Intraoperative ultrasound in neurosurgical procedures

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Abstract

The objective of the present study was to study the utility and the effectiveness of intraoperative ultrasound in neurosurgical procedures and to assess the outcome.

Material and Methods

In this prospective study, operative procedures by a single surgeon under intraoperative ultrasound localization for basal ganglia/thalamic haematoma or traumatic brain contusions or brain tumours were included. Ultrasound scanning of the brain was performed before and after the excision of the lesion and during the procedure to verify the extent of removal of the lesion.

Results

74 patients underwent surgery for brain tumor/basal ganglia bleed/head injury with hemorrhagic contusion with the help of intraoperative ultrasound. Gross tumor resection was noted in 25 out of 36 cases of brain tumors (69.44%), complete evacuation of hematoma was noted in 14 out of 34 cases (41.2%) of basal ganglia bleed and in 2 out of 4 cases (50%) of intracerebral contusion. As per Modified Rankin scale (MRS) score, among the brain tumor cases, all patients had fared well in recovery and had better MRS scores except in one patient who expired during postoperative period.

Conclusions

IoUS is a widely accessible, cheap, portable and less space occupying and reliable imaging tool to follow and modify the surgical plan in real time, and is more accurate and helpful in complete tumor resection, evacuation of intracerebral bleeds and contusions, and biopsy of deep seated lesions. It is easy and safe to handle with no risk of radiation.

Introduction

Intraoperative Ultrasound (IoUS) has significant consequences on the outcome of both adult and pediatric neurosurgical patients. It is a great boon to the Neurosurgeons as it is useful to localise and precisely excise the pathological lesions during intraoperative period in intracranial surgeries. It helps in foreseeing of surgical path for precise excision of pathological lesions and allows a real-time localisation and visualisation of any residual tumour mass while operating on any kind of central nervous system lesions, even after brain shift and deformation have occurred, and where traditional navigation systems like Computer tomography scan (CT) and Magnetic Resonance Imaging (MRI) have lost accuracy. (39, 40) It helps to follow and/or plan the progression of tumor excision with accuracy and ease of use. (9, 14, 20, 28, 31, 46) The objective of this project is to study the utility and the effectiveness of Intraoperative ultrasound (IoUS) in Neurosurgical procedures and to assess the outcome.

Material And Methods

This prospective study was conducted from September 2016 to November 2018 in the Department of Neurosurgery in a tertiary care hospital after approval from the institutional ethical committee. All the participants consenting for operative procedures under intraoperative ultrasound localization for basal ganglia/thalamic haematoma, traumatic brain injury (TBI) with contusions, brain tumours were included in the study. All the patients fitting into the criteria included in the study were operated by a single surgeon with the use of intraoperative ultrasound localization (Hitachi Healthcare's Aloka Prosound Alpha 7 intraoperative ultrasound using standard abdominal convex phased-array probe and with 5 MHz, 7.5 MHz transducer frequencies). B-mode (grey scale) ultrasound is used for the localisation of the site, extent, depth and structure of the lesion (16) Data was collected with the help of a pretested, structured interview schedule which contained the demographic and clinical features including age, gender, diagnosis, surgical procedure, and details of vital parameters, GCS at admission and discharge, non-invasive investigations including imaging such as preoperative CT/MRI volume and postoperative CT/MRI volume and outcome using Modified Rankin Scale (MRS) at discharge. Management and outcome details for all the patients were noted. During surgery after the craniotomy, the probe was placed gently above the dura after pouring of normal saline over the brain surface and the lesion is localized by intraoperative ultrasound for its location, anatomical margins, depth and extent by sterile

ultrasound probe and it is intermittently checked for the extent of surgical removal of lesion till the maximum possible/ complete removal of lesion is done.

Postoperatively each patient was taken for CT brain as early as possible and assessed for residual lesion or any new evolved bleed in the scan. The volume of the lesion/bleed is noted from both preoperative CT/MRI and post-operative CT by measuring its length (l), breadth (b) and height (h) and calculated by the formula $(l \times b \times h)/2$. The clinical outcome of the patient after the proposed intervention was assessed by comparing the Modified Rankin Scale(MRS) at admission and at discharge which measures the degree of disability/dependence .Following approval from Institutional Ethics Committee (IEC), a written informed consent was obtained from all the participants. Standard surgical procedure was followed, including patient positioning, localization and surgical approach were identical as per standard operative procedures practiced in our centre. Data was entered into MS excel and interpretation was done by using statistical software SPSS Statistics Version 24.0. The data was expressed using descriptive statistics such as mean and standard deviation for continuous variables, and frequency and percentage for categorical variables. Chi-square test was used for significance of categorical data at five per cent level of statistical significance.

Results

Out of a total of 74 patients who were admitted and underwent surgery for brain tumor/basal ganglia bleed/head injury with hemorrhagic contusion ,there were 25 females and 49 males. Among these,34 patients had basal ganglia bleed,36 patients had brain tumor, 4 had traumatic brain injury with contusion. MRS scale at admission was 5 in 40 patients, 4 in 8 patients, 3 in 2 patients, 2 in 2 patients,1 in 20 patients. At the time of discharge twenty seven patients had MRS score 1,twelve patients had MRS 6, eleven patients had MRS 5, fifteen had MRS 4,four patients had MRS 3,and five patients had MRS 2.Among the subtypes,in basal ganglia bleed cases ,ten patients had MRS 6,eight patients had MRS 5,twelve had MRS 4,one had MRS 3,One had MRS 2,and one had MRS 1. Among the brain tumour cases,one had MRS 6,two patients had MRS 5,three had MRS 4,three had MRS 3,four had MRS 2,and twenty three had MRS 1. Among the head injury with contusion cases, one had MRS 6,one had MRS 5,two had MRS 1.

As per MR scale, among the brain tumor cases all patients had fared well in recovery and had better MRS scores except in one patient who expired during postoperative period.In basal ganglia bleed cases 16 patients had fared well and had better MRS score and 10 patients with poor GCS at admission expired and others had same MRS. Among the traumatic contusion cases, one patient had expired and others had same MRS score. Residual tumor/bleed was seen in 35 patients and no tumor or bleed was seen in 39 postoperative patients. Among the subtype ,Gross tumor resection was noted in 25 out of 36 cases of brain tumors (69.44%) and residual tumor was noted in 11 cases(30.56%) and the percentage of residual tumor volume ranged from 0 to 48.5% and the mean of the percentage of the residual volume was 8.52;Among the basal ganglia bleed cases,complete evacuation of hematoma was noted in 14 cases(41.2%) and residual bleed in 20 cases(58.8%),and the percentage of residual volume ranged from 0 to 44.3% and the mean of the percentage of the residual volume was 9.72. Among the four patients with head injury with intracerebral contusion, complete removal of contusion was done in 2 cases (50%)and residual contusion was noted in 2 cases(50%),percentage of residual volume of contusion ranged from 0 to 26.6% and the mean of the percentage of the residual volume was 10.5%.

Discussion

Intraoperative ultrasound (IoUS) is useful in providing real time intraoperative information like the location, size of tumor/bleed, residual tumor/bleed etc during cranial surgeries. The exact identification of anatomical landmarks and their variants, localization and portrayal of the extent of lesions, and foreseeing of surgical procedures to optimize surgical access and enhanced dexterity are critical in the planning and execution of any surgical procedure.(18) IoUS effectively detects deeply or superficially placed brain and spinal cord lesions. (41, 43) It had recently gained popularity in neurosurgery, after a series of publications have demonstrated that this method is safe and effective, especially when used with contrast medium (contrast-enhanced ultrasound—CEUS).(10, 38, 41, 43, 52)

IoUS is cost effective and gives precise location of a lesion when compared to other imaging modalities, but it requires training for orientation. For this limitation, clubbing it with preoperative MRI was proposed (30) Though preoperative MRI and /or Computer Tomography gives accurate preoperative localisation of the lesion, intraoperative MRI or USG are required for correct localisation during surgery to avoid the brain shift .Among all the three, IOUS is cost effective, but it does not match the routine orthogonal planes of MRI or CT images, and therefore less impressive to the neurosurgeon. (5, 12, 20) Due to these problems, IoUS was connected with other navigation modalities and is used during surgery with commercially available systems.(57) In this an arbitrary Ultrasound system is connected to a navigation system via a calibration procedure of the ultrasonography probe or scan plane.(7, 21, 22) Many imaging techniques are available to acquire baseline images; the frequently used are computed tomography (CT) and magnetic resonance imaging (MRI), but now a days other modalities are also being used, from preoperatively acquired metabolic imaging, as in the case of positron emission tomography (PET), to intra operatively acquired ultrasound (IoUS) and immunofluorescence, based on 5-aminolevulinic acid or indocyanine green. (11, 15, 17, 19, 34)

The microsurgical treatment of hypertensive Basal ganglia haemorrhage (Fig. 1) assisted by intraoperative ultrasound localisation improved the precision of the operation, better evacuation of the haemorrhage and decreased number of reoccurrences, as well as improved the quality of life of patients after the operation. (33) Few articles had mentioned regarding the detection of intracerebral hematomas and contusions causing mass effect and midline shifts with the help of a low frequency ultrasound probe through the temporal bone of an intact skull.(1, 4, 8, 23, 35) This can also be used bedside in decompressive craniectomy patients.(37, 48, 49) The quality of the image is good, and the accuracy is not reduced by dural grafts. A better knowledge of the brain parenchyma can be obtained and specially when massive intraoperative brain herniation is encountered, IoUS can be useful for differentiating various ipsilateral pathologies requiring surgery, such as, intracerebral hematoma or sub dural hematoma with severe brain swelling. This also lessens the time and effort needed for imaging compared to the time required for surgical wound closure, transporting to CT room for a post-operative CT scan and thus lessens the decision making time and also the risk of patient getting worse during shifting (25)

The applications of IoUS related to intracranial space occupying lesions, was due to the ability to demonstrate several aspects of solid and cystic lesions, including: septated fluid collections, areas of thick septations, nodularity and solid components. (18) IoUS imaging by using navigated intraoperative 3D-ultrasound (3DUS) for brain glioma surgeries is well documented in the literature (51) Best results in treatment of CNS tumors is possible only by Gross Total Resection(GTR) with postoperative adjuvant chemoradiation, which depends on the surgeon's capacity to accurately delineate intraoperative tumor margins and its characteristics (9, 20, 28) This reduces further neurological damage leading to better outcomes in these patients(28, 31, 55) Safe resection of CNS tumors have good clinical outcomes in both adults and children.

When attempting GTR, we demonstrated a 69.44% GTR rate (25 out of 36 cases of brain tumors) in our study. In our study, awake craniotomy and excision of the lesion with IoUS localisation was done in 5 out of 34 brain tumor cases and IOUS helped in early localisation and speedy removal of the tumor. IOUS usefulness in both adult and pediatric CNS tumor surgery in achieving a successful GTR, and in improving surgical outcomes is well supported in many articles.. However, further studies are a need of the hour to show case the existing limitations in order to improve the efficacy and its definitive role as an intraoperative imaging modality(53) For still better results other modalities like intraoperative fluorescein imaging can be used simultaneously, mainly in high grade gliomas. Steno et al, suggests an additional benefit of 3DUS over conventional navigation especially in resections of eloquent low grade glioma. (50) Metastatic tumors often have well-demarcated borders with the surrounding brain parenchyma, and this helps in en bloc resection with good outcomes. (56) They often appear hyperechoic and homogeneous with well-defined borders on IOUS. All lesions were hyperechoic in relation to normal brain. The high-grade gliomas exhibited a non-homogenous hyperechoic pattern with areas of necrosis and cystic degeneration being hypo-echoic (Fig. 2). When there was haemorrhage within the tumour these areas were intensely hyperechoic. The low-grade tumours were also hyperechoic, and were however, more homogenous in appearance (9) Several studies had mentioned that the margins of parenchymal brain tumours can be readily differentiated from surrounding brain (14, 28) As per few studies ultrasound can differentiate oedema from solid tumour which is difficult on both CT and MR imaging(6) Hammoud et al stated that the IoUS was able to clearly define tumour margins in most tumours, except for those that had undergone prior radiation. (20)

At present, the preferred method of estimating residual tumour postoperatively is by MR imaging. Hammoud et al, used postoperative MR imaging for measuring post excision tumour volumes and established that intra-operative ultrasound was able to define well the extent of resection in several tumors. However, the extent of resection was poorly defined in all patients who had radiation-induced lesions. (20)

As per our study using post-operative CT scan for measuring post excision tumor values, we were successful in complete excision of 24 out of 36 cases (66.6%) of cases and there was a gross reduction in tumor volumes postoperatively even in remaining cases. In our study IoUS was able to define well the extent of resection in 14 patients with gliomas, 3 patients with tuberculomas, 4 patients with metastasis, 7 patients with meningioma, 4 cases of cerebello pontine angle schwannomas, one case each of cerebellar haemangioblastoma (Fig. 3) and cavernoma. However the extent of resection was poorly defined in a case of recurrent glioma which had undergone radiotherapy after the first surgery and in a case of thalamic primitive neuroectodermal tumor, where the tumor was diffuse.

Advantages

IoUS clearly defines the tumor margins and facilitates the tumor resection in both adult and pediatric patient populations. (9, 20, 32, 54). It improves the extent of resection of parenchymal brain tumors (9). Furthermore, early tumour-bed haematomas have a characteristic appearance on ultrasound which have been well documented. (29, 47). It does not require any changes in patient positioning or the intraoperative setting, while at the same time offers significant spatial and temporal resolution. (42). Although conventional US machines cannot help in planning the craniotomy, transcranial ultrasound can identify brain tumours through the skull in areas where the bone is thin (2, 3). Being a real time imaging modality, IoUS has the advantage over other preoperative imaging modalities, to take into account intraoperative changes, therefore it appears to be a reliable tool for image-guided spine surgery as well (for intradural pathologies and to localize and visualize non-intradural pathologies).

As a diagnostic tool, IoUS can provide relatively sensitive images of the brain. Accurate descriptions of sonographic features of cerebral anatomy are available in the literature. (25). IoUS does not have the drawbacks that the frame-based or frameless stereotactic methods have and has many advantages over intra-operative CT and MR imaging. The IoUS is a real-time modality, that facilitates the surgeons to immediately correct the trajectory to deep-seated lesions (45, 58). Moreover, ultrasound scans are stereotactic by themselves, in that the reference frame is always the transducer itself, that is located at the site of craniotomy. This makes biopsy and guidance of procedures very simple obviating the need for additional computers or stereotactic frames to map the co-ordinates from the frame of reference of MR imaging to that of the operator (47).

In conclusion, IOUS is a cheap and useful real-time tool for localizing and defining the margins of the tumour not seen on the brain surface, and for determining the extent of maximal surgical resection, and for assessing the tumor volumes, and for detecting residual tumor (9, 20, 28, 44). In intracerebral hematomas, IoUS provides accurate information about the location, volume, and distance of the hematoma from the cortex, through the use of high echogenic area ultrasonic imaging (33). As it was possible to select the optimal route of approach to the hematoma, and identify the responsible artery for the hematoma, haemostasis has become more reliable, allowing the hematoma to be almost entirely evacuated. (33). It also proved effective at locating irregular hematomas, which otherwise become difficult to locate, with the procedure causing minimal brain damage, along with an increased rate of evacuation compared with the traditional method. (36). This is portable and not operation theatre specific. There is no radiation as compared to intraoperative CT Scan and it saves time when compared to Intraoperative MRI. During IOUS, there will be less patient fatigue. This is less space occupying and easier to incorporate into existing operation theatres.

Limitations

IoUS overcomes several limitations of conventional intraoperative navigation systems, which rely upon preoperatively acquired imaging data sets. The major factors that limit the usage of IoUS are the efficiency of the performing surgeon (operator dependant) which in turn depends on one's learning curve, which enhances its utility in various neurosurgical procedures. (16). The

tumour-brain interface may be difficult to define intraoperatively and the surgeon relies on a change in tissue colour and consistency. We acknowledge that there are limitations in any study using imaging modality for the detection of residual tumour. In our study, the tumour margin was well delineated by IOUS in 34 of 36 cases. (In one case, it was a recurrent tumor and the other case was a diffuse tumor, a primitive neuroectodermal tumor which was extending all over including the brain stem). It needs to be borne in mind that current imaging techniques may not fully reflect the biological extent of the tumor. That is, the detection of microscopic tumour cell migration into the surrounding parenchyma may not be feasible and hence the aim of intra-operative image guidance would be to achieve the optimal extent of resection. Keeping this limitation in mind, the utility of ultrasound is limited only to cases where a margin can be well defined. (9, 13)(13)(1) Though 3DUS along with neuronavigation is an useful intraoperative modality in awake procedures, the limitations are the increased cost of surgery and the patient fatigue, at times due to the duration of surgery. (13, 24, 26) In operations with greater surgical difficulty when the risk-cost comparison is performed, the surgical resection results have greatly increased. Due to quick access to the pathology, the dangers of cortical and vascular injuries can be reduced. (24, 26, 27) The study design and interpretation was subject to several limitations. This was a relatively small study, with all the patients attending a single centre, and operated by a single surgeon (to avoid bias). Further studies with larger study populations are required to make better conclusions.

Future

The optimization of neuronavigation systems and the introduction of IoUS for both cranial and spine surgeries have been fostered by numerous advancements in several scientific fields (including: biomedical engineering, imaging, electronics, nanotechnology, etc). Those technological aids serve now as an excellent tool for surgical planning and help surgeons to preserve vital structures encountered intraoperatively. Training and fellowship programs on IoUS may help many surgeons in a great way. As such, many spine surgeons all over the world are now utilizing IoUS in their practice, and this trend should foster the incorporation of IoUS in both intracranial and intraspinal surgical training and fellowship programs; in fact, the use of IoUS is likely to further increase in the coming decade when the use of ultrasonic contrast agents will further enhance the definition of images acquired intraoperatively. (18)

IoUS (with CEUS) has been useful in evaluating blood perfusion in a real-time fashion, as it helps neurosurgeons establish in advance the fine vascular pattern of any brain tumor, as well as the larger arterial/venous blood supplies of brain, similar to intraoperative angiography. (39, 40) Integration of an external ultrasonography system into the BrainLab navigation is accurate and precise. By modifying registration (and measurement conditions) via software modification, the in vitro accuracy and precision is improved and requirements for a clinical application are fully met. (57) To prevent errors in neuronavigation associated with potential changes in aneurysm localization following draining of cerebral-spinal-fluid or hematoma, confirmation with intra-operative ultrasonography imaging reduces the risk to a minimum.

Conclusions

Real-time intraoperative imaging technologies have shown utility in providing assistance to resection in a dynamic surgical field. Increasing attention has been paid to IoUS technologies, with IoUS being reported as a widely accessible, portable and less space occupying and reliable imaging tool to follow and modify the surgical plan in real time. Our study provides a prospective cohort analysis of the efficacy of IoUS in brain tumor resections, basal ganglia hematomas and other traumatic intracerebral contusions/hematomas. Our results support previously reported findings on the practicality and efficacy of IoUS, while also supporting current limitations to its use. IOUS is a cheap and effective tool that helps in real-time decision making, and more accurate and complete tumor resection, thus rendering the best possible outcomes for both pediatric and adult neurosurgical patients. (53) It is useful for determining the extent of resection in parenchymal brain tumours when intra-operative MRI and CT are not available. (9) This is useful for identification of solid and cystic components of a tumor, lessens the duration of surgery. This guides in planning the shortest pathway for the removal of the lesion, biopsy of deep seated lesions and also it is easy and safe to handle with no risk of radiation exposure.

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Tables

Table 1
Clinical and demographic details

Parameter		Number	Percentage	Right	Left
Age Range	0–10	1	1.4		
	11–20	5	6.8		
	21–30	3	4.1		
	31–40	9	12.2		
	41–50	18	24.3		
	51–60	21	28.4		
	60–70	12	16.2		
	> 70 Years	5	6.8		
GENDER	Female	25	33.8		
	Male	49	66.2		
Bleed/Tumor/ contusion	Basal Ganglia bleed	34	45.9	14	20
	Brain tumor	36	48.6		
	Traumatic contusion	4	5.4	2	2
Region	Atrial	2	2.7	1	1
	Basal Ganglion	25	33.7	11	14
	Basal ganglia frontoparietal		1.4		
	Cerebellum	2	2.8	1	1
	CP Angle	4	5.4	2	2
	Frontal	15	14.9	9	7
	Frontoparietal	2	2.7	1	1
	Multiple	1	1.4	1	
	Occipital	2	2.7	1	1
	Parietal	3	2.7	2	1
	Parieto-occipital	4	5.4		4
	Temperoparietal	3	1.4	1	2
	Temporal	7	10.8	2	5
	Thalamus	3	2.7	1	2
	Side of Lesion	Left	39	52.7	.
		Midline	1	1.4	
		Right	34	45.9	
Change_Neurodeficits	Improved	6	8.1		
	New deficits	1	1.4		
	No Change	50	67.6		

Parameter		Number	Percentage	Right	Left
Residual tumor/bleed	No deficits	17	23.0		
	No	39	52.7		
	Yes	35	47.3		

Table 2
Profile of Brain tumors with pathological diagnosis

Pathology	Subtype	Location	Right	Left	Midline
Supratentorial					
High grade glioma	Glioblastoma multiformae	Frontal	2	1	
		Parieto occipital		2	
	Anaplastic oligodendroglioma	Temporal		1	
	Ependymoma	Temporal	1		
Lowgrade Glioma(LGG)		Frontal	1		
		Atrial		1	
	Diffuse astrocytoma	Temporal(Insular)		1	
	Oligodendroglioma	Frontal		2	
	Pilocytic Astrocytoma	Thalamus	1		
	Ependymoma	Temporal	1		
	Gemistocytic astrocytoma	Parieto occipital		1	
Neuronal tumors	PNET	Thalamus		1	
Infections	Tuberculomas	Frontal	1		
		Temporo parietal		1	
		Parietal	1		
Metastasis	Metastasis	Frontal		1	
		Parietal	1		
		Multiple locations(1)			
		Temporal		1	
		Occipital	1	1	
Meningioma		Frontal parasagittal	2	1	
		Falx(anterior1/3)	1		
		Atrial	1		
		Parieto occipital		1	
Cavernoma		Temporal		1	
Infratentorial					
Haemangioblastoma		Cerebellar vermis			1
Schwannoma		Cerebellopontine angle	2	2	

Table 3
Modified Rankin Scale (MRS)-at admission and at discharge

MRscale	Contusion at admission	Contusion at discharge	BG Bleed at admission	BG bleed at discharge	Tumor at admission	Tumor at discharge	MRScale (admission time)	MRS(discharge)
6		1		10		1	-	12
5	2	1	31	8	7	2	40	11
4			3	12	5	3	8	15
3				1	2	3	2	4
2				1	2	5	2	5
1	2	2		2	20	22	20	27
0								

Table 4
Descriptive statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
AGE	74	69	8	77	49.00	15.78
preopVolume	74	100.90	0.50	101.40	40.96	27.81
postopVolume	74	99.75	0.00	99.75	5.66	9.70
preop_GCS	74	12	3	15	11.02	3.85
postop_GCS	74	12	3	15	12.08	4.05
Valid N (list wise)	74					

Figures

Figure 1

(a) The T2W axial and (b) T2W Sagittal post –gadolinium MRI scan of left parasagittal high grade glioma, showing mixed intensity lesion with central moderate intense solid lesion (small arrow) and peripheral hyperintense cystic component(large

arrow) and (c) IoUS done after opening the dura, showing hyperechoic solid component(s) with surrounding hypoechoic cystic (cy) collection

Figure 2

(a)The T2W sagittal and (b) T1W Sagittal post –gadolinium MRI scan of cerebellar haemangioblastoma, showing mixed intensity lesion with central hyperintensity and peripheral hypointensity (c) IoUS done after opening the dura, showing hyperechoic mural nodule(M) with hypoechoic cystic (cy)collection surrounding the mural nodule. Well defined tumor margin is seen (arrow head)

Figure 3

(A) CT axial image showing acute left basal ganglia bleed(h) with mass effect and midline shift (large arrow) (B) IoUS image showing hyperechoic bleed (h)