ORIGINAL ARTICLE

Correlation between Transcranial Ultrasound and CT Head to Detect Clinically Significant Conditions in Post-craniectomy Patients Performed by Emergency Physician: A Pilot Study

Rahul Chouhan[1], Tej P Sinha[2], Sanjeev Bhoi[3], Atin Kumar[4], Deepak Agrawal[5], Jamshed Nayer[6], Ravindra M Pandey[7], Praveen Aggarwal[8], Meera Ekka[9], Prakash R Mishra[10], Akshay Kumar[11], Divya C Chouhan[12]

Received on: 03 January 2024; *Accepted on:* 05 February 2024; *Published on:* 29 February 2024

Abstract

Background: The main objective is to detect clinically significant conditions by transcranial ultrasound (TCS) in post-decompressive craniectomy (DC) patients who come to the emergency department.

Materials and methods: This was a cross-sectional observational study. We studied 40 post-DC patients. After primary stabilization, TCS was done. Computer tomography of head was done within 2 hours of performing TCS. The correlation between both modalities were assessed by the measurement of lateral ventricle (LV) (Bland-Altman plot), Midline shift and mass lesion. Additionally, normal cerebral anatomy, 3rd and 4th ventricles and external ventricular drainage (EVD) catheter visualization were also done.

Results: About 14/40 patients came with non-neurosurgical complaints and 26/40 patients came with neurosurgical complaints. Patients with non-neurosurgical complaints (4/14) had mass lesions and 1/14 had MLS. Patients with neurosurgical complaints (11/26) had mass lesions and about 5 patients had MLS. A good correlation was found between TCS and CT of head in measuring LV right (CT head = 17.4 ± 13.8 mm and TCS = 17.1 ± 14.8 mm. The mean difference (95% CI) = [0.28 (–1.9 to 1.33), ICC 0.93 (0.88–0.96)], Left [CT head = 17.8 ± 14.4 mm and TCS = 17.1 ± 14.2 mm, the mean difference (95% CI) 0.63 (–1.8 to 0.61), ICC 0.96 (0.93–0.98)], MLS [CT head = 6.16 ± 3.59 ($n = 7$) and TCS = 7.883 ± 4.17 ($n = 6$)] and mass lesions (kappa 0.84 [0.72–0.89] [95% CI] p-value < 0.001). The agreement between both modalities for detecting mass lesions is 93.75%.

Conclusion: Point of care ultrasound (POCUS) is a bedside, easily operable, non-radiation hazard and dynamic imaging tool that can be used for TCS as a supplement to CT head in post-DC patients in emergency as well as in ICU. However, assessment of the ventricular system (pre/post-EVD insertion), monitoring of regression/progression of mass lesion, etc. can be done with TCS. Repeated scans are possible in less time which can decrease the frequency of CT head.

Keywords: Decompressive craniectomy, Point of care ultrasound, Transcranial ultrasound.

Indian Journal of Critical Care Medicine (2024): 10.5005/jp-journals-10071-24662

Highlights

Transcranial ultrasound (TCS) in post-decompressive craniectomy (DC) patients is dynamic, without any radiation hazard and bedside tool as compared with CT head. With TCS, we can measure midline shift, measure ventricle diameter, and identify and measure mass lesion.

Introduction

Decompressive craniectomy is one of the methods to decrease intracranial pressure. Decompressive craniectomy describes the temporary removal of a portion of the skull for the relief of high intracranial pressure. This can be achieved by the removal of the frontotemporoparietal bone over one or both side.[1] Hemorrhage (hematoma expansion), external cerebral herniation, wound complications, CSF leak/fistulae, postoperative infection, and seizures/epilepsy are the early complications and late or delayed are subdural hygroma, hydrocephalus, syndrome of the trephined.[2] The overall rate of complications of decompressive craniectomy ranges up to 53.9%.[3]

Point of care ultrasound (POCUS) is being used for the identification of raised ICP.[4] Recently, it has been used by emergency physicians for resuscitation, diagnosis, and procedural guidance including during CPR.[5,6] Our group also has explored novel techniques such as water bath for identifying extremity fractures[7]

[1–3,6,8–12]Department of Emergency Medicine, All India Institute of Medical Sciences, New Delhi, India

[4]Department of Radiodiagnosis, All India Institute of Medical Sciences, New Delhi, India

[5]Department of Neurosurgery, All India Institute of Medical Sciences, New Delhi, India

[7]Department of Biostatistics, All India Institute of Medical Sciences, New Delhi, India

Corresponding Author: Sanjeev Bhoi, Department of Emergency Medicine, All India Institute of Medical Sciences, New Delhi, India, Phone: +91 8527050391, e-mail: sanjeevbhoi@gmail.com

How to cite this article: Chouhan R, Sinha TP, Bhoi S, Kumar A, Agrawal D, Nayer J, *et al*. Correlation between Transcranial Ultrasound and CT Head to Detect Clinically Significant Conditions in Post-craniectomy Patients Performed by Emergency Physician: A Pilot Study. Indian J Crit Care Med 2024;28(3):299–306.

Source of support: Nil

Conflict of interest: None

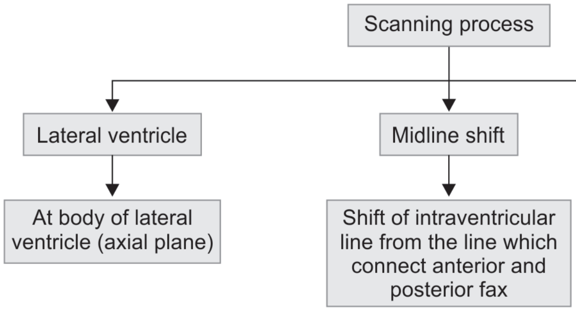


Fig. 1: Scanning process

Table 1: Characteristics of structures in CT and TCS

CT head	*TCS*
Hyperdense	Hyperechoic
Hypodense	Hypoechoic
Isodense	Isoechoic

and cervical spine injuries.[8] CT scan is the gold standard for the identification of complications after post-craniectomy, but it has its drawbacks and limitations, such as radiation hazard, being unavailable at the bedside, less repeatability, and being expensive.[9]

Novel TCS has been used to assess the normal anatomy and technique in neonates through open fontanelles.[10] Similarly, images of the brain and intracranial structures can be obtained after removal of a part of the cranial vault.[11] Previous studies have demonstrated its feasibility and correlation with CT head. Its utility in resource-limited settings where CT scans may not be available makes TCS a key tool for identifying clinically significant brain findings for making critical treatment decisions in triage and resuscitation. We studied the correlation between TCS and CT head to identify clinically significant brain conditions in postcraniotomy patients.

Materials and Methods

Study Design and Setting

This was a prospective, single-center, cross-sectional observational study. It was conducted in the emergency department (ED), at a tertiary care teaching institute in India. The study was divided into two phases as training phase and the execution phase. In the training phase, a single EM resident was trained in TCS technique and identification of abnormal findings (mass lesions, collection, midline shift [MLS], etc.) (Fig. 1) in 5 patients, and normal findings (lateral, 3rd and 4th ventricles, and gray white differentiation) in 5 patients in TCS were performed under the supervision of faculty of the department of emergency medicine. The standardization of the technique was completed after comparing the images and structure with gold standard imaging (CT head) (Table 1), and the scanning technique was explained (Fig. 2; then cases were recruited in the execution phase. The ethical approval was obtained from the Institute Ethics Committee before the commencement of the study (IECPG-753/30.01.2020, RT-19/27.02.2020).

Interventions and Measurements

Primary stabilization was done before the imaging (CT head/transcranial ultrasound) then the whole procedure was explained to a legally authorized representative of the patient, and consent was taken on a preformed consent form in Hindi as well as in English.

Scanning Technique

Transcranial ultrasound was done by using the large curvilinear probe/echo probe (according to post-DC site) of 1–6 MHz of Sonosite M-turbo USG machine. A probe placed at the orbitomeatal line (in the case of FTP craniectomy) (Fig. 2A) or parallel to this if the DC site is other than this, with the pointer facing anteriorly for the axial scan. By fanning the probe from cranial to caudal, the whole brain was scanned (Supplementary Video 1). The coronal section was obtained by rotating the probe to 90° by facing the pointer toward an upward direction (Fig. 2B) and the whole brain was scanned by fanning the probe from anterior to posterior (Supplementary Video 2). A sagittal section was taken if the DC site was at the frontal or occipital area. Depth was adjusted to see the opposite skull bone or scalp (bilateral DC) for adequate image. Images and videos were periodically reviewed by emergency medicine consultants to optimize image interpretation.

The image interpretation should not be interrupted during the procedure and the machine was kept at the head end of the patient and observer's face in one line (Fig. 2C).

During scanning, we focused on three structures – midline shift, bilateral lateral ventricle (LV) diameter and identification mass lesion (if any) (Fig. 1). All the images and videos were saved with measurement and later compared with CT head findings. The CT was performed within 2 hours after TCS in most cases and in some cases, it was done before TCS, then the radiologist who reported the CT scan head was blinded for the TCS findings.

According to the British Medical Ultrasound Guideline 2009, the thermal index of the given procedure is considered rather low.[12] We kept the ALARA (as low as reasonably achievable) principle in mind to minimize the thermal hazard by minimizing the contact time as little as possible.

Selection of Participants

We screened 49 patients with a history of decompressive craniectomy from the AIIMS emergency medicine department and included 40 patients in the study. We excluded patients with craniectomy site wound infection, craniectomy site laceration, pregnant patients, and patients having sutures and bandages over the scalp (If a clean probe application site was not achieved). Our primary objective was the correlation between CT head and TCS to detect clinically significant conditions and user-friendliness of the technique on image acquisition, image optimization, and image interpretation.

Definitions

Lateral Ventricle Diameter

The diameter of the LV at the level of the body of the LV (in mm) in the axial section of the brain was noted. The image was captured

Figs 2A to C: (A) Probe position for axial scan; (B) Probe position for coronal scan; (C) Body ergonomics

Fig. 3: Axial scan of the brain

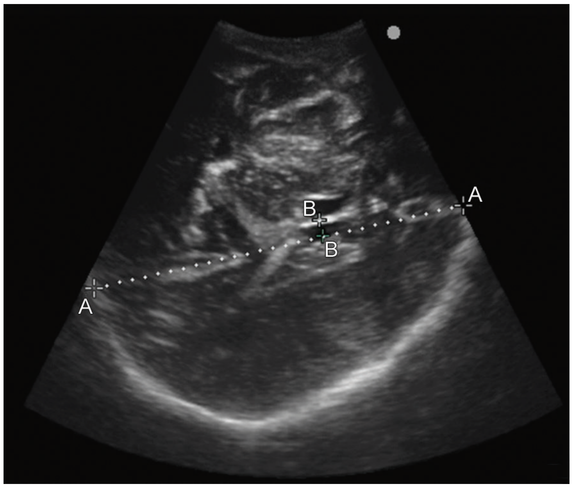


Fig. 4: Midline shift measurement: A, imaginary line joining anterior and posterior fax; B, deviation of intraventricular septum from line A (midline shift)

by fanning of the probe at the level of the body of the bilateral LV and then at the same level, the diameter was measured for both sides (Fig. 3).

Midline Shift (mm)

In the axial section of the brain, the image was frozen at the body of the LV where the septum pellucidum was visible. Then anterior and posterior fax were identified and joined with a line with the help of a caliper in ultrasound. The shift of the intraventricular line (septum pellucidum) from the line joining anterior and posterior fax was recorded (in mm). Midline shift was measured by the method described by Caricato et al.[13] (Fig. 4).

Mass Lesion

Areas of focal localized altered echogenicity, such as anechoic, hypo/hyperechoic areas were considered as mass lesions (Fig. 5).

Outcomes

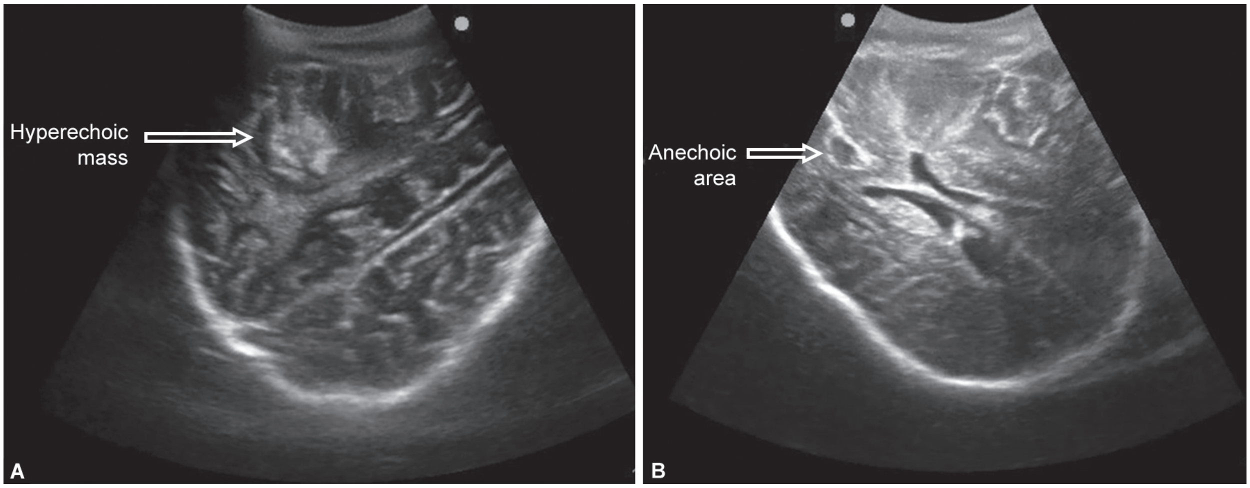
The primary outcome measure was to determine the level of agreement and correlation between TCS and CT scan. The secondary outcome was to study image acquisition, image optimization and image interpretation by TCS.

Analysis

Data were collected in beta-tested predesigned proforma. Statistical analysis was done by SPSS 25.0.0.0. We expressed the test data as frequencies for nominal variables and as mean ± SD or median with range for continuous variables. The associations between TCS and CT scan for detecting and identification of mass lesions were analyzed using Cohen's K-coefficient. To analyze the agreement between both modalities in the measurement of LV diameter, a Bland-Altman plot was done and correlation was analyzed with an intraclass correlation coefficient (ICC of >0.90 was interpreted as excellent intraclass correlation).

RESULTS

We recruited a sample size of 40 patients with decompressive craniectomy in this study based on previous studies. Of these 40 patients, 14 patients came with non-neurosurgical complaints (fever, breathlessness as many patients were tracheostomized) and 26 patients came with neurosurgical complaints. The patients who came with non-neurosurgical complaints had a lower number of patients with intracranial findings (mass lesion/MLS) (mass



Figs 5A and B: (A) Arrow showing hyperechoic mass lesion in temporoparietal area; (B) Arrow showing anechoic area between fax cerebri and frontal horn of lateral ventricle

Table 2: Correlation between presenting complaint and presence of mass lesion and midline shift

Total = 40			
Complaint	*N*	*Mass lesion*	*Midline shift*
Non-neurosurgical	14	4	1
Neurosurgical	26	11	5

lesion = 4/midline shift = 1) rather than the patients who came with neurosurgical complaints (seizures, altered sensorium, or worsening sensorium) (mass lesion = 11/midline shift = 5) (Table 2). Good correlation was noted between TCS and CT head in measuring LVs. The measurements of the right LV noted were (17.4 ± 13.8) mm by CT head and (17.1 ± 14.8) mm by TCS. The mean difference observed was 0.28 with 95% CI (–1.9 to 1.33), a *p*-value of 0.720 which shows a statistically nonsignificant difference with an ICC of 0.93 (0.88–0.96) between the two methods.

The measurements of the left LV observed were (17.8 ± 14.4) mm by CT head and (17.1 ± 14.2) mm by TCS. The mean difference observed was 0.63 with 95% CI (–1.8 to 0.61), a *p*-value of 0.308 which shows a statistically nonsignificant difference with an ICC of 0.96 (0.93–0.98) between the two methods. The agreement between these two modalities was done by the Bland-Altman plot (Fig. 6). The measurements of the diameter of the LV and the correlation between the two methods in measuring the ventricular diameter have been depicted in Table 3.

The scattered diagram plotted between an average of LV diameter by (CT head and TCS) and the difference between CT head and TCS (Fig. 6) shows that most of the cases are clustered in the central line. There are three cases in which the difference was higher because of their extreme dilatation as the axial section of ultrasound is not completely horizontal which explains the higher difference in those three cases.

About 7 patients had MLS detected by CT head and TCS was able to detect MLS in 6 patients. The mean ± SD for NCCT head is 6.1 ± 3.5 and for TCS it is 7.8 ± 4.1 (*p*-value 0.05) (Table 3).

In TCS, 25 patients were found to have no mass lesion (parenchymal lesion, CSF collection, etc.). About 8 patients were found to have hypoechoic lesions and 7 patients were found to have hyperechoic mass lesions. Similarly, in CT head, 22 patients did not have any lesions, 9 patients were found to have hypodense lesions, and 9 patients were found to have hyperdense lesions. So, from all the patients, TCS was able to detect mass lesions in 15 patients and by the gold standard method, a total of 18 patients had mass lesions. Cohan's K-coefficient value was 0.84 [95% CI (0.72–0.89)] with a *p*-value of <0.001 in the identification of mass lesions by both methods. The level of agreement between both modalities was 93.75% (Table 4).

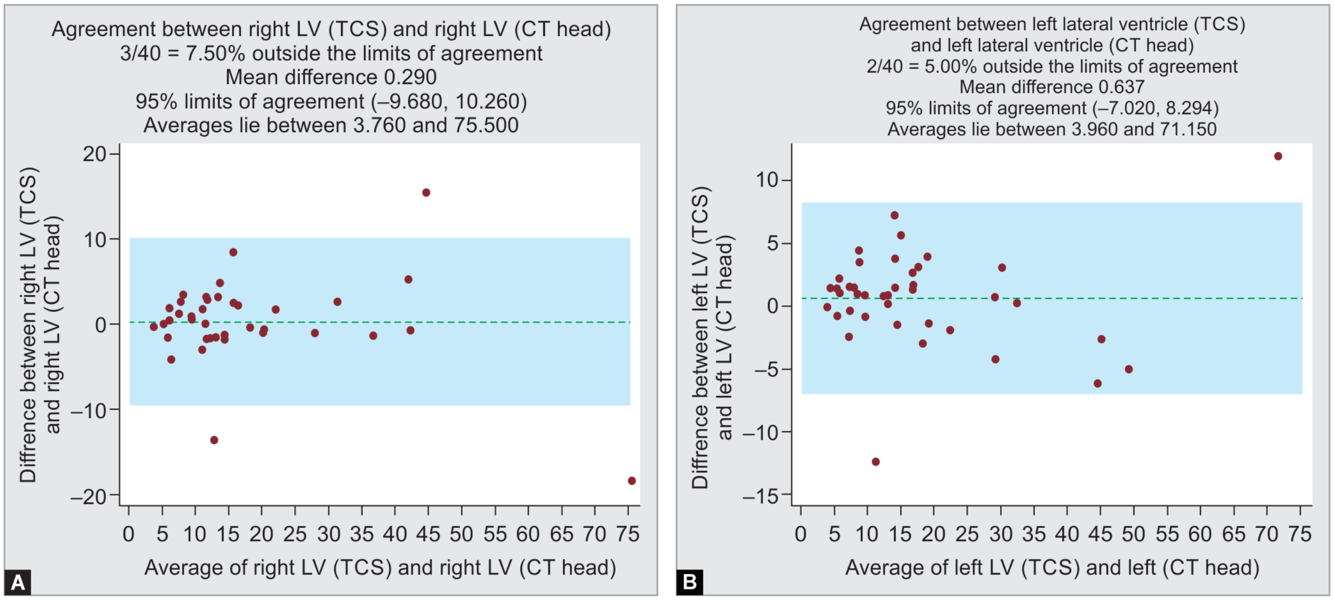
Most of the patients visited the ED within 3 months after discharge from the hospital (Table 5).

DISCUSSION

Transcranial ultrasound is a dynamic imaging modality that is feasible, easily available, and without any radiation hazard. We recruited patients with decompressive craniectomy. It was observed that patients who were coming with neurosurgical complaints had high chances of having an intracranial cause of their clinical condition as 11 patients had mass lesions and 5 patients had MLS out of 26 patients. Opposite to these, 14 patients came with non-neurosurgical complaints, only 4 patients had mass lesions, and MLS was noted in 1 patient.

We observed that in the CT scan of the head, every structure in the CT images represents themselves according to their Hounsfield unit but broadly, we can classify them as hypodense or hyperdense. Similarly, TCS structures can be classified as hypo/hyperechoic or anechoic. We are describing characteristics and key results of ultrasound images in correlation with CT head, which were observed during the image interpretation (Table 6). The major difference between the observation by these two modalities is that sulci of brain parenchyma look hypodense in CT head but in TCS, it looks hyperechoic (Table 6).

We measured the diameter of the LV and compared it with CT head. The mean difference was low between both the modalities which was statically nonsignificant. A high standard deviation was found because only 2 or 3 patients had grossly dilated bilateral ventricles. We observed that the difference between the measured diameter was high if the ventricles are dilated, as in CT, the axial scan does not depend on the craniectomy site but in TCS, we have to fan the probe for the proper visualization and if the ventricles are dilated, the axial scan will not be able to take proper transverse diameter, it will somewhat take diagonal diameter of the ventricle.



Figs 6A and B: (A) Agreement between TCS and CT head for measurement of right lateral ventricle diameter; (B) Agreement between TCS and CT head for measurement of left lateral ventricle diameter

Table 3: Correlation between CT head and TCS for measuring lateral ventricular diameter and midline shift

	CT head (mean ± SD)	*TCS (mean ± SD)*	*Difference (95% CI)*	*p-value*	*ICC (95% CI)*
Lateral ventricle					
Right (mm)	17.4 ± 13.8	17.1 ± 14.8	0.28 (–1.9–1.33)	0.720	0.93 (0.88–0.96)
Left (mm)	17.8 ± 14.4	17.1 ± 14.2	0.63 (–1.8–0.61)	0.308	0.96 (0.93–0.98)
Midline shift (mm)	6.16 ± 3.59 (*n* = 7)	7.88 ± 4.17 (*n* = 6)	—	0.05	—

Table 4: Correlation between CT head and TCS for detection and identification of mass lesions

Mass lesion	*CT head*			*Agreement*	*Kappa (95% CI)*	*p-value*
TCS	Nil	Hypodense	Hyperdense			
Nil	22	1	2	93.75%	0.84 (0.72–0.89)	<0.001
Hypoechoic	0	8	0			
Hyperechoic	0	0	7			

Table 5: Demographic data

Characteristics	
N	40
Age (years)	34.98 ± 16.29
Sex	
Male	70% (28)
Female	30% (12)
Post-craniectomy duration	
<3 months	45% (18)
3–6 months	32.5% (13)
>6 months	22.5% (9)

Bendella et al. did the study with a sample size of 102 in which they calculated the same variables.[14] They measured bilateral LVs, 3rd, 4th, and MLS. In our study, we did not include 3rd and 4th ventricles but we detected mass lesions and described their echogenicity that was comparable with density in the CT head, which was not done in this study. As TCS is a new modality that is why more standardization is required for brain imaging. The most useful probe for this purpose is curvilinear but small convex or cardiac also can be used if the decompressive craniectomy site is small.

For the MLS, TCS was able to detect MLS in 6 patients and a total of 7 patients had MLS as shown by the gold standard CT head. The mean difference between the two modalities was statically nonsignificant. Transcranial ultrasound interpretation is subjective, small MLS may get missed. The first attempt was taken for TCS in 1989 in Tokyo, in which they suggested that ultrasound is more beneficial in detecting hydrocephalus irrespective of cause and the suboccipital craniectomy window does not allow for good brain images.[15] In their images also, they showed only ventricles. De Slegte et al. carried out two studies, the 1st in 1984 and the 2nd in 1986. In their 1st study, they only presented a preliminary report on 6 cases in which they only focused on the posterior fossa because most of the patients had suboccipital craniectomy with cerebellar cyst and 4th ventricle.[16]

Table 6: Identification characteristics of intracranial structures in CT head and TCS

	CT scan	*TCS*
Sulcus	Hypodense	Hyperechoic (echogenicity higher than gyrus)
Gyrus	Isodense (density higher than sulcus)	Isoechoic (echogenicity lower than sulcus)
CSF (Ventricles or CSF-filled spaces)	Lowest density (HU ~ 0)	Anechoic
Acute hemorrhage	Hyperdense	Hyperechoic
Ischemic area	Hypodense	Hypoechoic
Perilesional edema	Hypodense	Hyperechoic
Old hemorrhagic lesions	Hypodense	Hypoechoic
Foreign body	Hyperdense/hypodense	Hyperechoic/hypoechoic
1 Metal	High density (HU ~ 3000)	Hyperechoic (with posterior acoustic shadow or reverberation)
2 Nonmetal	Hyperdense/hypodense (depends on the content)	Hyperechoic/hypoechoic (depends on the content)
EVD	Linear/round hyperdensity in lateral ventricle	Linear/round hyper-echogenicity with or without reverberation
Lateral ventricle (axial section)	Elongated curve-like shape [hypodense (CSF)]	Elongated curve-like shape (anechoic content)
3rd ventricle (axial section)	Small round with hypodense (CSF) content	Small round with anechoic content
4th ventricle (axial section)	Semilunar-shaped hypodense (CSF)	Semilunar-shaped (anechoic content)
Possible sections	Axial/coronal/sagittal	Axial/coronal/sagittal (depends on post-craniectomy site)
Imaging	Static	Dynamic

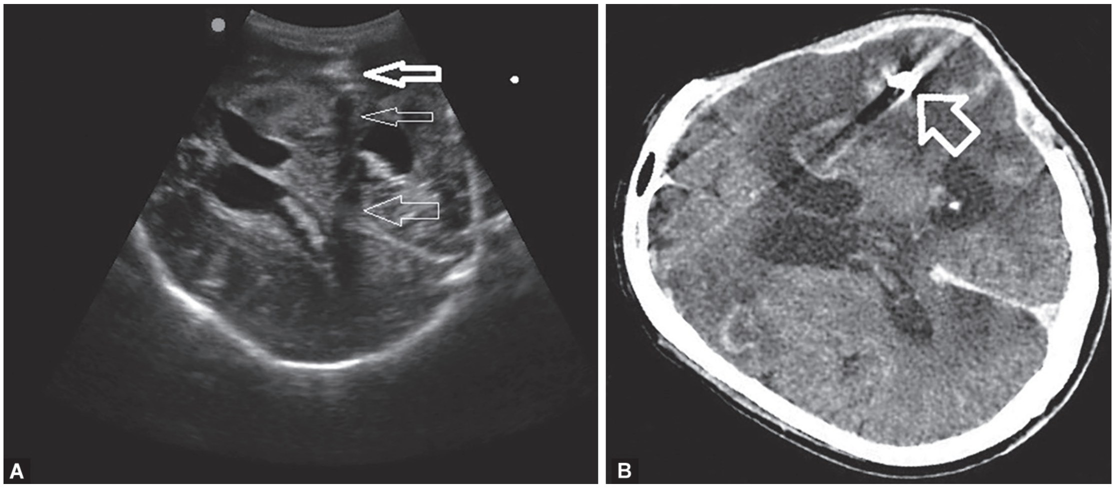
They did not comment on the LV, 3rd ventricle, MLS, and normal cerebral imaging was not addressed. In their 2nd study, they addressed LVs. They mentioned that an ultrasound cannot be done in the first 10 postoperative days.[17] The reason for that is the bandage over the post-op site. But we found that TCS can be done just after the operation as the bandage usually only covers the area where the incision was given, the rest of the area of the decompressive craniectomy site is usually normal and there is no contraindication for placing a probe there. Therefore, without giving any pressure with probe and using liberal amount of jelly, we can do TCS. They also suggested that the hemorrhagic lesion cannot be detected but we found that the echogenicity of the hemorrhagic lesion is more than the CSF. So, it appears hyperechoic and hyperechoic lesions are easy to pick on ultrasound. In our study, TCS was able to detect and identify mass lesions in terms of hyper/hypoechoic (hyper/hypodense in CT scan). An excellent level of agreement (93.7%) was found between TCS and CT scan for detecting and identifying mass lesions. The visualization of the hyperechoic mass lesion was good compared with hypoechoic as TCS was able to detect almost all the hyperechoic lesions. We observed that the hypoechoic lesion in TCS was hypodense in the CT scan and the hyperechoic lesion was hyperdense in the CT scan (except sulci of the parenchyma which was hyperechoic in TCS and hypodense in the CT scan). Martin F and Ochoa J[15] did a study with 5 patients; they did TCS 2 hours before CT head and then they detected a hemorrhagic mass lesion and MLS.[18] Najjar et al. submitted a case report in which they monitored 3rd ventricle diameter after the insertion of external ventricular drainage (EVD) in a patient with a history of decompressive craniectomy because of subarachnoid hemorrhage.[11] In our study, the findings showed a good correlation between previous studies on TCS in post-decompressive craniectomy.

Most of the patients had neurosurgical presents like seizure/worsening of the baseline sensorium. In terms of post-craniectomy duration, most of the patients came within 3 months after decompressive craniectomy as this is the critical period, and understanding and handling the patient by their family members is difficult. This is the time when the patient starts antiepileptic medications and giving the proper dose at the proper time is essential but in the initial period there are high chances of missing the doses and to understand the precautions to prevent seizures as even sleep deprivation, missed doses of antiepileptic, hypoglycemia or other minor illness can provoke the seizures[19] (Table 3). During the study, a patient presented to emergency who underwent craniectomy because of a gunshot injury. While performing TCS (Fig. 7A), a hyperechoic lesion with posterior acoustic shadow (small arrow)[20] suggested that it may be a foreign body, later, it was confirmed with the official report that this patient had a history of gunshot injury so he had a remnant of bullet or bony fragment which showed as a hyperdense lesion in CT head (Fig. 7B) and the density of the lesion is equal to the density of the bone. This is how a mass lesion because of an IC bleeds and a mass lesion because of a foreign body can be differentiated with the help of TCS. Point of care ultrasound is a good bedside noninvasive technique of neuromonitoring with reliable and reproducible assessment of MLS if the examiner has a sound knowledge of brain anatomy.[21] A study done in ICU setting in India included 17 postoperative patients of moderate-to-severe TBI, showed TCS to detect MLS in patients with traumatic brain injury with reasonable accuracy.

In a separate supplementary figure section, we have compared some TCS images (B) with their CT head images (A) (Supplementary Figs 1–13). Apart from the detection of mass lesion, LV diameter and MLS, we also mentioned normal brain anatomy in ultrasound images (Supplementary Figs 21A to D).

Limitations

- Images and video interpretation are subjective.
- There are not many previous studies on TCS in decompressive craniectomy, which leads to a lack of standardization of imaging.
- The definition of hydrocephalus was not addressed.
- Samples of convenience were taken.



Figs 7A and B: Axial scan of TCS. (A) Bold arrow showing hyperechoic area with posterior acoustic shadowing (leftward white arrows); (B) Axial scan of CT head: arrow showing beam hardening artifact

Conclusion

There was excellent agreement between TCS and CT scans in identifying clinically significant conditions among postcraniotomy patients. It can be used as an adjunct to clinical examination to monitor post-decompressive craniectomy patients in resource-limited settings where a CT scan is not available. Transcranial ultrasound can help to make critical bedside decisions such as Burr-hole, EVD insertion, abscess drainage, etc. in correlation with clinical examination. Emergency physicians can make early treatment decisions, such as triaging the patients, ordering further imaging and involving neurosurgeons as soon as possible in crowded and busy emergencies with the help of TCS. Point of care ultrasound is also helpful to see the progress or regress in size of the hematoma or development of new onset lesions in postoperative patients in ICU.

Supplementary Materials

All the supplementary materials are available online on the website of www.IJCCM.org.[23,24]

Orcid

Rahul Chouhan https://orcid.org/0000-0001-8866-1046
Tej P Sinha https://orcid.org/0000-0002-3779-1446
Sanjeev Bhoi https://orcid.org/0000-0002-5392-1976
Atin Kumar https://orcid.org/0000-0001-5874-1336
Deepak Agrawal https://orcid.org/0000-0002-5499-0746
Jamshed Nayer https://orcid.org/0000-0002-4343-8809
Ravindra M Pandey https://orcid.org/0000-0002-5613-0512
Praveen Aggarwal https://orcid.org/0000-0002-4611-5458
Meera Ekka https://orcid.org/0009-0006-0619-838X
Prakash R Mishra https://orcid.org/0000-0002-1747-3248
Akshay Kumar https://orcid.org/0000-0002-7976-9765
Divya C Chouhan https://orcid.org/0009-0007-9912-2807

References

1. Schirmer CM, Ackil AA Jr, Malek AM. Decompressive craniectomy. Neurocrit Care 2008;8(3):456–470. DOI: 10.1007/s12028-008-9082-y.
2. Gopalakrishnan MS, Shanbhag NC, Shukla DP, Konar SK, Bhat DI, Devi BI. Complications of decompressive craniectomy. Front Neurol 2018;9:977. DOI: 10.3389/fneur.2018.00977.
3. Ban SP, Son YJ, Yang HJ, Chung YS, Lee SH, Han DH. Analysis of complications following decompressive craniectomy for traumatic brain injury. J Korean Neurosurg Soc 2010;48(3):244–250. DOI: 10.3340/jkns.2010.48.3.244.
4. Fernando SM, Tran A, Cheng W, Rochwerg B, Taljaard M, Kyeremanteng K, et al. Diagnosis of elevated intracranial pressure in critically ill adults: Systematic review and meta-analysis BMJ 2019;366:l4225. DOI: 10.1136/bmj.l4225.
5. Ultrasound Guidelines: Emergency, point-of-care and clinical ultrasound guidelines in medicine. Ann Emerg Med 2017;69(5): e27–e54. DOI: 10.1016/j.annemergmed.2016.08.457.
6. Brunda RL, Keri VC, Sinha TP, Bhoi S, Mishra PR. 'Sono-cardiopulmonary resuscitation' in COVID-19: A proposed algorithm. Postgrad Med J 2021;97(1143):3–4. DOI: 10.1136/postgradmedj-2020-138747.
7. Shrimal P, Bhoi S, Sinha TP, Murmu LR, Nayer J, Ekka M, et al. Sensitivity and specificity of waterbath ultrasound technique in comparison to the conventional methods in diagnosing extremity fractures. Am J Emerg Med 2022;53:118–121. DOI: 10.1016/j.ajem.2021.12.067.
8. Vishnu VK Bhoi S, Aggarwal P, Murmu LR, Agrawal D, Kumar A, Sinha TP, et al. Diagnostic utility of point of care ultrasound in identifying cervical spine injury in emergency settings. Australas J Ultrasound Med 2021;24(4):208–216. DOI: 10.1002/ajum.12274.
9. Fred HL. Drawbacks and limitations of computed tomography. Tex Heart Inst J 2004;31(4):4. PMID: 16107131.
10. Gupta P, Sodhi KS, Saxena AK, Khandelwal N, Singhi P. Neonatal cranial sonography: A concise review for clinicians. J Pediatr Neurosci 2016;11(1):7–13. DOI: 10.4103/1817-1745.181261.
11. Najjar A, Denault AY, Bojanowski MW. Bedside transcranial sonography monitoring in a patient with hydrocephalus post subarachnoid hemorrhage. Crit Ultrasound J 2017;9(1):17. DOI: 10.1186/s13089-017-0072-1.
12. Hoskins PR, Martin K, Thrush A, editors. The British Medical Ultrasound Society. Guidelines for the safe use of diagnostic ultrasound equipment. In: Diagnostic Ultrasound [Internet]. 2nd ed. Cambridge: Cambridge University Press; 2010 [cited 2021 Dec 5]. pp. 217–225.
13. Caricato A, Mignani V, Bocci MG, Pennisi MA, Sandroni C, Tersali A, et al. Usefulness of transcranial echography in patients with decompressive craniectomy: A comparison with computed tomography scan. Crit Care Med 2012;40(6):1745–1752. DOI: 10.1097/CCM.0b013e318246b6ea.
14. Bendella H, Maegele M, Hartmann A, Spreer J, Rommel N, Lefering R, et al. Cerebral ventricular dimensions after decompressive craniectomy: A comparison between bedside sonographic duplex technique and cranial computed tomography. Neurocrit Care 2017;26(3): 321–329. DOI: 10.1007/s12028-016-0359-2.

15. Kobayashi S, Kitamura T, Isayama K, Yokota H, Nakazawa S. Clinical value of bedside ultrasonography in craniectomized patients. Neurol Med Chir (Tokyo) 1989;29(8):740–745. Japanese. DOI: 10.2176/nmc.29.740.
16. Olislagers-De Slegte RG, Smeets RW, Valk J, Crezée F. Ultrasound in follow-up of the postoperative brain. Preliminary report on six cases. Neuroradiology 1984;26(4):267–272. DOI: 10.1007/BF00339769.
17. de Siegte RGM, Valk J, Broere G, de Waal F. Further experience with ultrasound examinations in the postoperative brain. Acta Neurochir 1986;81(3–4):106–112. DOI: 10.1007/BF01401230.
18. Martín F, Ochoa J. Ecografía transcraniectomía. Revista Argentina de Radiología 2015;79(4):205–208. DOI: 10.1016/j.rard.2015.03.003.
19. Al Sawaf A, Arya K, Murr N. Seizure Precautions. [Updated 2021 Sep 2]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021.
20. Skalski M, Yonso M. Acoustic shadowing. Reference article, Radiopaedia.org. DOI: https://doi.org/10.53347/rID-24967. Accessed on: 10 Dec 2021.
21. Srinivasan S, Kumar PG, Govil D, Gupta S, Kumar V, Pichamuthu K, et al. Competencies for point-of-care ultrasonography in ICU: An ISCCM Expert Panel Practice Recommendation. Indian J Crit Care Med 2022;26(Suppl 2):S7–S12. DOI: 10.5005/jp-journals-10071-24199.
22. Kapoor I, Pandit S, Prabhakar H, Mahajan C. Comparison between transcranial sonography and computerized tomography scans to assess the midline shift in patients with traumatic brain injury. Indian J Crit Care Med 2023;27(1):64–66. DOI: 10.5005/jp-journals-10071-24376.
23. Morgan M, Bell D. Reverberation artifact. Reference article, Radiopaedia.org. DOI: https://doi.org/10.53347/rID-31989. Accessed on: 10 Dec 2021.
24. Naidich TP, Chakera TM. Multicystic encephalomalacia: CT appearance and pathological correlation. J Comput Assist Tomogr 1984;8(4): 631–636. PMID: 6736360.