UTILIZATION OF CHARACTERISTIC X-RADIATION TO IDENTIFY GAMMA RADIATION ORIGINATING EXTERNAL TO SKULL

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The large extracellular space of scalp and the active uptake of certain tracers such as ^{99m}Tc-pertechnetate by parotid commonly create a considerable superficial tissue background originating external to skull (*1*). This high extracranial background will be seen with any tracer of which a substantial part is circulating unbound to plasma protein. It obscures subtle changes in brain concentrations and necessitates some form of background subtraction. Presently this subtraction is uniform for the entire cranium and thus cannot adequately correct for scalp seen tangentially and for thick extracranial tissues such as obscure the posterior fossa. This report describes a method whereby a considerably more definitive regional subtraction of superficial nuclide should be obtainable. It depends upon the great radiopacity of skull to photons of energies less than 30 keV (*2*). Many of the common nuclides emit characteristic x-radiation in the range of 18–30 keV in addition to their gamma radiation. This study was undertaken to determine the feasibility of using this lower energy x-radiation to determine how much of the higher energy gamma radiation was originating superficial to skull.

MATERIALS AND METHOD

The pulse-height spectra of four nuclides producing characteristic x-radiation through the range of 18–30 keV were determined through an air path and again when a piece of wet human skull 6–7 mm thick was interposed between the isotope source and detector. By this means the radiopacity of skull to photon energies in this range was determined. The nuclides studied are shown in Table 1.

TABLE 1. NUCLIDES STUDIED

Nuclide	Approximate energy level (keV)	Mean number (percent) of x-rays per disintegration (approximate)*
^{99m}Tc	18	7%
^{113m}In	24	20%
^{125}I	27	111%
^{133}Xe	30	58%

* See refs. 3–4.

The energy levels of the characteristic x-radiation and the efficiency of production per disintegration of most of the common nuclides are readily available (*3–4*).

Equipment used for spectral analysis was a pulse-height analyzer (Radiation Instrument Development Laboratory, Single Channel Analyzer, Model 33-13A) set at a 6–8-keV window width. This window width should be as narrow as possible to minimize the broad-spectrum Compton scatter from the main gamma peak. The high voltage was set at 1,365 volts, and the preamplifier gain increased to move the major photopeak energy near the upper end of the discriminator range. Multiple counts were made at various threshold settings to define the spectra. The resolution of this arrangement was inadequate to clearly define the 35 keV gamma radiation of ^{125}I as distinct from its much more prominent characteristic x-radiation.

Approximately 20 μCi of the nuclide in water solution in a 3-cc plastic syringe were fixed in position approximately 20 cm above a 3-in. (7.62 cm)-dia NaI(Tl) well crystal (Harshaw Chemical Co., Crystal-Solid State Department, Integral Line Scintillation Detector Assembly, Type 12 SW 12-W4) with a 2.54-cm well dia. The light-tight shield on the crystal was 0.032 in. (0.813 mm) aluminum plus 20 mg/cm^2 Al_2O_3 reflective coating. The crystal was at the bottom of a cylindrical opening in a lead shield. This probably accounts for the prominent 72 keV spectral peak due to the fluorescence x-ray of the lead on the surface of the cylindrical opening. This peak could have been removed by lining the shield with some low-Z material. This was not done here because this peak was well removed from all of the

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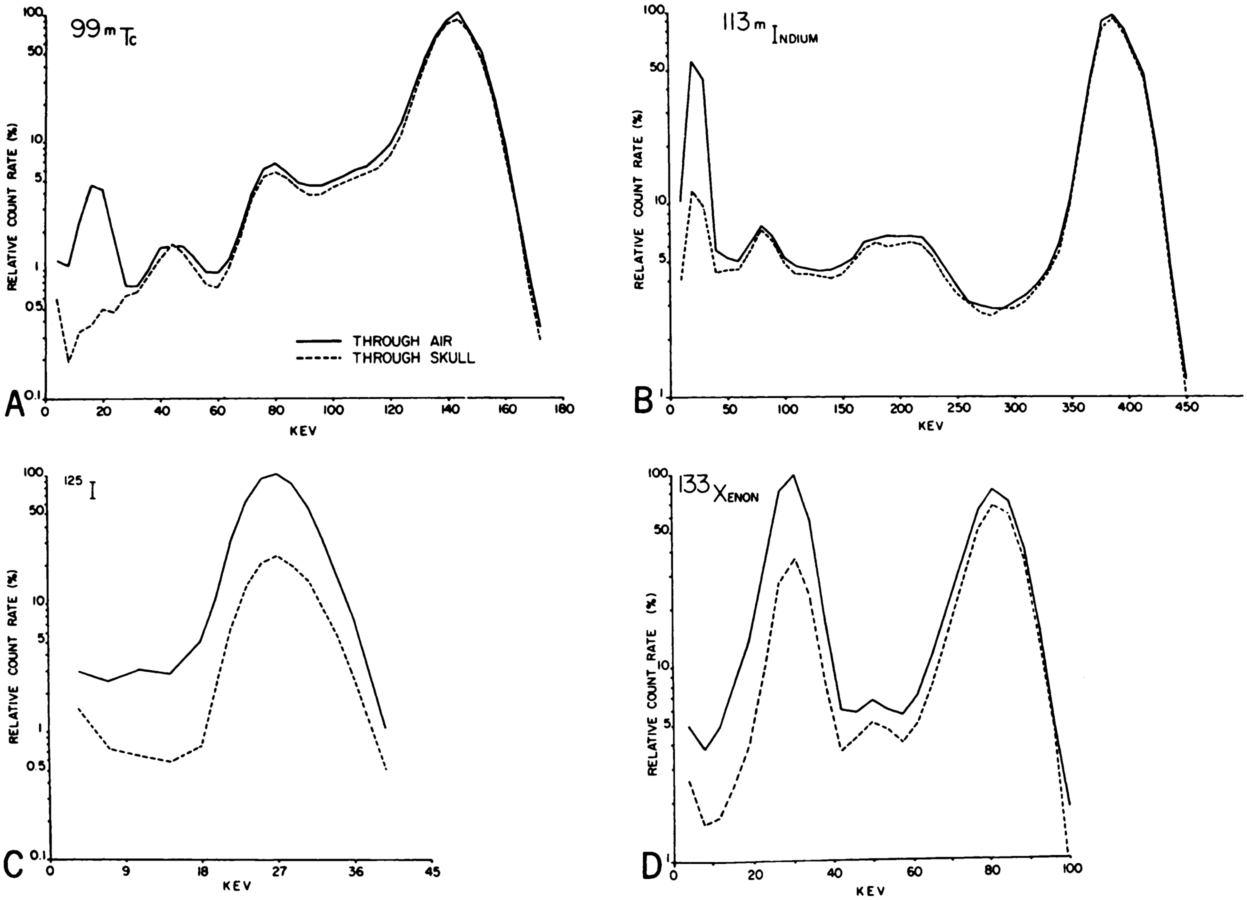

FIG. 1. A–D indicate pulse-height spectra of four nuclides through air path and through piece of wet skull interposed in beam path. At energies below 24-keV x-ray of ^{113m}In, absorption is essentially total. X-ray of ^{99m}Tc is approximately 70% absorbed by 0.81-mm aluminum cover on crystal detector used here. X-ray of ^{113m}In is about 45% absorbed. With thinner cover about three times as many technetium x-rays would be obtained, and with indium, about twice as many.

emissions of interest except the 81-keV gamma of ^{133}Xe.

With each nuclide a spectrum was obtained with an air path. A second spectrum was obtained with a full-thickness piece of wet human vertex skull placed on top of the shield opening approximately midway between source and detector. The bone was approximately the size of the opening in the shield and was large enough that all direct radiation had to pass through the skull to reach the crystal.

RESULTS

The spectra obtained with and without the skull in the path are shown in Fig. 1A–D.

The 18-keV characteristic of ^{99m}Tc and the 24-keV radiation of ^{113m}In are quite completely blocked. The lesser absorptions of the 27-keV rays of ^{125}I and the 30-keV rays of ^{133}Xe are apparent.

DISCUSSION

These data support the feasibility of using the characteristic x-radiation of nuclides with atomic numbers in the range of 40–55 to subtract gamma counts originating external to skull. Above an atomic number of about 50, the characteristic x-radiation begins to penetrate skull effectively and below about 40 the x-radiation will be sufficiently soft that it will largely be absorbed by the scalp.

The characteristic x-radiation can be counted by positioning a separate, narrow pulse-height window to accept these low-energy x-rays. The usual pulse-height window setting would accept the higher energy gamma ray. With a given combination of low- and high-energy window settings, a fixed ratio of x- and gamma-ray counts is obtained. This would allow electronic or photographic subtraction of the superficially originating gamma radiation since it can be assumed the low energy x-rays and a corresponding number of gamma rays originated superficial to skull. The number of gamma rays to be subtracted per detected x-rays would depend upon their relative efficiency of production by the nuclide in use.

Although the characteristic radiation of ^{125}I is at an energy level suitable for this method, the relatively inefficient gamma production is at such a low energy (35 keV) that it, too, is quite effectively absorbed. It was included here only because its characteristic x-radiation was at an energy level (27 keV) which would fill out the energy range of interest.

The method seems particularly suited to ^{99m}Tc and ^{113m}In which produce characteristic x-rays sufficiently penetrating to traverse the scalp but not the skull. Because of the much greater efficiency of production of ^{113m}In x-rays and their higher energy level, this nuclide would seem much more suitable than ^{99m}Tc. Using the experimental arrangement used in this study, the half-thickness of water is approximately 10 mm for ^{99m}Tc 18-keV x-rays and 16 mm for ^{113m}In. This suggests that nuclides of lower atomic number than these will suffer a prohibitive absorption from scalp, particularly when the scalp is viewed tangentially.

The 0.813-mm aluminum cover on the crystal detector used in this study absorbs approximately 70% of the characteristic x-radiation of ^{99m}Tc and about 45% of ^{113m}In x-radiation. A thinner aluminum cover would provide substantially more x-ray counts. At these low energies a beryllium cover would be ideal but is quite expensive.

The ability to regionally subtract superficially originating counts from the brain scan should improve the ability to demonstrate subtle differences in isotope distribution in brain. It should also improve the visualization of posterior fossa structures now obscured by superficial isotope. This method should also partially correct for the isotope content of the skull. For most clinical scanning techniques, this will be minor relative to scalp isotope content. For maximum sensitivity of display of brain extravascular isotope, it would be desirable to subtract the contribution from isotope in the blood pool.

SUMMARY

Skull transmission data for the gamma and characteristic x-ray emissions of several common nuclides are presented. There is production of 18-keV x-rays by ^{99m}Tc and 24-keV x-rays by ^{113m}In which are effectively absorbed by skull whereas the high-energy gamma is insignificantly absorbed.

A method is suggested in which the gamma radiation originating external to skull can be differentiated from x-rays originating inside skull. Gamma-ray production will bear a fixed numerical relationship to the characteristic x-rays produced. With daughter products of decay with atomic numbers between 40 and 50 the low-energy x-rays counted externally all originate external to skull because skull is opaque to those generated inside. This would allow the subtraction of externally originating gamma radiation produced concomitently with the externally detected characteristic x-radiation. The method is most suited to nuclides with atomic numbers between 40 and 50 since the characteristic x-radiation produced in this range is nearly completely absorbed skull but will penetrate the scalp. Both ^{99m}Tc and ^{113m}In seem well suited to this method.

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