特集 最新検査法の小児頭部画像診断への応用

4. Quantification of Flow and Regional Cerebral Tissue Perfusion in Children Using MR and Xenon CT

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Abstract

Non invasive imaging studies such as CTA and MRA have advanced rapidly over the previous few years. Less effort has been devoted to the quantification of cerebral blood flow in spite of the fact that absolute measures of flow and tissue perfusion may be critical in our understanding of CNS disease and permit objective measures of the success or failure of therapeutic interventions. With MR, phase contrast cine angiographic techniques can be employed to measure bulk flow in intracranial vessels. When applied to arteriovenous malformations (AVMs), this technique allows the evaluation of treatments such as embolization or stereotactic radiation. Similarly, neurosurgical preoperative assessment of AVMs may be enhanced by an objective method of measuring flow in both the feeding arteries and draining veins. This prompted us to develop a method of measuring vascular flow [1]. In contrast, Xenon CT allows for the objective measurement of absolute regional cerebral tissue perfusion (rCBF) and can be used to determine the risk of stroke in ischemic neurovascular diseases. We have used such an approach to monitor the effect of hyperventilation in children suffering from head injuries as well as to determine the risk of stroke and treatment response in children suffering from Moyamoya disease.

This review will outline the technical issues that must be considered when developing quantitative MR flow imaging and its application in pediatric neuroimaging. The pitfalls and challenges of using Xenon CT to measure rCBF will then be discussed followed by its clinical application in children.

Keywords : Xenon CT, Quantitative MR flow, Pediatric neuroimaging

MR Q FLOW

MR phase contrast angiography relies on the fact that moving spins in a magnetic field gradient obtain a different phase than static spins. This phase shift is in proportion to their velocity, allowing MR to create an image with a controlled sensitivity to flow, which we will call MR Q flow[2~5]. Cardiac gating is employed to divide the phase encoding data through the cardiac cycle into increments in either a prospective or retrospective fashion. From such velocity maps it is possible to estimate intraluminal bulk flow. For through plane flow, the product of mean velocity (㎝/sec) and the pixel area (㎠) of the region of interest (ROI) will determine the flow through the ROI (㎤/sec). Such techniques have been widely pursued in cardiovascular imaging, but infrequently applied to the CNS[6]. It is critical to understand that in very small vessels the technique will underestimate the true velocity because of partial volume effects, but that flow measurements will still be correct. The method of flow calculation is valid because the average velocity is summed up over a greater area than

the true lumen of the vessel and the included velocities outside the vessel boundary should be zero. Thus, correct background phase values are crucial.

There are many potential sources of error in MR Q flow techniques and these must be carefully evaluated. Errors may be introduced by; aliasing, misalignment, partial volume effects, misregistration, phase shifts and signal loss[4,6,7]. These are briefly considered here in order to point out desired choices for gradient performance and sequence selection.

Aliasing occurs because of the cyclic nature of phase with an inherent limitation of 2 π radians. Postprocessing can unwind some of these errors, but it is best to carefully select the correct velocity encoding (VENC) that does not result in aliasing. When the true velocity is unknown we often select three or more VENC values when performing a clinical study. The VENC with the smallest value that does not alias is the most accurate estimate of flow.

Misalignment occurs when the velocity encoded slice is not perpendicular to the vessel because velocity is only measured in the encoded direction. If the slice is oblique to the true direction of flow, the error is proportional to the cosine of the angle between the flow and direction of encoding. In general the error is small over a broad range; 1% at 5 degrees and up to 6% at 20 degrees. If the background phase is truly zero, then no flow error occurs in the estimate of flow since a larger ROI is generated to encompass the vessel. However the simplest approach is to place the slice in the direction of flow which means MR equipment should have the ability to obliquely orient the slice in all three dimensions.

Partial volume effects have been briefly discussed above. Although the mean velocity will be reduced, flow values will be correct if the background phase is zero since the resulting larger ROI will compensate. These effects are greatest with small vessels and thick slices and can be minimized by choosing a slice perpendicular to the flow and eliminating background phase errors. Misregistration is caused by movement between slice selection, phase encoding and frequency encoding and if the slice is oblique to the direction of flow some of the signal will be displaced outside the vessel. This problem is also reduced by selecting a plane perpendicular to the flow and a sequence with short TEs.

Phase shifts are also caused by higher orders of motion such as acceleration or jerks. The subtraction of velocity sensitive from velocity insensitive phase images removes lower order phase shifts only while higher orders of motion will be more effectively managed with a shorter TE. Factors such as the duration of the gradient profile influence the derived velocity. For example, a true velocity of 1 ㎝/sec and an acceleration of 10 ㎝/sec x sec and a TE= 22 ms velocity will be estimated at 1.079 ㎝/sec while with a TE= 6 ms the velocity would be calculated at 1.017 ㎝/sec[7]. Thus it is important to have an MR system with gradients that allow for minimal echo times.

Signal loss also occurs for similar reasons as phase shifts since higher orders of motion also cause phase dispersion and loss of signal. In plane velocity measurements are less susceptible than through plane measurements. Signal loss is also minimized by selecting a slice perpendicular to the direction of flow and having short gradient profiles that lessen the time of higher orders of motion to influence the image signal.

Other factors that influence the accuracy and precision of MR Q flow measurements include the field of view, temporal resolution as well as the background pixel value and ROI selection[8]. With a smaller field of view there is a demand for increasing gradient performance that may cause eddy currents and shifting background values that are not equal to zero. Thus smaller filed of views have both a lower signal/noise ratio and a larger potential for error. Similarly high temporal resolution is important because

average velocities may change rapidly throughout the cardiac cycle.

Background pixel values and ROI generation are extremely important issues to consider. Flow values are highly dependant on the background pixel values being correctly assigned a value of zero since this enables a generous ROI to encompass all of the flow from the vessel whether it is displaced or misaligned. Background phase errors may be caused by many factors including susceptibility effects, microcirculation effects, and MR design limitations such as RF instability, gradient repeatability, echo centering or echo sampling[4]. In general, background phase errors are less serious in the brain than in the chest. The lack of signal and random noise in the lungs translates into a greater challenge to find a background value of zero than occurs from the signal of the brain. However one of the keys to success in MR Q flow is to pay careful attention phase errors; if the errors are large, then the values cannot be trusted.

Differences in flow rates have been reported to be as great as 8-24% due to intra-observer variability in selecting ROIs[3]. Burkart describes an automated technique of vessel detection that shows less inter user variability with an accuracy within 10% of true flow values in phantom tests. A reliable manual method of ROI generation consists of using the magnitude images and setting the window width and levels at 50% of the maximal intraluminal signal intensity in the image. Magnification of the magnitude image allows for easier manual tracing of the ROI and care must be taken to include only the vessel in question. The generated ROI is then applied to the velocity map and each image is reviewed to ensure that vessel motion or distortion through systole and diastole is accounted for. ROIs of the background may be generated to ensure that the phase errors are minimal. Although we have stated that if the background phase errors are minimal, flow estimates are accurate with ROIs greater than the true lumen, it is important to minimize the ROI size and obliquity of flow because the noise in the image will increase. Both noise and partial volume effects are non-linear and may cause significant errors.

It is clear that an MR system with superb gradient performance and the ability to place the sample slice in oblique planes are important factors in the success of MR Q flow. We use a Picker 1.5 T Edge system with power drive gradients. The gradients are actively shielded with a peak gradient strength of 27 mT/m and a slew rate of 72 mT/m/ms and a temporal resolution of 40 ms when using prospectively gated velocity encoded studies. Table one outlines the scan parameters available on our scanner that have largely addressed these technical requirements for flow studies.

The best way to ascertain the accuracy of the method is to perform bench test on each velocity encoded sequence using pulsatile flow and tubing of different sizes in order to determine the relative accuracy of the method before employing the technique in a clinical setting. We carried out such tests using a UHDC (University Hospital London Development Corporation, London, Canada) flow phantom that could create a range of continuous and pulsatile flows[1]. The data was analyzed with the provided cardiac software package by two radiologists who were unaware of what flow rate had been selected and the results compared to the known answer. A similar approach was also used using an ECMO (extra corporeal membrane oxygenation) machine normally employed for intra-operative cardiac bypass. Our tests indicated we could expect a measured value within 10% of the true flow value, which is competitive or superior to any current method. Indeed, the MR approach yields a result freer of assumptions than other methods by permitting the creation of ROIs that match the vessel lumen over time and sampling of all velocities within the cross sectional area.

We first applied MR Q flow to infants with Vein of Galen malformations[1] because the optimal time for intervention was unclear and

the draining vein is large and technically easy to sample. Having established the feasibility of the technique and generated believable data we proceeded to measure flows in selected AVMs where both the arterial feeders and draining veins could be sampled[9,10]. These studies showed an agreement between arterial and venous flows within 5-10% and this confirmed our belief that flow measurements in smaller arteries could be performed accurately. We followed these studies with selective arterial MR Q flow measurements in children with ischemic neurovascular diseases. The technique was the same in all studies.

Although the initial work outlining the MR Q flow measurement was presented in 1995[1], the complete work was first presented at Kumamoto[9]. MR investigation of children with AVMs included routine sequences and MRA performed as 3D TOF MOTSA sequences. Routine imaging included axial, sagittal and/or coronal T1 (600/20/2/192×256) (TR/TE/AV /MATRIX SIZE), axial FSE T2 (2500-3500/40, 80/1-3/192× 256) and a 3DT1 weighted sequence (24/4.4/2㎜/256×256). The MRA was an incoherent gradient echo sequence, (RF-FAST) (42/6.9/20/20/0.9/180×180 TR/TE/FOV/FLIP ANGLE/ THICKNESS /MATRIX SIZE) with or without a presaturation pulse. All patients selected for MR Q Flow evaluation also had angiography performed.

MRAs were used to place velocity sensitive sequences perpendicular to either and/or both the arterial input and venous outflow of the vascular malformation. Velocity sensitivity was run in the slice select plane and the sequences were combined with prospective ECG gating across two cardiac cycles. Multiple flow sensitive sequences were performed and visually assessed for the presence of aliasing. In infants with VGAMs, a similar approach to MR Q Flow was utilized to determine cardiac output by choosing a sample slice across the ascending aorta.

The MR Q flow data was analyzed with standard cardiac software. Once ROI's were created the software calculated peak velocity, average flow rates per duty cycle (30-40 ms) and average flow rates per second. Arterial flow rates were determined by adding the flow rates/duty cycle because of marked variation in flow during systole and diastole. Flow values were expressed in ㎖/min and in patients with VGAMs, cardiac output and systemic flow (total cardiac output-AVM flow) was expressed in ㎖/kg/min. These values were compared to normative data, and combined with AVM flows to express AVM flow as a per cent of cardiac output

The initial report discussed 11 pediatric patients who underwent a combination of studies including CT, CTA, MRI, MRA, and angiography as well as 26 MR Q Flow studies[9]. MRA and/or CTA faithfully demonstrated the arterial and venous components of the vascular malformations in all. Seven patients with Vein of Galen vascular malformations were studied; five with Vein of Galen aneurysmal malformations (VGAM) and two with Vein of Galen aneurysmal dilatation (VGAD). In the patients with VGAM, MRA routinely captured arterial and venous flow, correlating well with corresponding angiograms, before and after treatment. Q Flow data from the VGAMs showed pre-treatment shunts ranging from 55-73% of cardiac output compared to 25-47% in the patients with VGAD. After embolization in VGAMs, there was an immediate 40-60% reduction in shunt flow and a significant delayed reduction of flow in all three patients 15-30 months after embolization. With the reduction of the vascular shunts, total systemic cardiac output returned to the normal range of 150-200 ㎖/min/kg. The serial flow data from one of these 3 patients is outlined in table 2. Our data suggests there is a delayed involution of flow many months following embolizationin VGAMs that is hard to ascribe to the treatment. Thus it may be unnecessary to re-embolize until a significant length of time has passed after the first treatment and points out the strength of having an objective, noninvasive

method of measuring treatment effects.

We then selected AVMs where both the draining vein and arterial input appeared possible to sample. In these cases the calculated venous outflow measured with different VENC varied less than 5 %. Similarly there was 5-10 % difference between the calculated arterial input and the venous outflow. In one case the MR Q flow indicated that there were two feeding arteries to the vascular malformation even though the angiogram had suggested that one of the arteries likely did not contribute flow (**Fig.1, 2**). A subsequent super-selective angiogram at the time of embolization confirmed the MR data. Excellent agreement between the arterial and venous results increased our confidence in arterial sampling and prompted us to apply the technique to major vessel neurovascular disease.

Ischemic neurovascular disease in children may be caused by traumatic dissection,

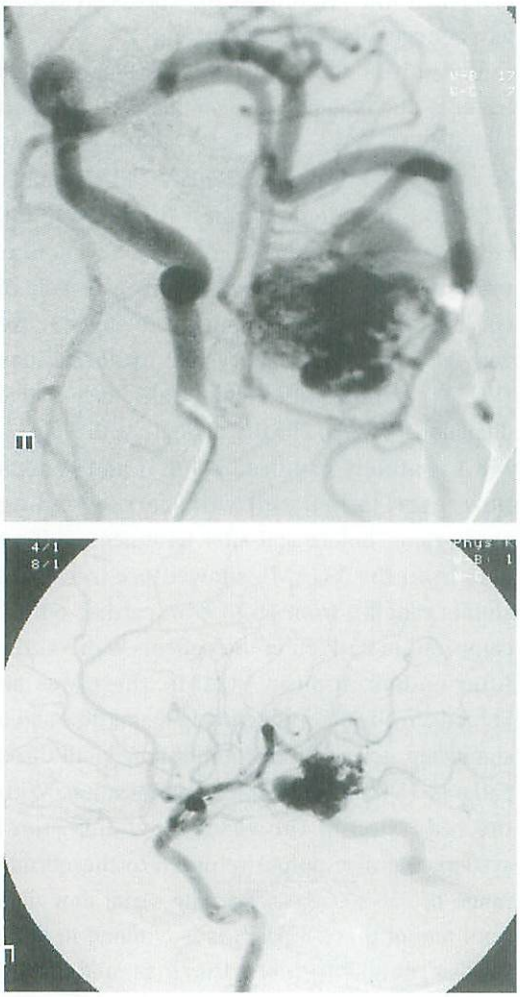

Fig.1

Two views from an angiogram showing a left middle cerebral artery AVM. Note two potential arterial feeders on the submental view and the draining vein on the lateral projection.

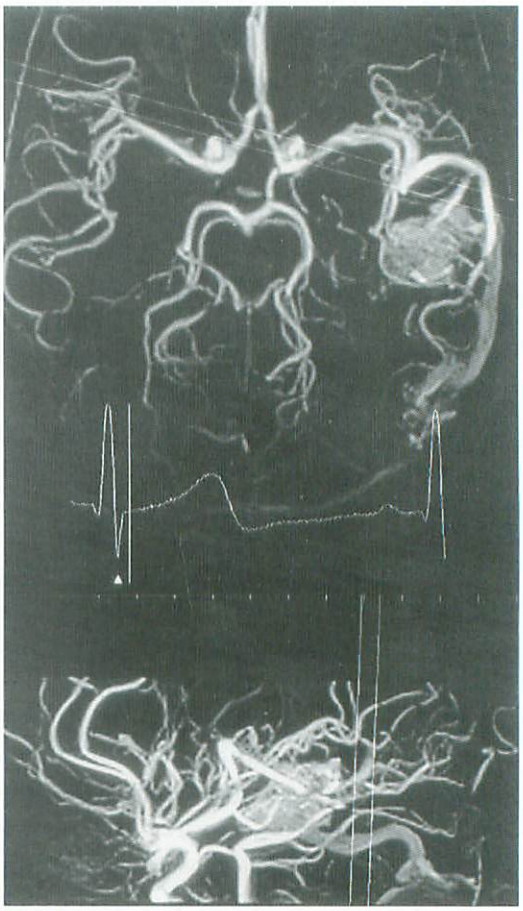

Fig.2

Corresponding MRA images accurately duplicate the angiogram and locate both the arterial feeders and venous outflow. The oblique lines on the submental and lateral views represent the sample slices used for MR Q Flow. Venous flow was estimated at 424 ml/min. with an error of <5 % using velocity encoding of 100, 200, and 400 cm /sec. The combined arterial flow from both arteries was calculated to be 450 ml/min.

inflammatory vessel stenosis, fibromuscular hyperplasia, or Moyamoya disease and place the child at risk for inadequate regional tissue perfusion (rCBF). Any intervention performed to augment cerebral perfusion should be assessed by an objective measurement of rCBF. MRA may image major vessel occlusive neurovascular disease, and flow alterations may be assessed over time by employing MR Q Flow techniques[11,12]. Estimation of distal cerebral tissue perfusion requires a method such as Xenon. Here we will only outline the value of MR Q flow. The only difference in this technique from that described above was the repetition of the Q flow studies with acetazolamide in an effort to estimate the amount of vascular reserve present.

In Kumamoto we first reported on 12 pediatric

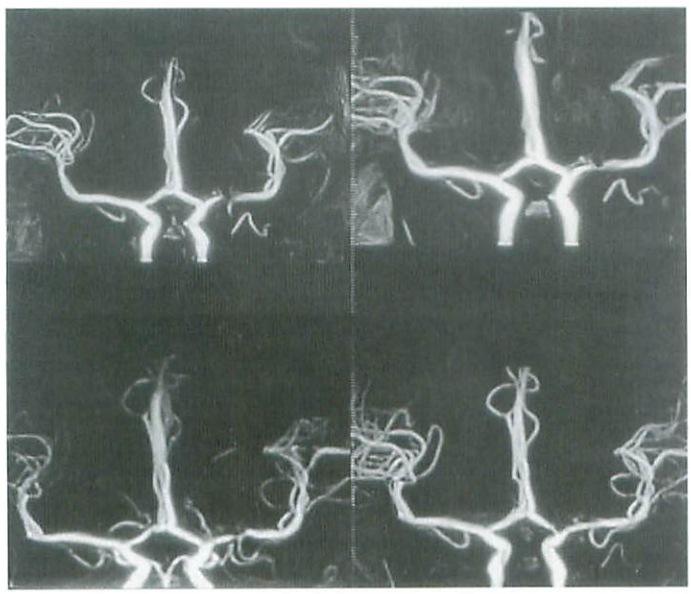

Fig.3
Serial MRAs done three months apart. The initial image shows a marked focal stenosis of the left MCA that resolves over time. MR Q Flow at the times of diagnosis documented a 20% increase in MCA flows after acetazolamide. The patient was not considered at risk for a stroke and was treated conservatively.

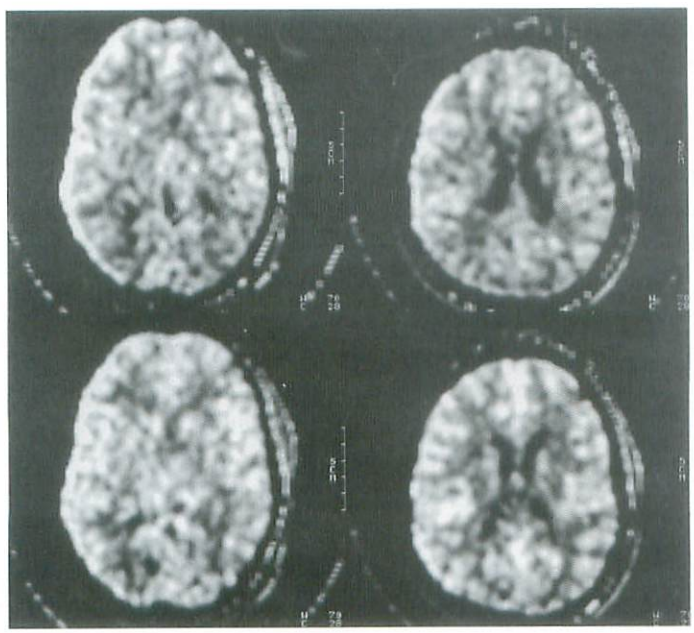

Fig.4
Xenon CT of patient described in Figure 1 at the time of diagnosis. The study shows normal rCBF which augmented with acetazolamide. The top two images are baseline flows that show adequate perfusion to both cerebral hemispheres. The bottom two images show augmentation after acetazolamide and no regions of oligemia. Compare with figure 7.

patients with an occlusion or stenosis of one or more major intracranial vessel[11]. Focal large vessel disease was present in seven children; three with traumatic dissections and four with a major vessel stenosis. Six additional children had diffuse ischemia.

Twelve of nineteen MRA studies were performed within one month of a cerebral angiogram and allowed direct visual evaluation of the quality of MRA. All MRA studies were abnormal, outlining the segments of altered flow, but in four cases the length of abnormal vessel was overestimated by visual inspection. In all six patients who were prospectively chosen for MR Q Flow and vasoreactivity assessment, MRA images permitted accurate placement of the sample slices and correlated well with the Xenon CT findings performed on the same day (Fig.3, 4). In nine studies the MR investigations preceded the angiogram, while in three the angiographic study was available to assist the MRA acquisition. The MRA studies were most accurate in the group of children with major vessel stenoses and demonstrated diffuse flow alteration and collaterals in patients with more diffuse ischemia.

In three children with major vessel stenosis there was decreased flow that did not augment following acetazolamide challenge. In all cases there was a decrease in rCBF as measured by Xenon CT that corresponded to the flow data. In two cases with MR Q Flow and vasodilatation, the decrease in major vessel flow estimated by MR was identical to the estimated decrease in rCBF measured by Xenon CT. In three cases, serial MR and Q flow studies indicated improvement in the appearance and flow of the affected vessel; one in a patient who had returned for a clinically suspected stroke. Angiography performed within seven days of the MR confirmed the MR observations in all three cases.

Thus MRA and MR Q flow performed in children with major vessel occlusive disease can assess the degree of ischemic risk and allow non-invasive serial studies of vascular physiology. The studies correlate well with angiography and rCBF measurements, particularly in focal disease. However the technique is best used in conjunction with XeCT which can measure absolute regional tissue perfusion[11].

Xenon CT

Xenon CT as a method for calculating regional cerebral blood flow is an old technique that has never gained popularity in North America, but has been more widely accepted in Japan. The technique has some notable advantages; it is relatively inexpensive and can be easily added onto any CT scanner, it is quick and can be repeated within twenty minutes so that multiple interventions may be tested at the same sitting. The method also measures absolute rCBF rather than relative flows as in nuclear medicine, and the generated ROIs are prescribed from an anatomic map rather than drawn on a physiological map of flow. The main drawback is the radiation dose incurred by the patient, and this limits the number of studies in a patient. Other issues to be aware of concern the influence of ROI size and flow values on the error of measurement and the challenge of patient motion. One of the best sources of information is "Cerebral Blood Flow Measurement with Stable Xenon-Enhanced Computed Tomography" edited by Howard Yonas[13]. This book is based on papers presented at the First International Conference on Xenon CT in 1990 and outlines the history of the method, technical aspects and includes at least twenty papers from Japanese research groups.

The estimates of cerebral blood flow using xenon are based on the time dependent concentration measurements of an inert, diffusible tracer using the Fick principle. In the XeCT method gas is inhaled and the end tidal concentration of Xenon assumed to be equivalent to the arterial concentration. Selected levels of the brain are sampled over time and the

change in density used to estimate the rCBF based on the Kety-Schmidt equation and a one compartment model. These studies may be performed as a wash in, plateau, wash out, or combined study. We have empirically chosen to use a combined study sampling over six minutes using a three to four minute inhalation of 28% xenon. The accuracy of XeCT rCBF values is influenced by CT noise, tissue heterogeneity, errors in estimating arterial xenon concentrations and uncertainty about xenon arrival time. Discussion of these issues may be found elsewhere[13].

Small ROIs are fraught with errors and generally need to be as large as 5×5×10㎜ in order to keep the error < 20%. For this reason we require a difference > 20% or >10㎖/100 g tissue/㎜ in order to identify a difference in rCBF. Most software packages currently available will also estimate the confidence interval of a given measurement.

Patient motion is the most difficult technical problem influencing the reliability of the data. Although most investigators have performed their studies without sedation we have performed all of ours with sedation using intravenous Nembutal or Propofol. This results in high quality data sets but opens the studies to question about the influence of these drugs. We have performed over 600 studies, many with acetazolamide challenges or serial exams over time. We are comfortable with the reproducibility of the data and the clinical correlation with outcome would indicate the derived values of rCBF are valid.

Radiation exposure may be high. Depending on exposure factors the dose may be in the range of 2-3 cGy to the brain and up to 20 cGy to each level sampled. The lens of the eye may be avoided and the brain is considered less sensitive to radiation than other organs. Still, the decision to study a patient must clearly evaluate the radiation risk. Thus even though newer CTs permit many levels to be sampled, we have chosen to sample no more than three levels in our studies. Since XeCT offers the only readily available quantitative method of rCBF measurement, it allows for the only objective method of measuring tissue perfusion in response to disease to therapeutic intervention. Our studies have focused on the effect of hyperventilation in head injuries and the risk of stroke in ischemic neurovascular diseases[14-18]. Since our method has been constant, we briefly outline it here before discussing clinical applications.

After sedation all XeCT subjects underwent a routine CT study to select 3-5 levels for sampling rCBF. The Xenon studies were performed with an Anzai (Anzai Medical Co. Ltd., Tokyo, Japan) re-breathing inhalator using a 28% mixture of Xenon gas. The chosen levels were sampled five or six times at 60 second intervals beginning at 30 seconds, resulting in a combined wash-in, plateau, and wash-out study. Patients were monitored with an oximeter and had continuous recordings of $C0_2$, blood pressure, and exhaled Xenon gas. If a second study was performed following hyperventilation or the administration of acetazolamide, at least twenty minutes was allowed to elapse before re-sampling. When used, acetazolamide was administered in a dose of 20㎎/㎏. More details are available in the literature[14].

The results were analyzed with the provided software that calculated flow maps and associated confidence maps. Circular ROIs >2 sq. ㎝. centered on the cortex were created on the corresponding anatomic slice. Oligemia was defined as any ROI measuring <20㎖/100 g tissue/㎜., and tissue with borderline perfusion was defined as any ROI with flow values <25㎖/100 g . tissue/㎜. On serial studies a minimum difference of 20% was required to diagnose a true change.

We reported our initial findings of the effect of hyperventilation on rCBF in head injured children at the XV Symposium Neuroradiologicum in Kumamoto[14]. The completed work detailed 23 children who had isolated severe head injury

who were part of a prospective study[15]. The patients underwent intentional, serial changes of $PaCO_2$ at three defined time periods following head injury while XeCT studies were used to measure the effect on rCBF. There was a clear relationship between the frequency of cerebral ischemia and hypocarbia that was time dependent and often unpredictable in severity. As a result we suggested that hyperventilation should be used with caution and not used routinely for managing high ICP levels. In other work we also showed a correlation between oxygen extraction fractions of greater than 30% and cerebral ischemia[16].

We have also reported our experience with XeCT in children with ischemic neurovascular disease as mentioned above when discussing its combined use with MR flow techniques[11,12]. More recently we have presented our work with seven children suffering from Moyamoya disease[18]. Estimates of rCBF were performed at three different levels before and after acetazolamide administration. Six studies were performed at diagnosis and ten follow up studies were carried out after surgical intervention with post treatment follow up exceeding two years. In this group of patients four diagnostic studies showed regions of oligemia (< 20 mℓ/100 g. tissue/min.) and demonstrated a pattern of augmented vertebral basilar flow with regions of diminished flow or steal, in the carotid distribution. This pattern was also identified in MR Q flow studies and was used as a method of recognizing which patients may be at risk of stroke. Three of four patients suffered new strokes in the oligemic areas before surgery while the others did not suffer from additional strokes. Follow up XeCT studies showed improved tissue perfusion at six months in two patients with angiographically proven successful EDAMs (Fig.5-9). Two other studies showed improved tissue perfusion at six months without angiographic change, while at one year angiography showed failed EDAMs and new native collaterals. Comparison of XeCT data with angiography showed the oligemic areas were confined to areas associated with vessel stenosis and little neovascularity. From this work we have shown that XeCT with an acetazolamide challenge objectively measures rCBF as well as vascular reserve, and permits the evaluation of stroke risk in Children with Moyamoya disease and may even predict outcome earlier than angiography.

Others have attempted to estimate ishemic regions in Moyamoya disease with SPECT or MR techniques such as perfusion imaging[20-22]. However, all these techniques suffer from the fact that they only measure relative differences. Having identified regions of reduced perfusion,

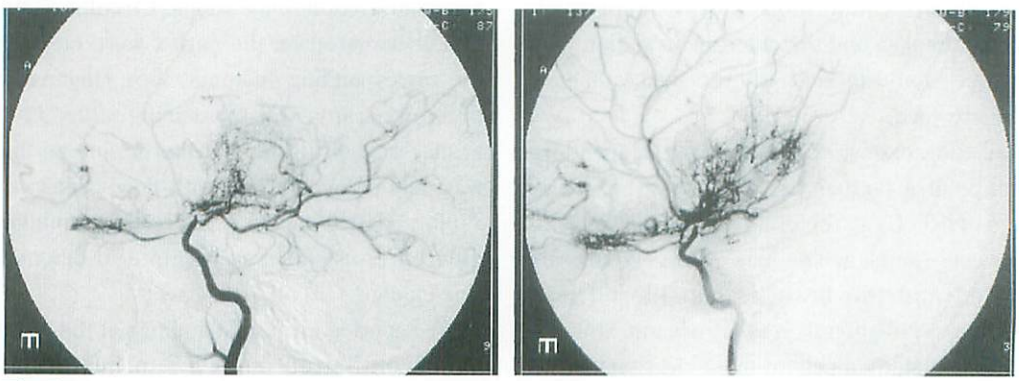

Fig.5

Lateral views of R&L ICA from an angiogram showing typical changes of Moyamoya disease in a seven year old boy who presented with headaches. Note the poor filling of the middle cerebral arteries.

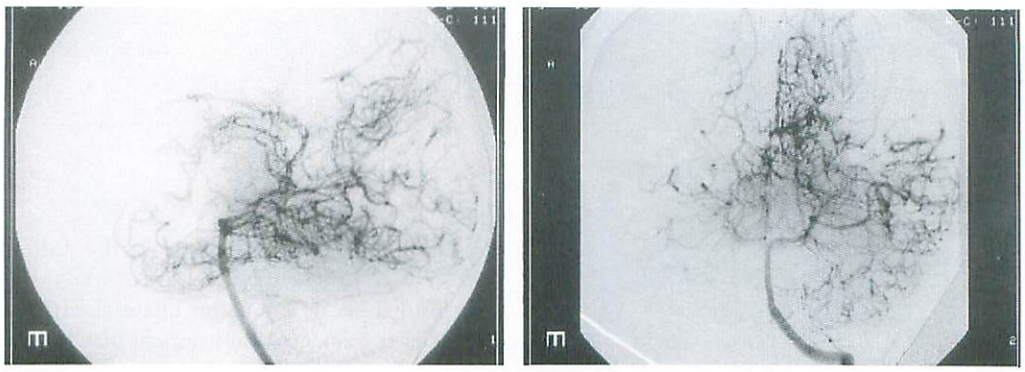

Fig.6

The vertebral basilar injection from the patient described in Figure 5 shows increased perforating vessels and retrograde filling into the middle cerebral artery territories.

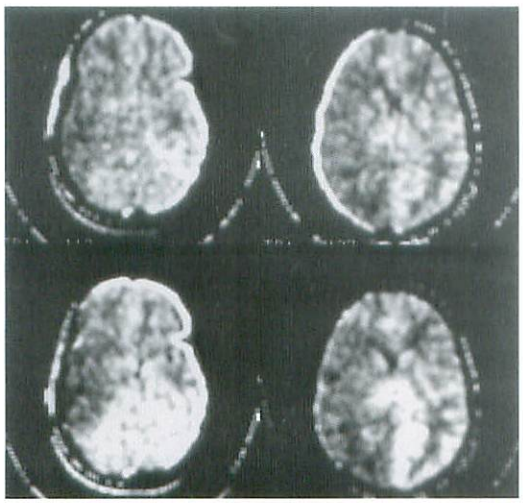

Fig.7

The initial Xenon CT study in the patient described in Figures 5 & 6. The top two images show an oligemic right hemisphere while the bottom two images obtained after acetazolamide show increased flow to the cerebellum, thalami and left posterior cerebral artery but decreased perfusion to the right hemisphere.

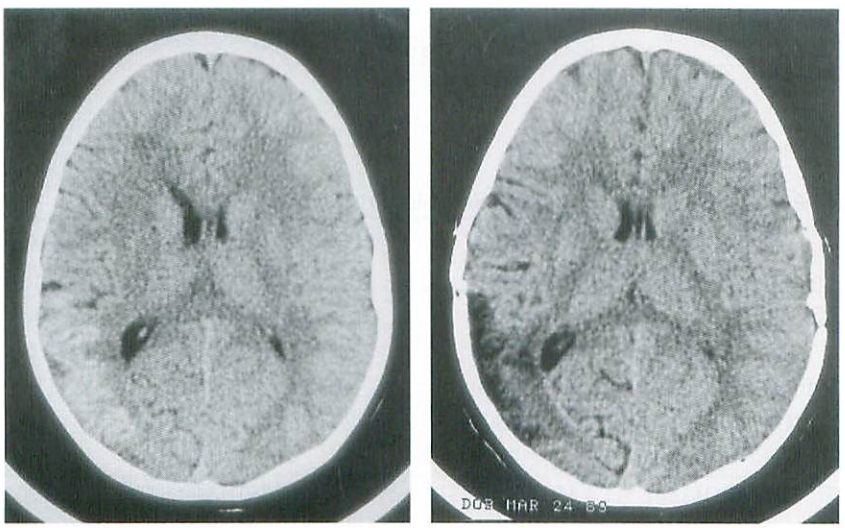

Fig.8

A follow up CT study in the patient described in Figures 5-7 demonstrating an evolving infarct before surgical intervention.

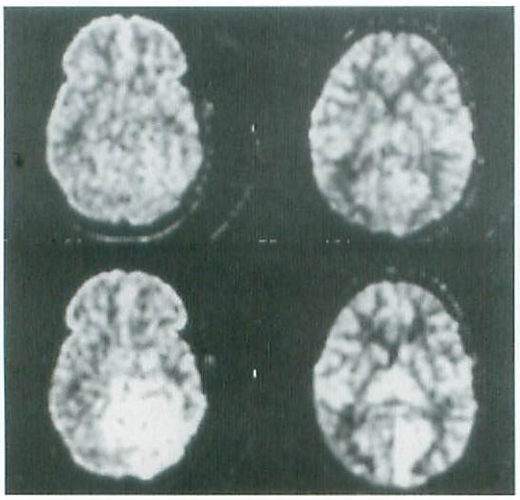

Fig.9
A follow up Xenon CT study in the patient described in Figures 5-8. The study was performed six months after bilateral EDAMs. The top two images show normal flow to both hemispheres while the bottom two images obtained after acetazolamide show increased flow to the cerebellum, thalami and left posterior cerebral artery and preservation of perfusion to both hemispheres.

Table 1 Scan Parameters for VENC studies

TR	varies with heart rate
TE	2.4-6.6 ms
FLIP ANGLE	30 degrees
FOV	30 or 40 cm
MATRIX	192 × 200
PIXEL SIZE	1.6 × 1.5 mm or 2.1 × 2 mm
SLICE THICKNESS	4.7-6.8 mm
AVERAGES	2
CARDIAC PHASES	20-45 per cardiac cycle (collected 2 RR intervals)
BANDWIDTH	15.63 KHz
GRADIENTS	27mT/meter & 72 mT/meter/ms shielded power gradients
VENC	50-600 mm/sec (in slice)

Table 2 Calculated flow : V. of Galen Malformation

	AVM ml/min	CO ml/min	AVM/CO %	CO* ml/min	CO*/KG ml/min/kg
3WKS.	862	1180	73	318	106
3MO.	926	1416	65	490	102
Rx 7MO.	400	1500	27	1100	115
Rx 11MO.	340	1309	25	969	117
Rx 30MO.	80	2073	4	1993	170

PATIENT EMBOLIZED AT 4 MONTHS CO*= SYSTEMIC CARDIAC OUTPUT (CO-AVM)

these methods cannot determine whether these regions are truly ischemic (15 ml/100 g . tissue/min). This deficiency is also fairly aimed at MR Q flow since the interrogated vessels are so small that the answer is unlikely to be an accurate measurement. Furthermore MR Q flow does not evaluate tissue perfusion. PET[23] certainly offers a more complete assessment of circulation and oxygen metabolism than XeCT, but both appear to offer insights into the disease and the response to treatment.

This review has outlined the technical considerations and pitfalls that must be faced when developing quantitative MR flow imaging and Xenon CT and their applications in pediatric neuroimaging. The careful application of MR Q flow measurements to intraluminal flow permits accurate and noninvasive flow quantification of vascular lesions which may assist in treatment planning and serve as an objective measure of treatment response. Similarly Xenon CT allows for the objective evaluation of rCBF, measures the effects of hyperventilation in head injuries and can be used to determine the risk of stroke in ischemic neurovascular diseases. Both techniques are complementary in ischemic vascular disease with MR flow measurements most useful in focal disease while the strength of Xenon CT lies in diffuse ischemia. Such quantitative measures of flow and tissue perfusion may be critical in our understanding of CNS disease and permit objective measures of the success or failure of therapeutic interventions in both children and adults.

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和文抄録

ここ数年でCTAやMRAなどの非侵襲的画像手法の急速な進歩が見られた。しかし、中枢病変を理解する上で、またIVR等治療的手技の効果を評価する上で脳血管血流と組織潅流の絶対的計測は重要であるにもかかわらず、脳血流の定量には多くの努力が払われてきたとはいえない。MRIではフェーズコントラスト法によるCineangiographyの手法を用いて頭蓋内血管の血流量を計測することができる。これをAVMに応用すれば、塞栓後や照射後の血流評価を可能にするし、同様に治療前においてもfeeder, drainerの血流の客観的評価法として強い味方となる。この事実が私たちをMRによる血流測定法の開発に駆り立てた。一方、XeCTは客観的な局所脳血流量が測定でき、虚血性血管性疾患の発作の危険性を予測するのに使用できる。私たちはこの方法を、頭部外傷患児における（頭蓋内圧を下げるという意味での治療的な--訳者加筆）過呼吸の効果とモヤモヤ病患児における発作発現の危険性および治療効果の判断に使用してきた。

本稿では、定量的MR血流画像を作成する上での技術的問題点と小児神経領域への応用を解説し、次に小児におけるXeCTを使用した局所脳血流測定の臨床応用について述べる。

（和訳　相田典子）