Measurement of the Change in Noise-effective Count-rate During PET Brain Studies with Additional Shielding

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Abstract - We have recently installed removable shielding on a CTI HR+ PET scanner, and have evaluated its effect on the noise-effective count (NEC) rate during bolus water activation, and FDG studies. This removable shielding system, known as the "NeuroShield" consists of a "U" shaped lead plate attached to the removable head-rest with a plastic coupling piece.

Bolus water activation studies, with injected activities ranging from 170 to 750 MBq were performed before the NeuroShield was installed. Based on the known improvements at 370 Bq, and the way the dead time and random count rates change with activity the NEC was calculated with and without additional shielding.

The glucose utilization studies were done on the same subjects first without, then with NeuroShield in place. Forty minutes after injection of 110 MBq 18F-FDG, subjects were scanned for one minute with the scanner's normal headrest. The subject then sat up to allow the NeuroShield to be installed, and a ten-minute emission followed by a ten-minute transmission scan were done in the same position. During the entire scan, a "rates" file recorded the prompt and delayed count-rates and live time every five seconds.

Since the NeuroShield is not fixed in the gantry, its effectiveness at different axial positions was also measured. Count-rates from four subjects undergoing serial Raclopride studies were also evaluated as a function of shield position. The shielding was slightly more effective when placed forward of the field of view. The NEC improves by 24% in the early frames of these studies.

The percentage of random counts improved for the FDG studies from 17 to 12%/100 MBq of injected activity. The NEC in bolus water studies improves by up to 45% with additional shielding. Most of this improvement comes from a reduction in random counts.

I. INTRODUCTION

A. Shielding PET scanners from external activity.

PET Scanners acquiring scans with their septa retracted are much more susceptible to excessive random count rates, scattered radiation and dead time due to activity outside the field of view (FOV). Several recent reports show the advantage of additional shielding to reduce these effects [1,2,3,4,5]. Grootoont et al [1] showed the advantage of a permanent "Neurological insert" in the CTI HR+ scanner, an option available with the instrument. Sossi [2] and Laforest [3] used lead shielding of the body regions axially beyond the field of view which were made for their situation. Hasegawa et al[4] have shown that in designing the shielding for use during neurological PET studies, the area of the shielding is more important than the thickness. More recently, Thompson et al.[5] showed the benefits of the prototype NeuroShield® in the reduction of random counts and dead time during bolus water activation studies. However the noise-effective count-rates were not measured in that study.

1Manuscript received November 6, 2001. This work was supported by a grant from the National Science and Engineering Council of Canada (OGP-0036672) to Dr. Thompson. The materials for this project were provided through a group grant from the Medical Research Council of Canada to Dr. Alan Evans and collaborators.

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B. Design and Development of the NeuroShield

The “NeuroShield” is a removable shielding system for use during neurological studies on whole body PET scanners. The principal novelty is that lead in the NeuroShield is attached to the headrest, not the gantry, and so moves with the couch. The advantage is that the diameter of the hole through which the subject’s head must pass can be much smaller than when the lead is fixed.

The headrest on all recent CTI PET scanners is made from rigid plastic and part of its strength comes from its complex curvature. In order to mount the lead, a thermoplastic piece was designed to fit closely the contour of the headrest in the region between the couch top and the head support. This piece has a plane vertical surface to which a cut lead plate is attached. Four ribs between these two surfaces to provide structural support.

The headrest is attached to the scanner’s couch with Velcro® strips (see Fig. 2). The lead piece is only 10 cm from the end of the couch, so even though the centre of gravity is at the end farthest from the head and lifting it off. After a few studies have been performed, the Velcro is quite firmly set and it becomes more difficult to remove.

The lead plate in the NeuroShield is attached to the scanner’s headrest, which attaches to the couch with Velcro.

II. MATERIALS AND METHODS

A. Raclopride studies

Unlike the CTI Neurological Insert, the NeuroShield is attached to the couch, and so the position of the lead shielding can vary from subject to subject. From figure 1, the shielding effect should change depending on the position of the lead with respect to the permanent lead shielding forward of the detectors. We have encouraged the subjects to move on the bed so that their shoulders were as close as comfortable to the lead plate. When this is done, with the subject optimally positioned for a brain scan, the lead plate would be in a slightly different position depending on the length of the subject’s neck. In order to see if there would be a preferred scanning position, we selected subjects who were to have three studies on three different days. The protocol used was one involving a “reward”. Four subjects were injected with approximately 1/3 of the maximum dose of $^{11}$C-Raclopride permitted by the MNI research ethics committee of 750 MBq. In each case the subjects played a video game. In the baseline study they were paid a $100, and in the activation case, the better they played, the more money they received. If the subjects had long necks, the bed was positioned differently for each study, but the positioning laser was used to ensure the subjects head was placed in the same place for all studies.

All studies were done within a week, and the doses administered varied from 220 and 265 MBq. During that time the NeuroShield was not removed from the couch, so the “bed position” is directly related to the location of the shield with respect to the field of view. From the scanner’s “head-curve” files the delayed and prompt counts were integrated from 120 to 240 seconds (in order to avoid the effects of injection rate), and the ratio of random to (prompt-delayed) counts calculated. This ratio was normalized to an injected dose of 250 MBq and plotted against bed position. The bed positions varied from 420 to 479 mm from the full out position. (The lower the bed position, the further the shield is from the field of view.)

B. Bolus Water Studies

In our previous study we examined the effect of the NeuroShield when using a 370 MBq injection of water during cerebral activation studies. It is well known that randoms rates increase when higher doses are administered. At the MNI all cerebral activation studies are now performed with 370 MBq injections and data are acquired in the 3D mode with a span of 9 and a maximum ring difference of 22.

In a previous paper we examined the effect of various shielding strategies for one injected activity (370 MBq)[5]. In order to assess the effectiveness of the NeuroShield at other injected activities, it would be necessary to study subjects with lower and higher doses, with and without the NeuroShield in place. These studies would be difficult to justify before the Institute’s research ethics committee. Instead we re-examined data acquired just after the scanner was purchased. At that time studies were performed on one subject with no additional shielding, using injections of 5,10,15,20 mCi (175, 370, 545 and 740 MBq) [6]. Comparison of the random fraction and dead times encountered during these 370 MBq studies and recent unshielded studies acquired during trans-cranial magnetic stimulation, show that both the dead time and random fractions are similar. Also from our previous study[6], the scanner’s dead time increases linearly with dose, and the random counts are proportional to the livetime*(dose)^2. The ratio of the livetime with and without the NeuroShield for 370 MBq injections is 1.02 and the ratio of the random counts is 0.69. The random fractions, count-rates, and livetimes are known without shielding, for four doses, and they were estimated for the same doses, based on their known values at 370 MBq with the NeuroShield in place. From these values, the noise-effective count-rate (NEC) was calculated. The randoms field of view factor, f, was assumed to be 0.4, the randoms multiplication factor, 2.0, and the scatter fraction S/T 45% unshielded and 43% shielded.
C. Glucose Metabolism Studies with FDG

The noise-effective count-rate of the scanner was measured with and without the NeuroShield installed during the acquisition of glucose metabolism studies for routine 3D brain scans in patients of the Montreal Neurological Hospital. The FDG protocol consisted of one-minute unshielded emission scans followed by ten minute emission scans (with the NeuroShield present) on patients 40 minutes after administration of 100-130 MBq $^{18}$F-FDG. Since this procedure is different from routine FDG studies, the protocol required approval by the research ethics committee, and all patients gave informed consent. The patients were asked to lie on the couch in the normal CTI scanner’s headrest. Marks were made on their faces with a felt pen where the alignment laser shone to ensure accurate re-positioning. The scan protocol consists of three frames, one of one minute, then a second of variable length, and the third of 10 minutes. A “rates-file”, or “head-curve” was used to sample the prompt and delayed count-rates and dead time every 10 seconds. During the variable length frame, the couch was withdrawn, the patient asked to sit up and the headrest was replaced with the one to which the NeuroShield is attached. A ten minute scan (which was read for diagnostic purposes) was then performed, followed by a transmission scan from which the attenuation was measured.

III. RESULTS

A. Raclopride Studies

The NEC for eight studies was calculated after normalizing for injected dose, and plotted against the scanner’s bed position. The NEC with no extra shielding was estimated assuming a scatter fraction of 45%, a live-time and random fractions of 95% and 145% respectively of that with the NeuroShield in place as explained in the previous section. When the bed position is at 475 mm the upper surface of the lead on the NeuroShield was aligned with the front of the scanner’s field of view. The results are shown in Fig. 2. The average NEC would decrease from 35 kcps to 28.2 kcps with the NeuroShield removed, suggesting that the benefit to the NEC during shielded studies is 24%. There appears to be a slight improvement in NEC as the shield is moved further forward but the scatter of the points prevents this from being statistically significant.

B. Bolus Water Studies

The NEC for bolus water studies at four different injected doses, performed before the NeuroShield was in use was calculated assuming a scatter fraction of 45% from the prompt and random rates measured in that study. The NEC was then estimated as if the NeuroShield was in place. The results are summarized in Table I. Fig. 4 shows the count-rates as dashed lines with no extra shielding, and as solid lines with the NeuroShield in place. Fig. 5 shows the NEC data only, in order...
Figure 6 True plus scattered and random count rates during a one minute unshielded scan and a 10 minute scan with the NeuroShield in place.

Figure 7 Random count rates with and without NeuroShield in place.

to emphasize the difference. The peak NEC without the NeuroShield is at 500 MBq whereas it appears to be beyond 750 MBq with the NeuroShield in place.

C. Glucose Metabolism Studies with FDG

Of the six subjects who were enrolled in this protocol, two were rejected as examination of their scans showed that the head position had moved more than 5 slices after repositioning. The rates file from one of the subjects is shown in Fig. 6. There is an appreciable reduction in the random rates in the later part of the study where the NeuroShield is in place. After correcting the random/true count-rates for isotope decay, the random percentage was plotted against injected dose. The randoms fraction is reduced from 17%/100 MBq to 12%/100 MBq injected dose. The randoms percentage is plotted against injected dose for the four available subjects in Fig. 7.

IV. DISCUSSION

The NeuroShield is easy to install and well accepted by patients, staff and researchers. The 22 cm wide vertical cutout does not pose any problems when the subjects are viewing a large screen video monitor, nor in their access to the touch sensitive surface sometimes used to provide feedback during scanning.

The doses used at the Montreal Neurological Institute may be lower than used in other centres. Most studies are done on normal volunteers. The doses are limited by the radiation exposure to normal subjects. Many studies require multiple injections, which implies that the dose be fractionated further. For this reason, the improvements in NEC obtained with the NeuroShield in these studies may be lower than in other centres where PET is used for diagnostic purposes, and higher doses are justified.

In the Raclopride studies, there did not seem to be any significant advantage in placing the bed forward in order for the shield to cast a larger shadow on the detectors. There appears to be a slight improvement, but it the advantage would have to weighted against patient comfort, and the possibility of movement if the shoulders are touching the lead shield. A substantial improvement in NEC was indicated when the NeuroShield is in place. The improvement is greater early in the study, where the frames in a dynamic study are shorter. The noise in early frames is due to the short counting times providing limited number of total counts, but also to increased dead-time and random counts. The dose in single studies may be limited by the NEC at the start of the study. The use of additional shielding may extend the scanner’s effective dynamic range in these cases.

It is likely that during cerebral activation studies using $^{15}$O-Water or $^{15}$O-Oxygen where additional shielding will provide the greatest benefit. The data presented here for the NeuroShield was based on the way the dead time and random count rates changed in other studies. Since the NeuroShield is always used at the Montreal Neurological Institute, it was not possible to obtain comparative data from the same subject with and without additional shielding. Other institutions which have purchased NeuroShields may be able to provide comparative data in a more rigorous way.

The headrest used in this scanner is the same one used in all recent CTI scanners, so the NeuroShield should work on any of these. It may be of greater benefit on the PET-CT scanners which have a larger patient port (see fig. 1), and reduced shielding to activity outside the scanning field. The same NeuroShield also can be used on other whole body PET scanners like the GE Advance®.

V. CONCLUSIONS

The NeuroShield has now been tested in a wide variety of protocols. It is most effective in reducing random counts, so has its most important applications with short lived isotopes and at the start of dynamic studies. It has the great advantage of being easily removable making it suitable for use in sites which do a mixture of “whole body” PET scans and brain studies. It has been very well accepted by subjects, researchers and technical staff.
### Table I

**COUNT-RATES AND DEAD TIMES DURING BOLUS WATER ACTIVATION STUDIES**

<table>
<thead>
<tr>
<th>Injected dose mCi</th>
<th>True counts Kcps</th>
<th>Scattered counts</th>
<th>Random counts</th>
<th>Dead time (%)</th>
<th>NEC Kcps</th>
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### VI. ACKNOWLEDGEMENTS

The data from human subjects was available as a result of studies done by several researchers at the MNI including Isabelle Boileau and Denise Kline. We would like to thank the technical staff of the McConnell Brain Imaging Centre especially Richard Fukasawa and Garry Sawchuck for their help and enthusiasm.

### VII. REFERENCES


