INTERFERENCE OF SCALP AND SKULL WITH EXTERNAL MEASUREMENTS OF BRAIN ISOTOPE CONTENT: PART 2. ABSORPTION BY SKULL OF GAMMA RADIATION ORIGINATING IN BRAIN

William H. Oldendorf and Youichi Iisaka

Wadsworth Hospital, Veterans Administration Center
and UCLA Center for the Health Sciences, Los Angeles, California

This report concerns documentation of several factors related to the shielding effect of human skull against gamma radiation originating within the cranial cavity. The skull overlying the brain absorbs some gamma rays and will therefore reduce the counting rate recorded by an externally positioned detector. This reduction of counting rate is a function of the energy level of the radiation concerned and of the thickness and degree of mineralization of the skull. Of these variables, only photon-energy levels and variations of skull thickness are examined here. Variations of mineralization will not be considered even though this must, to some degree, affect the skull's shielding action, particularly for lower-energy photons. Four radionuclides were selected to provide gamma radiations of energy levels covering the range of common clinical interest. These nuclides are: ^{125}I, ^{133}Xe, ^{99m}Tc and ^{131}I.

METHODS

Absorption by thick and thin skull. A total of ten randomly selected male adult Caucasian skull caps were obtained wet from unembalmed autopsies. Two regions of each specimen were counted representing the thinnest and thickest skull areas. The thinnest was in the temporal region and the thickest usually in the parieto-occipital midline. In one small piece of skull (4 × 4 cm) filed flat to a 3.25-mm thickness, the half-thickness was determined for each nuclide.

Each skull cap was placed stationary over an open well counter midway between a 0.5–2.0-cm-diameter radioactive source and the 5 × 5-cm NaI(Tl) crystal. With this arrangement, a circular area of skull approximately 3 cm in diameter cast a shadow on the crystal. The scaler pulse-height threshold was set at approximately three-fourths of the major photopeak of each nuclide. No upper threshold was used. All measurements included at least 40,000 net counts.

Rotation study of absorption. One dry skull was studied by placing it on a turntable rotating at 1 rph and plotting the counting rate from a fixed external detector looking at a small radioactive source within the cranial cavity on the axis of rotation (Fig. 1). The counting rate was plotted for one complete revolution of the turntable for each nuclide. In this

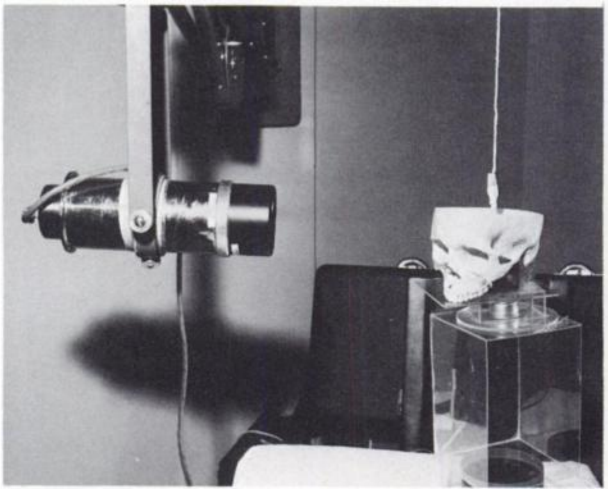

FIG. 1. To obtain display of variability of counting rate shown in Fig. 4, dried skull was placed on 1-rph turntable. Radioactive source was suspended near axis of rotation. Counting rate derived from stationary 5 × 5-cm NaI(Tl) detector was plotted as function of rotation.

Received June 5, 1968; revision accepted Sept. 23, 1968.

For reprints contact: W. H. Oldendorf, Wadsworth V.A. Hospital, V.A. Center, Wilshire and Sawtelle Blvds., Los Angeles, Calif. 90073.

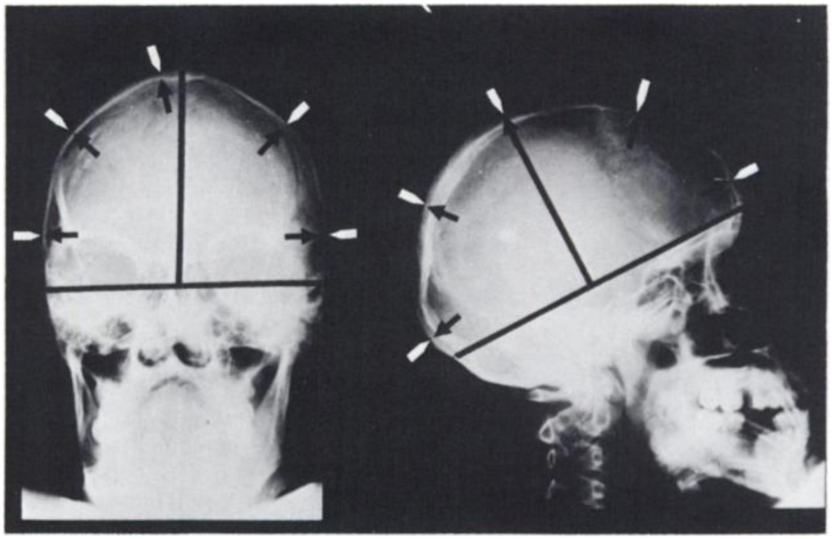

FIG. 2. Location of points is indicated at which skull thickness was measured for estimating mean skull thickness. Skull under consideration here is that covering cerebral hemispheres. Small portion of skull covering temporal lobes will not be included.

way a graphic representation was obtained of absorption in the narrow strip of skull swept by this rotation. Pulse-height threshold settings were approximately three-fourths of the major photopeak energy.

Radiographic estimation of cranial skull thickness. Ten intact adult male skulls were studied radiographically postmortem by taking AP and lateral projections. The radiographic technique was 10 ma at 80 kV at 180 cm on Eastman Parspeed film in nongrid screen cassettes. Correction was made for size distortion of the image due to the finite distance of the x-ray source.

Cranial skull thickness was measured on both the AP and lateral projections of the strip of skull viewed tangentially. Only skull rostral to a plane through the roof of the orbits and inion on the lateral projection and petrous ridges on the AP projections was considered. Five thicknesses were measured on each AP and the lateral projection as shown in Fig. 2. The ten measurements were then averaged for each skull study and an over-all average was calculated for the group.

RESULTS

The average broad-beam absorption by thick and thin areas of ten wet skull caps as a function of photon energy for the four isotopes studied is indicated in Fig. 3 and Table 1. The collimation used here is broad-beam, indicating that a substantial proportion of the forward-scattered secondary radiation will strike the detector crystal.

TABLE 1. PERCENT ABSORPTION OF GAMMA RAYS BY CRANIAL SKULL

Skull study*	^{131}I		^{99m}Tc		^{133}Xe		^{125}I	
	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
1	12.05	9.44	13.58	9.42	24.87	18.87	86.37	75.29
2	9.47	7.90	15.21	9.55	21.43	14.91	77.58	61.87
3	10.46	8.37	15.09	12.76	22.87	19.24	77.17	70.39
4	13.90	9.88	17.82	15.22	29.80	21.08	85.00	71.93
5	10.93	7.33	15.48	10.57	25.04	18.31	79.50	66.80
6	9.54	6.97	13.32	10.78	18.06	16.10	70.96	60.44
7	16.57	11.16	22.04	21.83	26.05	26.06	81.47	84.02
8	9.11	8.66	20.57	20.45	17.22	14.68	65.13	58.28
9	16.76	11.36	20.78	14.30	31.86	22.48	84.03	72.63
10	9.54	8.25	15.07	13.74	19.79	18.73	72.57	67.23
Avg.	11.83	8.93	16.90	13.86	23.69	19.05	77.98	68.89
s.d.	2.78	1.43	3.02	4.11	4.55	3.33	6.44	7.32

* Range of skull thicknesses (wet skull cap).
Thick skull—average 6.2 mm. Range—5.5–7.5 mm.
Thin skull—average 3.3 mm. Range—2.5–4.5 mm.
Percent absorption of gamma rays by cranial skull is calculated by:

$$\% \text{ absorption} = \frac{\text{Counting rate in air} - \text{Counting rate through the specimen}}{\text{Counting rate in air}} \times 100$$

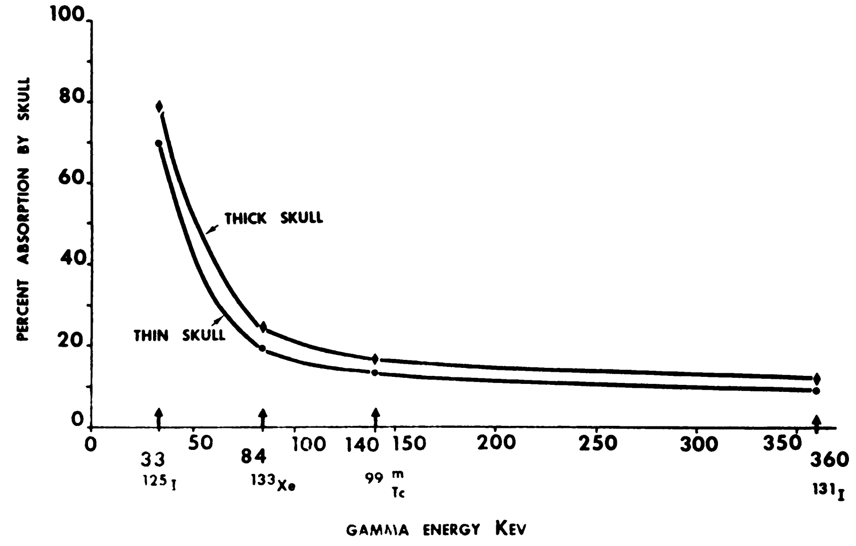

FIG. 3. Absorption by thick and thin portions of ten wet skull caps is shown. Four gamma energies were used to cover energy spectrum of interest. This demonstrates greatly increased absorption for lower energies where photoelectric absorption becomes prominent. Standard deviations for each point are included in Table 1.

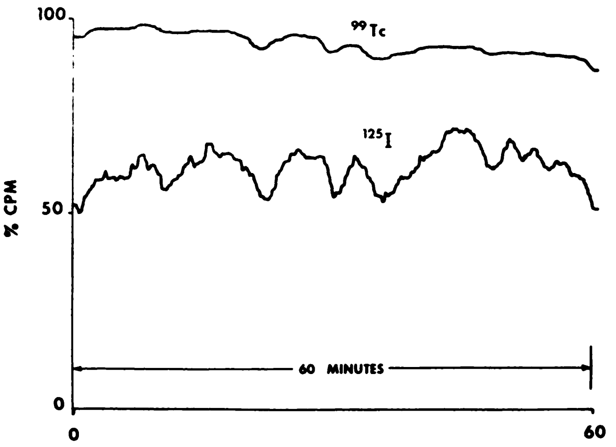

FIG. 4. Absorption of ^{125}I and ^{99m}Tc gamma emissions by horizontal strip of dried skull studied with equipment in Fig. 1. This is intended to show variability of thickness of skull. Absorption indicated is less than would be expected from Table 1. This is largely explained by use of dried, bleached skull which was particularly thin.

TABLE 2. RADIOGRAPHIC ESTIMATION OF CRANIAL SKULL THICKNESS

Skull study*	Average thickness (T) of skull (mm)
1	6.31
2	5.28
3	6.77
4	5.31
5	6.31
6	5.19
7	6.47
8	4.80
9	6.52
10	6.68
Avg.	5.96
s.d.	0.69

* Each skull represents one study as shown in Fig. 2.

The half-thickness of the small piece of noncancellous skull was found to be: ^{125}I—2.5 mm, ^{133}Xe—17.6 mm, ^{99m}Tc—28.6 mm and ^{131}I—62.4 mm.

The absorption of gamma radiation from ^{99m}Tc and ^{125}I during 1 hr of turntable rotation is shown in Fig. 4 which displays graphically the variability of bone thickness encountered in one skull. The pattern shown here is representative only of the particular narrow horizontal plane swept by the beam measured. Other patterns would result from slightly different levels and from other planes of rotation. This plane was chosen because this skull happened to be cut at an adjacent level for anatomical display (Fig. 1).

In ten radiographic examinations, the over-all mean thickness of the group is 5.96 mm. The range of radiographic thicknesses is 4.80 mm–6.77 mm. The mean thickness (T) for each of these ten skull projections is given in Table 2.

DISCUSSION

Since the electron density of skull is higher than that of soft tissue, it can be anticipated that photoelectric absorption will result in an increased absorption of lower-energy photons. As Fig. 3 indicates, this absorption increases markedly below about 100 keV. At the energy levels of ^{197}Hg and ^{133}Xe, considerable absorption (20–30%) occurs. At the energy level of ^{125}I, most (60–80%) of the rays emerging from the cranial cavity will be absorbed.

These degrees of absorption should be kept in mind when considering lower-energy brain scans. If isotope is present in scalp in significant concentrations, the superimposed scalp background will be accentuated relative to brain because of the absorption by skull. The absorption of ^{125}I radiation is so complete that the variable thickness of skull penetrated by internally originating radiation would produce an apparent scan distribution that would be a function largely of skull thickness.

In lateral scans of the cranium, radiation from parasagittal brain would pass nearly tangentially through skull, greatly accentuating the absorption of photons less than 100 keV.

Cranial defects would be expected to produce "hot spots" when one uses low-energy emitters. Skull lesions resulting in excessive regional thickening should produce "cold spots." These artifacts should be particularly apparent during the early postinjection period when the brain isotope content is high due to its content of highly radioactive blood. The influence of skull lesions on brain scans has recently been discussed (*1*).

The photoelectric absorption by skull of the lower-energy rays cannot be predicted precisely because of the variable diploic spaces in skull which contain blood.

The break at about 100 keV in the curve shown in Fig. 3 suggests that energies below this level are sufficiently absorbed by skull to introduce a serious artifact into external measurements. This will be particularly true if isotope is present in scalp. This consideration enters into current brain blood-flow studies using ^{133}Xe. In inhalation studies (*2,3*) in which the scalp contains isotope, skull absorption (compounded by internal absorption of radiation originating in brain and the relative proximity of scalp to the detector) will cause a marked emphasis of scalp isotope. Correction for scalp isotope content by computer analysis to define this slow-washout compartment has been attempted (*3*). This relative weighting of scalp blood flow is obviated by the technically more complex internal carotid injection of ^{133}Xe in which isotope distributes only to brain (*4*).

SUMMARY

The broad-beam absorption of thick and thin wet human skull regions was measured. Isotope sources producing a range of photon energies were used. The absorption of gamma radiation rises sharply below about 100 keV. The radiation of ^{133}Xe is 20–30% absorbed and of ^{125}I is 60–80% absorbed. In external measurements of brain in which scalp contains isotope, skull absorption should be considered, particularly when counting photons less than 100 keV.

ACKNOWLEDGMENT

The authors are grateful to L. R. Bennett, for supplying some of the isotopic sources. Valuable suggestions were offered by Benedict Cassen and S. Z. Oldendorf, and technical assistance was given by Herbert M. Lundberg and John Palmer.

This work was supported in part by United States Public Health Service grant number NB-04745.

REFERENCES

1. Maynard, C. D., Hanner, T. G. and Witcofski, R. L.: Positive brain scans due to lesions of the skull. *Arch. Neurol.* **18**:93, 1968.

2. Mallett, B. L. and Veall, N.: The measurement of regional cerebral clearance rates in man using xenon-133 inhalation and extracranial recording. *Clin. Sci.* **29**:179, 1965.

3. Obrist, W. B., Thompson, H. K., King, C. H. and Wang, H. S.: Determination of regional cerebral blood flow by inhalation of 133-xenon. *Circulation Res.* **20**:124, 1967.

4. Høedt-Rasmussen, K., Sveinsdotter, E. and Lassen, N. A.: Regional cerebral blood flow in man determined by intra-arterial injection of radioactive inert gas. *Circulation Res.* **18**:237, 1966.