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Ventricular Tap for Post-hemorrhagic Ventricle Dilatation: How Much CSF Should be Removed?

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Abstract

Background: Preterm neonates are at risk for intraventricular hemorrhage (IVH) and subsequent post-hemorrhagic hydrocephalus (PHH) due to the presence of immature and fragile vasculature called germinal matrix just beneath the lateral ventricles. Temporizing treatment is done by removing fluid from the ventricles by ventricular tap (VT) or tapping an Ommaya reservoir (an intraventricular catheter system) or by inserting an external ventricular drain (EVD). Traditionally, the amount of fluid drained is dependent on the weight of the baby, as well as following clinical symptoms during the tap. This study examines how much cerebrospinal fluid (CSF) can be drawn safely during each VT.

Objective: This study aimed to find a relationship among various parameters related to VT to determine the best predictor of tap amount.

Method: In this study, data of 70 neonates having IVH were analyzed retrospectively where 11 neonates received at least one intervention during the study period of April 2012 to May 2016. We studied all available parameters regarding 42 taps obtained from 11 patients and found poor correlations (R^2=0.29 to 0.38) between tap amount with age, weight and head circumference (HC), and better correlation (R^2=0.55) between tap amount and total lateral ventricular volume measured by 3D head ultrasound (US).

Conclusion: The result of this study provides support for the hypothesis that total lateral ventricle volume measured by the 3D US is the better predictor of tap amount than the weight of the neonate. The weak correlation between tap amount and weight suggests that the removal of CSF according to weight did not represent how much fluid was drawn during VT. However, the volumetric measurement of total lateral ventricles by the 3D US could be used concurrently with other physical parameters to determine the tap amount.

Keywords: Intraventricular hemorrhage; Post-hemorrhagic hydrocephalus; 3D Ultrasound; Ventricular tap; External ventricular drain; Ommaya reservoir; Cerebrospinal fluid

Introduction

Intraventricular hemorrhage (IVH) refers to the bleeding inside the brain ventricles, which is the most common intracranial hemorrhage in preterm neonates. Recent reviews showed that the rates of IVH have remained 25% to 30% for very low birth weight pre-term infants (VLBW, <1500 g) although their chances for survival have improved due to advances in specialized obstetric and neonatal intensive care in the past several decades [1,2]. Severe degrees of IVH, grades II-IV can lead to post-hemorrhagic ventricle dilatation (PHVD), which is the enlargement of ventricles by an increased amount of cerebrospinal fluid (CSF). Since PHVD is related to higher mortality and poor neurodevelopmental outcome later in life [3], it requires accurate diagnosis and proper treatment when necessary.

Cranial ultrasound (US) has been shown to be appropriate to diagnose IVH, PHVD, and to evaluate the need for intervention [4]. The need for intervention is based mostly on a combination of clinical signs of elevated intracranial pressure (ICP), apnea, bradycardia, a rapid increase in head circumference (HC), and ventricular size assessed by the 2D US; however, the timing of interventions is subjective [5]. Though the definitive treatment for PHVD requires the placement of ventriculoperitoneal (VP) shunt to divert CSF from the brain to the peritoneal cavity, there is a general agreement that an early VP shunt is not an option as the proteins in the CSF are elevated due to the blood, and therefore would block the valve; in addition shunting small infants whose body weight is less than 1 kg is not ideal. Younger infants are more at risk of shunt failure, blockage, infections, and skin ulcerations with the use of VP shunts [6]. Other temporary methods include ventricular tap (VT), lumbar puncture (LP), ventricular reservoir, ventricular access device (VAD), ventriculo-subgaleal shunt (VSGS), and endoscopic third ventriculostomy. The main goal of these treatments is to temporarily reduce ICP and therefore protect the brain from damage [7].

Previous works have been performed to compare various treatment methods [6,8,9], which are still controversial regarding which method is best treatment option for PHVD. Since many cases of PHVD resolve after temporary CSF diversion procedures and do not require a shunt, the primary treatment option in our institution is a ventricular tap (VT), which involves the removal of CSF by insertion of a needle into the lateral ventricle through the anterior fontanelle, unless it needs to be repeated too often in which case an external ventricular drain is inserted. Traditionally, 10 ml/kg CSF is removed in each VT, but that might not meet the need of the infant, and therefore other physicians might not always observe that guideline and instead look at clinical symptoms (difference in splaying of sutures, aspect of the fontanelle, heart rate, etc).

We gathered all the information of the infants who have undergone at least one VT in our institution from 2012 to 2016. During that time, we also had a 3D US study to assess ventricular volumes, but physicians were blinded to the actual volume of CSF in the ventricles. The objective of this study was to correlate the tap amount with infants' age, weight, HC, and 3D US volume of the total lateral ventricles to identify the strongest correlation among these parameters, which will help the neurosurgeons to determine how much CSF can be removed safely during each intervention.

Materials and Methods

This study is a retrospective review of physical, neurological parameters and 3D US-based ventricular volume charts of premature infants affected by IVH and PHH who were intervened by at least one VT.

Patient selection

Premature neonates in the neonatal intensive care unit (NICU) of Victoria Hospital, London, Ontario with a positive diagnosis of IVH on an initial clinical head US exam were recruited upon approval by the Research Ethics Board at Western University and parental informed consent during the years between April 2012 and May 2016. Once enrolled, recruited infants underwent serial 3D US exams one or two times per week according to the severity of IVH until discharge from the NICU or transfer to another center. Neonates with congenital hydrocephalus and any other congenital anomaly with IVH were excluded. We included IVH patients with other comorbidities such as meningitis who required intervention. Clinicians based their decision for interventions according to qualitative findings of 2D cranial US images and some combination of clinical and neurological findings (apnea, bradycardia, increase in HC, pupil condition and fontanelle palpation). The clinical care team was blinded to the 3D US images and ventricular volume measurements. 70 premature neonates with IVH were recruited and among them 11 infants had at least one VT, allowing us to analyze the data of 42 individual taps.

Determining tap amount

The need for interventions by VT was decided by the clinical teams based on the measurement of 2D cranial US and other clinical parameters such as head circumference, baby's weight, apnea, and bradycardias. Some physicians followed the traditional rule of 10 ml/kg, while others relied primarily on clinical symptoms such as the amount of suture splaying and its reduction during the tap, the fullness of the fontanelle and how it was decreasing during the tap as well as the relative size of ventricles on the 2D US. Therefore, in case of some patients, the tap amount was predetermined depending on weight, while for some of the patients, the amount was adapted during the procedure and recorded at the end, once the suture and fontanelle felt better. In both cases, the infants' clinical status such as heart rate, respiratory rate, blood pressure, oxygenation were also followed during the procedure, which would be stopped if there was a sudden change in the infant's status.

3D US system

We used a 3D US system, which we developed in our lab that can be coupled to any clinical 2D US machine with an appropriate conventional probe used for imaging neonatal brains [10,11]. This system consists of a handheld motorized device that can house a 2D US probe. Although this system can be used with any US machine and an appropriate probe, HDI 5000 (Philips, Bothel WA) US machine and C8-5 (Philips, Bothel WA) curved array 5 - 8 MHz broadband probe were used during the study period. After initiating the scan, the US probe is tilted about its front face and 2D US images are acquired into a computer via a digital frame grabber (Epiphan DVI2USB 3.0) and reconstructed into a 3D image as the 2D US images are acquired. Photographs of the motorized device with a probe attached are shown in Figure 1.

Figure 1: a) Device for 3D US imaging, b) device coupled with a neonatal probe, c) simulated position of the neonatal probe in the 3D US scanner.

3D US Image acquisition and ventricle segmentation

A 3D US image acquisition is performed by first locating the anterior soft part of the brain, and then firmly holding onto the device's hand grip (Figure 1) while the device tilts the probe on an axis at the probe tip, which is against the patient's head. Images are acquired over a scan angle of 30-72° with the image acquisition time between 4-14 s. Typically, for neonatal studies, we used an angular spacing between acquired 2D US images of 0.3° and a total scan angle of 65°, for a scan time of 8.7 s. Due to patient movement, 1-8 attempts were usually required to obtain 3D US images of both lateral ventricles, resulting in a total bedside scan time about 2-15 min.

After 3D US image acquisition, the lateral ventricles were manually segmented by trained observers in parallel sagittal slices with 1 mm spacing between adjacent slices and verified by a pediatric neurosurgeon. The boundaries of the ventricles were carefully observed in both sagittal and coronal planes and the lateral margins of the contours were manually adjusted if needed to ensure the full segmentation of the ventricles. Each image required 20 - 45 min to segment a ventricle. The process of segmentation is shown in Figure 2. For some patients, the right and left ventricles had to be segmented separately in separate images due to their large size. After full segmentation, the software automatically calculated the volume of the ventricles.

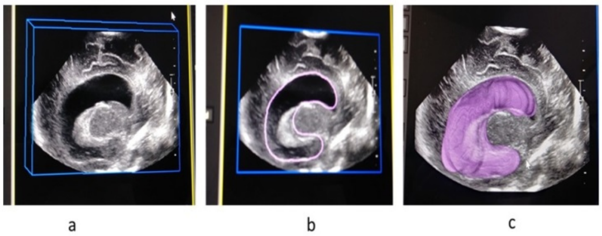

Figure 2: Process of segmentation a) 3D US cube of the ventricles before segmentation, b) the segmented ventricle boundary, c) segmented ventricle after full segmentation.

Data analysis and statistics

The recorded variables were: gestational age, gestational weight, HC at birth, gender, age at IVH diagnosis, 3D US-based volumes of each ventricle in every 3D image, number and date of tap for each patient, amount of CSF removed in every tap, age, weight at the day of individual tap, HC just before and after tap, 3D US total ventricle volume (TVV) before and after tap, requirement of shunt placement and neurological outcome. Linear regression was performed among selected variables (tap amount, weight, age, HC, TVV) and regression of $R^2 > 0.5$ was considered strong and $R^2 < 0.5$ was considered weak in this study. Bivariate correlation was also performed using SPSS v.25 (IBM Corp., Armonk, NY, USA).

Results

Patients characteristics

One to nine ventricular taps were performed on 11 infants among the 70 recruited IVH neonates during this study period. The demographic and clinical details of the 11 infants are shown in Table 1.

Characteristics	**Details**
Average gestational age (weeks)	29.57 ± 4.7
Average birth weight (gm)	1491.63 ± 869.57
Average head circumference (cm)	27.43 ± 6.1
Sex (male and female)	male 6 and female 5
No. of caesarian deliveries	7
No. of vaginal deliveries	4
Average age of IVH diagnosis (days)	4.5 ± 2.1
Grade of IVH	
Grade I	0
Grade II	2
Grade III	4
Grade IV	5
Other comorbidities	
Respiratory distress syndrome	8
Hyperbilirubinemia	5

Table 1: Clinical characteristics of the study population.

Ventricular tap amount

The differences of the expected tap amount according to the clinical rule of 10 ml/kg with the actual tap amount ranged from -19 ml to +23.15 ml. The actual tap amount, expected tap amount, the difference between actual and expected tap amount, and pre-tap total ventricle volume (TVV) by 3D US are listed in Table 2. The information that was not recorded is marked as not determined (N.D.).

Patient number	Number of taps	TVV by 3D US just before tap (ml)	Weight on the day of tap (gm)	Expected tap amount (ml) 10 ml/kg	Actual tap amount (ml)	Deviations from the expected tap amount (ml)
Subject 1	1	36.97	1460	14.6	21	6.4
Subject 2	1	47.9	850	8.5	21	12.5
	2	42	1000	10	23	13
	3	39.6	1050	10.5	9	-1.5
	4	36.2	1100	11	16	5
	5	45.8	1240	12.4	20	7.6
	6	N.D.	2758	27.58	25	-2.58
	7	305	3224	32.24	36	3.76
Subject 3	1	87.6	1220	12.2	27	14.8
	2	86.7	1300	13	9.5	-3.5
	3	117.6	1360	13.6	22	8.4
	4	N.D.	1540	15.4	25	9.6
	5	146.9	1690	16.9	15	-1.9
	6	N.D.	2300	23	25	2
Subject 4	1	79.2	3900	39	20	-19
	2	92	N.D	N.D.	20	N.D.
Subject 5	1	N.D.	2530	25.3	36	10.7
	2	N.D.	2685	26.85	50	23.15
Subject 6	1	107.96	N.D	N.D.	14	N.D.
Subject 7	1	45.67	1000	10	11	1
	2	59.41	1090	10.9	11.5	0.6
	3	74.68	1180	11.8	18	6.2
	4	96.23	1300	13	16	3
	5	103.7	1400	14	21	7
Subject 8	1	56.4	1350	13.5	15	1.5
	2	63.1	1550	15.5	28	12.5
	3	48.65	1600	16	10	-6
	4	71.61	1840	18.4	N.D.	N.D.
Subject 9	1	37.6	1480	14.8	9	-5.8
Subject 10	1	44.7	1270	12.7	10	-2.7
	2	48.5	1270	12.7	22	9.3
	3	46.3	1270	12.7	23.5	10.8
	4	N.D.	1320	13.2	31	17.8
	5	N.D.	1410	14.1	22	7.9

	6	119	1820	18.2	15	-3.2
	7	N.D	2320	23.2	37	13.8
	8	N.D	2650	26.5	48	21.5
	9	N.D.	2780	27.8	45	17.2
Subject 11	1	79.75	1100	11	22	11
	2	76.19	1210	12.1	19	6.9
	3	98.52	1880	18.8	24	5.2

Table 2: Measured variables on the day of tapping.

Correlations of tap amount with age, weight, head circumference, and 3D ventricular volume

Linear regression was performed to find any correlations between the actual tap amount with the age, weight, head circumference, and 3D ventricular volumes. R^2 of tap amount with weight, age, HC and pre tap total ventricle volume (TVV) were 0.33, 0.29, 0.39 and 0.55 respectively as shown in Figure 3a-3d. In addition to linear regression, we analyzed the data by bivariate correlation. The Pearson correlation of tap amount with weight, age, HC and pre-tap TVV were 0.595 and 0.468, 0.622 and 0.739 respectively. In both analyses, our result indicated that ventricle volume had the highest correlation with tap amount among the 4 predictors of interest. Analyses using linear regression are shown in Figure 3 and bivariate correlations among 4 predictors and tap amounts are shown in Table 3.

		Tap amount (ml)	Weight (gm)	Age (wk)	HC (cm)	Total ventricle volume (cm3)
Tap amount (ml)	Pearson Correlation	1	0.595	0.468	0.622	0.739
	P- value (2 tailed)		<0.0001	0.014	<0.0001	<0.0001
	N	42	38	27	37	32
Weight (gm)	Pearson Correlation	0.595	1	0.953	0.911	0.646
	P- value (2 tailed)	<0.0001		<0.0001	<0.0001	<0.0001
	N	38	40	27	38	29
HC (cm)	Pearson Correlation	0.622	0.911	0.846	1	0.692
	P- value (2 tailed)	<0.0001	<0.0001	<0.0001		<0.0001
	N	37	38	26	39	30
Total ventricle volume (cm3)	Pearson Correlation	0.739	0.646	0.531	0.692	1
	P- value (2 tailed)	<0.0001	<0.0001	0.006	<0.0001	
	N	32	29	25	30	32

Table 3: Results of Bivariate correlation between tap amount and 4 predictors (age, weight, HC and total ventricle volume).

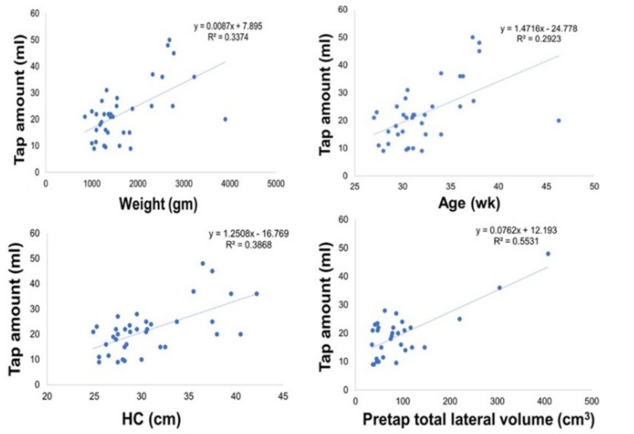

Figure 3: Linear regression of tap amount with weight, age, HC and the total lateral ventricle volume before the tap.

Outcomes of VT and requirement of VP shunt and revision shunt

Serial taps were performed on these neonates before the placement of the V-P shunt. The average number of taps performed per patient was 4. Among these 11 patients, 2 patients did not need any shunt placement, the other 9 infants received V-P shunt for management of PHVD. No infant died during this study period. The infants were observed for developmental and neurological assessments after the placement of shunts.

Discussion

In our retrospective study, we investigated the potential use of 3D US-based measurements of ventricular volume from neonatal brain images to help to determine the volume of CSF that should be removed in each tap. Currently, there is no general agreement on how much CSF is safe to drain, and practices vary among neurosurgeons and among institutions. However, several studies recommended that 10 ml of CSF should be removed for each kg weight [12,13] but maximum limits have not been studied. One recent study claimed that cerebral oxygenation would improve after the removal of less CSF than the standard of 10 mL/kg. They found improved cerebral hemodynamics and oxygenation during CSF removal after 50% of the planned 10 mL/kg CSF removal [14], but it was not reported how cerebral hemodynamics behaved after 100% or more than 100% of planned CSF removal. Removing a larger amount of CSF can cause transient apnea, bradycardia after the intervention [15] but the removal of a too-small amount may not improve the neonate's clinical status and may lead to excessively repeated interventions if the infant does not improve clinically. However, it was shown that too little aspiration (< 10 ml/kg body weight) had no effect on ventricle size or ICP [13]. Moreover, in our retrospective study of 42 VTs, the amount of CSF removed was tolerated by all the infants and no deterioration of clinical status was observed during this period.

Previously the 3D US measurements of the ventricular volume were validated against a test phantom with a known volume and showed that the 3D US geometric reconstruction was found to be accurate with an error of < 0.2% [10,11]. Furthermore, the volume difference of pre- and post-tap ventricle volume measured by 3D US was highly correlated with the tap amount with a Pearson correlation coefficient of R^2=0.92 [11]. 2D cranial US is still the clinically preferred method to diagnose IVH and to evaluate the necessity of intervention, but this method may have variability and cannot be fully relied on to provide accurate volume measurements [16,17]. Although the 3D US system was shown to be a better predictor of interventional necessity, it has not yet been adopted clinically as a standard care tool [11].

In this study we compared the amount of CSF removed in each tap with the age (post-menstrual) of the baby on the day of tap, weight on the same day, HC measured just before tap and the total volume of the lateral ventricles measured by the 3D US just before VT. Based on guidelines, the tap amount should be well correlated with neonatal weight as this is the well-accepted biomarker to determine how much CSF should be removed in each tap. However, in our study, the tap amount was better correlated with pre-tap total volumes of the lateral ventricles measured by the 3D US. As the clinical team was not aware of the volume of the 3D measurements, the removal of CSF was done according to the weight and the infants' clinical status. Since there is no acceptable parameter in 2D US-based measurements depending on which clinicians can determine the tap amount in each VT, they mainly rely on weight and other neurological and clinical parameters. In our study, the weak correlation between tap amount and weight suggests that this biomarker might not be sufficient to determine the volume of CSF that should be removed. 3D US-based volume measurements can be used as an additional indicator to avoid frequent taping and to improve the clinical status of the infant.

One limitation of the measurement of ventricle volume is the time required to segment each ventricle (20-45 mins) and requirements for training to perform this task. If this limitation can be overcome with methods such as deep learning, the 3D US-based measurement of ventricle volume might be adopted clinically considering that it might be a useful tool for the management of PHVD.

There are wide variations of interventional treatments such as lumbar puncture, VT, ventricular reservoirs tapping but we only considered VT in this study. The determination of tap amount by 3D US-based measurement of ventricle volume should be also validated for other interventional treatments. An additional limitation in our study is the small number of patients (n=11) who required interventions (total VT=42) and some information on some of the days were not recorded. Also, some manual segmentations were not possible when the dilatation of the ventricles was very large and resulted in poor 3D US images on some interventional days. These cases were excluded from our study. In some cases, the fontanelle size was a limiting factor and was the probable cause of producing poor 3D US images [18,19]. The median age of fontanel closure is about 13.8 months in the term group and fontanelle size in preterm infants do not differ significantly from that of term infants after reaching term age [20]. However, the anterior fontanelle usually shrinks as the neonates get older and the posterior acoustic shadow of the edge the frontal bone reduces the image quality.

Conclusion

Because of the diversity among various centers and also among neurosurgeons regarding the amount of CSF that should be tapped, it has become a priority to investigate a standard guideline for the neurosurgeons. As such, we have tried to present a potential clinical use of 3D US-based measurement of total lateral ventricular volumes in this regard. However, future larger, multicenter studies are required before generating guidelines for tap amount during intervention.

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