15	557.80	1395.50	1056.08	272.68
Imaging interval in months	15	<1	> 6	6.3	4.99
ICV Difference in cm3	15	7.00	659.60	193.91	203.45

This table showed that, the youngest cases involved was 5 months old while the oldest was 50 months old. Mean value was 21.07 while SD was 16.28. The least preoperative ICV recorded was 510.20 cm3. However, the highest value was 1231.60 cm3 with mean value of 862.18 and SD 206.70. Regarding postoperative ICV, values were 557.80, 1395.50, 1056.08 and 272.68 respectively. The least ICV difference recorded was 7.00 cm3 in a patient with postoperative follow-up scan done at less than one-month interval (4 days). However, the highest recorded ICV difference was 659.60 cm3 in a patient with postoperative interval of more than 6 months (around 10 months).

Table (2): Gender Inclusion

Gender	Frequency	%
Male	8	53.3
Female	7	46.7

This table showed that 8 male patients and 7 female patients were included in our study.

Table (3): Craniosynostosis Types

Diagnosis	Freq.	%
Scaphocephaly	6	40.0
Brachycephaly	5	33.3
Anterior Plagiocephaly	1	6.66
Oxycephaly	2	13.33
Complex: Cloverleaf skull	1	6.66
Total	15	100

This table showed that six patients with scaphocephaly, five with brachycephaly, two with oxycephaly, a single patient with anterior plagiocephaly and the last one with complex craniosynostosis.

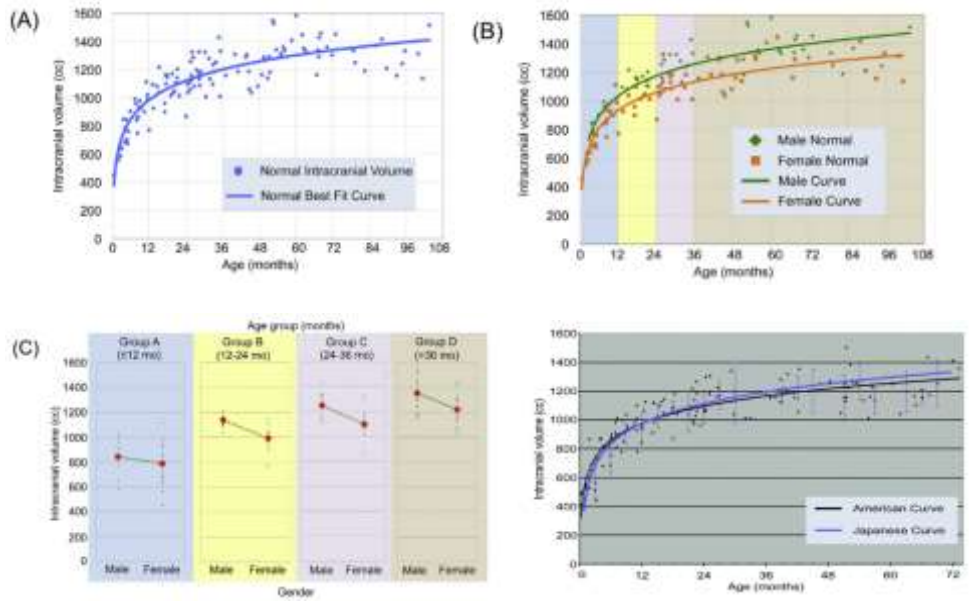

Fig. (1). Intracranial volume (ICV) of normal Asian children.

(A) Scatter plot of normal intracranial volumes by age (in months).
(B) Scatter plot of normal intracranial volumes by age (in months) in both male and female subjects.
(C) Data plotted incrementally by age as Group A (twelve months, blue), Group B (thirteen to twenty four months, yellow), Group C (twenty four to thirty three months, purple), & Group D (>36 months, brown) for gender comparisons (unpaired Student's t-test applied).
(D) Intracranial volumes in normal Asian children relative to American norms. The ICV curve of Japanese children is obtained as a blue line while the ICV curve of American children is in black.

Table (4): Normal ICV values.

Age (Month)	Male	Female
<12	850	790
12 to 24	1150	1000
24 to 36	1250	1100
>36	1350	1230

This table showed that, For Males, ICV was 850, 1150, 1250 and 1350 cm3 at age of <12 months, 12 to 24, 24 to 36 and > 36 months respectively. For females, ICV was at lower values being at 790, 1000, 1200 and 1230 cm3 respecting the same age groups.

Table (5) Statistics: Kolmogorov-Smirnova

	Kolmogorov-Smirnova		
	Statistic	df	Sig.
Pre ICV	0.084	15	.990*
Post ICV	0.196	15	.153*
Normal Volume	0.271	15	0.003

This table showed that "Pre ICV, Post ICV" are not significant, where (p = 0.990, p = 0.153) > 0.05, which means that we accept the null hypothesis which said that they are normal. "Normal volume" is significant, where (p = 0.003), which mean that we can't accept the null hypothesis which means that "Normal Volume" is non-normal.

Table (6) Statistics: Paired Samples T Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pre - Post ICV	-193.91	203.46	52.53	-306.58	-81.24	-3.691	14	.002

There is a Highly significant variance among the variables Pre & Post ICV, where p=0.002, p<0.01.
Case presentation
Case: Brachycephaly
Four-year-old female patient with brachycephaly
Pre ICV = 904 mL
Post ICV = 912 mL (3 weeks later)
ICV Difference 8 mL

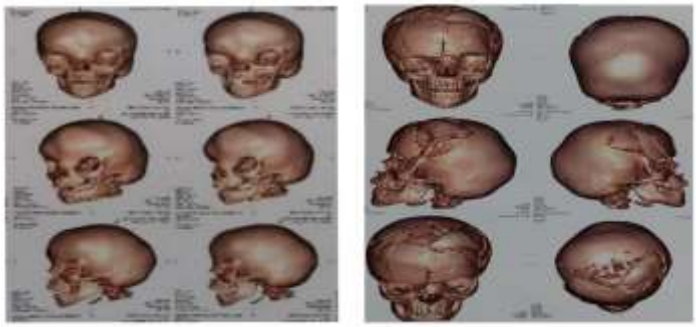

Fig. (2): Pre and Postoperative CT3D

Fig: (3) Imaging – 4-year-old male patient with brachycephaly (a) The left column: Preoperative. (b) The middle column: Intraoperative. (c) The right column: 6-months-Postoperative.

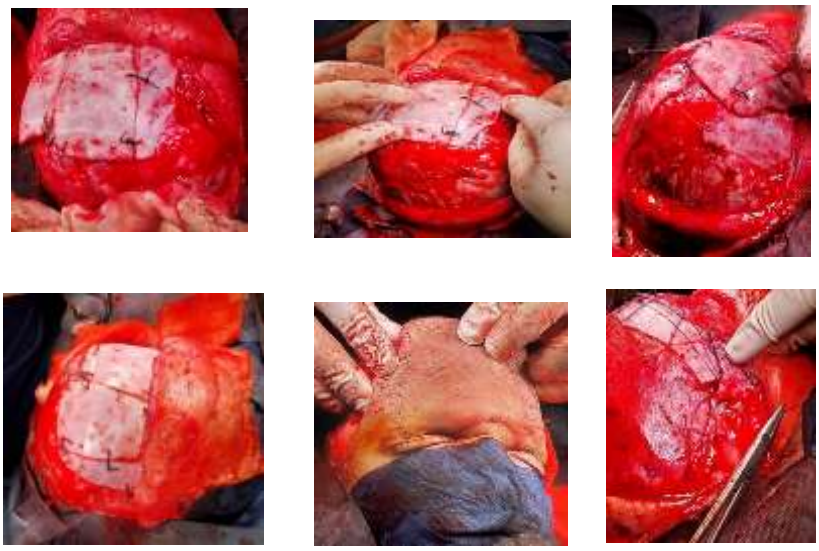

Fig. (4): Intraoperative – steps and interventions Bone fragmentation – Remodeling and fragment repositioning and suturing.

DISCUSSION

Our study emphasizes the importance of measuring ICV in early-presenting cases of craniosynostosis and its role in better-estimating the time for a proper surgical intervention, prediction of recurrence and decreasing the need for reoperations, which come with a higher risk of complications.

The timing of surgical intervention is usually dependent on various factors including the type of surgical approach, which was found to affect the overall clinical outcomes, intracranial volume and pressure, and even parents' preferences (8).

In terms of different surgical techniques, a study by Van Veleen showed that children who undergo sagittal suture synostosis in the second half of their 1st year of life yield a higher risk of developing papilledema (9).

The rationale behind such preference is to decrease the risk of developing increased ICP when surgeries are delayed, and to improve the long-term outcomes of therapy (10).

Intracranial pressure and volume are also crucial as they are important determinants of a successful therapeutic approach, especially in syndromic craniosynostosis (11).

Statistical estimates show that around 40-70% of cases with Apert syndrome, Crouzon-Pfieffer syndrome & Saethre-Chotzen syndrome may develop raised ICP, and hence are candidates for an earlier surgical approach (11).

One of the challenges that affect timely surgical intervention is the referral system complications. This is mainly due to the under recognition of craniosynostosis, especially in earlier phases, which limits referral to specialists in a timely manner (12).

This under-recognition can be caused by the lack of training for primary care physicians and the high rate of positional cranial deformities, which complicates spotting the diagnosis of craniosynostosis (13).

A study found that only 28% of patients with craniosynostosis are referred to specialists before the age of three months (11,14).

In terms of improving recognition, it was suggested that the use of a flowchart that helps in distinguishing among positional cranial deformity & craniosynostosis can be used to enhance the distinction and accelerate referral of craniosyntosis cases to specialist care (15).

In a study on eighty nine referrals with the initial diagnosis of non-synostotic occipital plagiocephaly (NSOP) made by the referrer, ten cases were found to have craniosynostosis (false negative 11.2 percent & false positive 22.2 percent) (11,16).

Identifying and assessing a deformed skull usually does not indicate the need for radiologic tests or genetic analyses (11). Current guidelines recommend that general practitioners and non-specialized professionals avoid delaying the referral of patients with skull deformities that are suspicious of

craniosynostosis to specialized clinic (11).

Our data showed that ICV measurement might be used as the key factor to determine the most proper timing for surgical intervention. Therefore, making the decision to assess ICV and choosing the best approach can be critical as part of the management plan. There are plenty of methods that allow for estimating the ICV. Some of these methods utilize the cephalometric measurements of the skull including width, height and length taken from specified dimensions of the bony structure (temporo-parietal and fronto-occipital), a predetermined formula is then applied to estimate ICV based on the skull's dimensions. Computed Tomography (CT) Scan & Magnetic Resonance Imaging (MRI) are the most commonly utelized radiographic methods that fall under this category, and they yield high accuracy and reliability (17).

Recurrence of craniosynostosis after surgical intervention, also referred to as "resynostosis" is not well investigated in the medical literature (18). There is inadequate evidence that describe its incidence, implications, prognostic factors or any preventive measures, in both syndromic and non-syndromic cases (18,19).

The available studies showed a spectrum of rates. For instance, Foster et al. retrospectively examined 119 consecutive patients with craniosynostosis (18).

Those outcomes were similar to another study by Wall et al. (20) but relatively smaller than percentages reported by McCarthy et al. whose data showed a resynostosis rate of 13.5% (n = 14) for isolated, non-syndromic cases (21).

Our outcomes also emphasize that ICV could help in predicting recurrence and avoiding any delay in reoperations. Assessing ICV and ICP, especially in patients with increased ICP symptoms (e.g., irritability and papilledema), is currently deemed as an important step in predicting resynostosis, confirming its diagnosis and achieving a timelier intervention (22).

CONCLUSION

Measuring intracranial volume in early-presenting cases of craniosynostosis would be the cornerstone in determining the optimal time for surgery on clinical terms. Also, in late-presenting cases, recurrence would be predicted, thus, reoperation options would be eliminated.

Corrective cranial surgeries improved both ICV and deformed appearance. ICV measurement might be used as the key factor to determine the most proper timing for surgical intervention. Increased ICV allows better neurodevelopment and denies any delay.

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