Performance Factors of CT Scanners

To the Editor:

We read with interest the recent article by Meyer et al. on the estimation of local cerebral blood flow (LCBF) from sequential transmission computed tomography (CT) during inhalation of stable xenon gas. There are a number of points we wish to raise concerning the methodology of the assertions made in the paper.

We are somewhat puzzled by a number of statements concerning the performance factors of CT scanners. Many of these points could be easily resolved if data were quoted relative to an accepted protocol such as the one recommended by the American Association of Physicists in Medicine (AAPM). The radiation dose at the center of the scan is stated to be approximately one rad. Although this value is in reasonable agreement with one set of published data, it differs significantly from others and is to some degree misleading since the entrance dosages are much higher (~4 rads) than the midline dose. If the proposed procedure requires approximately 10 scans at each level (3 baseline and 5 to 8 enhanced), the radiation dose to a large portion of the slice would be in the range of 30-40 rads. The discussion of the entrance dosages and 5 to 8 enhanced, the radiation dose to a large portion of the slice would be in the range of 30–40 rads. The discussion of the relative signal to noise ratio (SNR) of the EMI 1010 relative to third and fourth generation CT scanners is at best unclear. We are unable to determine whether the same physical conditions applied when the EMI 1010 was compared to the GE8800. The SNR for the EMI 1010 was quoted as being 97.1 for the iodine solution (H = 39.8 yielding a standard deviation (SD) of approximately 0.4) and a SNR of 37.4 for theGE8800 scanner was 9.4 where H was 4.2 yielding a SD of 0.4. The standard deviation would not be expected to vary significantly over a limited range of the Hounsfield Scale, therefore, the ratio should be calculated for similar degree of enhancement. In addition, the comparison should be made when the x-ray technique is adjusted to yield comparable radiation dosages. Since the relative spatial resolution of the scanners is of importance in regards to tissue specificity some mention of this performance factor would also be appropriate.

We also have some questions concerning the quoted errors on flow determinations. Since the flow is determined from the CT enhancement and the errors of both the pre-enhanced and enhanced images are both approximately 1 Hounsfield unit (HU), the maximum enhancement of 6 HU should result in at least 15% uncertainty which should propagate through the entire calculation. Despite the fact that flow determinations may be very reproducible, the error on the absolute value of the flow should be somewhat greater than the values given in the paper.

The procedure described for the determination of local partition coefficients (LX) by visual curve fitting to 15 minutes and infinity is unclear. Since a large number of scans were performed with flow and LX being the only unknowns, LX should be calculable. We cannot determine whether flow calculations were determined using tissue specific LX for each local or from average values for white and gray matter. The visual extrapolation of the number of LXs in Figures 9 and 10 would be quite cumbersome and time consuming. We do not understand why the number of significant figures listed in Tables I and II differ. The precision of these determinations as determined from a visual interpolation is quite surprising and we are unable to determine whether the errors represent statistical spread from all measurements or the estimated errors from each point. Figure 10 shows a number of extremely low values for LX of well below the value for water of approximately 0.6. Values this low must be associated with extremely low enhancement (~2 H) and we do not see how reliable determinations of partition coefficients such as 0.32 could be derived.

It would be most helpful if the authors had commented in somewhat greater detail concerning the real merits of the autoradiographic method and the monoexponential method using many scans. Virtually all the LCBF values quoted are from the 2.4 min scan and we see no utilization of the late washing or clearance data except for determining partition coefficients. Since the discussion on page 435 indicates that in tissue with slow flow LCBF values are relatively insensitive to the precise value of the partition coefficient, we cannot see how these scans significantly improve the derived information. Reducing the number of scans would decrease the radiation dose to the patient. A more detailed discussion of the optimum time for scanning when using the autoradiographic methodology would be helpful. The justification for optimal time of scanning (figs. 5A and B) and the selected sequence of scans is incomplete.

While we certainly believe that the xenon CT method for determination of LCBF merits serious investigations for possible routine clinical use, the ease by which the method is implemented and its reported high success rate is somewhat misleading. It would have been helpful if the limitations of the proposed method had been discussed in detail as well.

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References

Reply to Dr. Shabason et al. from the Authors

Methodological Advantages and Disadvantages of Xe CT CBF

The letter and comments of Dr. Shabason and co-workers concerning our article on xenon CT methods for measuring LCBF and LA have been reviewed and we thank them for their interest and helpful comments. We appear to be in agreement that the potentialities of the Xe CT CBF method merits further investigation to test its clinical applicability. Several important methodological considerations have been raised for further discussion. Nevertheless, we believe that the most important limitations of the method were discussed in this article as well as in the cited references to other publications, including some of our own, which address these methodological considerations in considerable detail.

Experience has now been gained at the VA Medical Center in Houston, with successful measurements made in 99 subjects including 88 patients and 11 normal volunteers aged 22–78 years. In the majority of subjects more than 1 series of LCBF and LX measurements were made. Most important methodological considerations...
are: 1) proper selection of cooperative patients since movement of the head invalidates results and 2) the concentration of xenon gas inhaled. Xenon concentrations higher than 35% in oxygen improve the contrast effects of the gas in brain tissue and thus improve the signal to noise ratio (SNR) but at the price of increasing possibilities of subanesthetic symptoms such as restlessness. This is particularly true during prolonged inhalation to saturate the brain tissues in order to determine xenon partition coefficients (LA). Subanesthetic symptoms are further minimized by beginning inhalation with 20% xenon for the first 1-2 minutes before increasing the concentration to 35%.

Measurements by our Radiation Physicist were made employing the phantom as recommended by the AAPM. It is encouraging that the radiation dose cited in our article, of approximately one rad at the center of the scan per 1 minute exposure, is in reasonable agreement with other publications. It is not unexpected that other centers may report higher exposures; since the exposure varies from scanner to scanner, and within the same scanner, depending on the technique factors used, which were defined in our paper. The highest dose measured by our Radiation Physicist among different EMI scanners in this medical center has been 1.5-2.6 rads at the center of the brain and 2.5-3.9 rads at the skin. The entrance exposure to the scalp may be as high as 4 rads but this is not considered biologically hazardous since the skin and the brain are relatively radio-resistant. We emphasized that the lens and cornea of the eye were always excluded during serial Xe" CT scanning, since these tissues are more radiosensitive. There is not yet consensus among Radiation Physicists, as to what dose index criteria should be employed in CT. Irradiation dose at the center of the scan is considered more relevant than the entry dose, although the latter is easier to measure. In patients undergoing conventional (non CT) tomography (e.g. for visualization of the inner ear) 20 rads per examination is considered acceptable exposure.

We agree that irradiation exposure can be reduced further by decreasing the number of scans. Although LCBF may be measured in both saturation and desaturation, we now only record from sequential scans made during saturation. We also avoid making scans during the first 2 minutes of xenon inhalation, since we have found that the optimal scanning times are between 2-10 minutes using 35% Xe". Thus, including the 3 control scans made before xenon inhalation and the 4 or 5 scans made during xenon inhalation the total number of scans is 7-8 per series of LCBF and LA measurements. It has always been our practice to measure LA from the same region of brain from which Ki is obtained. Our computer program achieves this, using the one compartment CBF program of Obrist for tissue curve analysis, after deconvolution of both air and tissue curves during the entire saturation interval. In our article, table 2 gives our normative data calculated by this method, which is in reasonable agreement with autoradiographic measurements shown in table 1. We agree that computer solution of λ values at infinity gives the most values and is less cumbersome than those estimated by visual extrapolation of the curves.

Regarding comparison of SNR between the GE 8800 (which is an excellent new generation CT scanner) and our EMI 1010; we described the technique factors used for making this comparison in the article. The same radiologist supervised the acquisition of comparison data in 11 sequential scans using the same phantom for each machine, ΔH/SD for EMI 1010 was 12.7 and for GE was 9.4 by these estimates. The important point is that although the GE 8800 is a faster and more sophisticated scanner, with distinct advantages in terms of resolution, reduction of movement artifact, reconstruction of images, automatic plotting of sequential data such as ΔH, the SNR is lower with the slower EMI 1010 equipment. In clinical practice one of our radiologists has now had experience measuring LCBF and LA with both the EMI 1010 and the GE 8800 and concludes that this is a fair summary of advantages and disadvantages of the two methods.

The reproducibility error or measurement error, as stated in our article, has been confirmed in both the baboon and human subjects. With our new computer program, which mathematically extrapolates curves to infinity, accuracy and reproducibility of LA values is more reliably calculated. Prior to the development of the computer program, visual curve fitting was used to estimate LA at 15 mins but the data shown in Table 2 of the article was derived by means of the new computer program which mathematically estimates infinity values.

All our data for LCBF and LA is now calculated from the one compartment program analysis, described in the article, during saturation with double integration of both end-tidal and Xe" tissue curves to infinity. The in-vivo autoradiographic method may be used, but the one compartmental computer program has the advantage of using all CT data points. Table 1 compares data measured in normal volunteers, analyzed by the in-vivo autoradiographic method with analysis made in the same subjects by the computer program described above (table 2). The results are in reasonable agreement except that white matter LCBF values are slightly lower and white matter LA values are higher, and we believe, more accurately analyzed by the new computer program. We agree with Dr. Shabason and associates that extrapolating the xenon curves to infinity by means of a computer program is a significant technical advance over earlier cumbersome and time consuming methods of analysis. We believe that the xenon CT method has considerable promise for clinical usefulness (certainly as a research tool) and we foresee new technical advances and computer programs that will lead to automatic visual color displays, in 3-dimensions of LA and LCBF values.

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