

HAIR RADIOACTIVITY AS A MEASURE OF EXPOSURE TO RADIOISOTOPES

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ABSTRACT

Measurement of hair radioactivity appears to be a suitable method for monitoring systemic exposure to radioisotopes and certain types of manmade radiation. This concept has developed from a suggestion we made in 1963 that the strontium-90 content of hair affords a nondestructive method of estimating the body burden of this radionuclide. Since many radioisotopes accumulate in hair, this tropism has been investigated by comparing the radioactivity of shaved with plucked hair collected from rats at various time intervals up to 24 hrs. after intravenous injection of ca 5 uCi of the ecologically important radioisotopes, iodine-131, manganese-54, strontium-85, and zinc-65. The plucked hair includes the hair follicles where important biochemical transformations are taking place. The data indicate a slight surge of each radioisotope into the hair immediately after injection, a variation of content of each radionuclide in the hair, and a greater accumulation of radioactivity in plucked than in shaved hair. These results have application not only to hair as a measure of exposure to radioisotopes, but also to tissue damage and repair at the hair follicle.

In 1963, we (ref. 1) suggested that the strontium-90 content of hair provided a nondestructive method of estimating the body burden of this radioactive fission product. Sternberg (ref. 2), had previously noted that strontium-90 injected in pregnant guinea pigs was distributed to hair

as well as to the embryos. Our results from studies on rats were quickly confirmed by Della Rosa et al. (ref. 3), who investigated beagles. Their data indicated that the strontium-90 content of beagle hair could be used to estimate directly the radionuclide concentration of the diet and plasma,

and indirectly the remodeling labeled portion of the skeletons. Late in 1964, Moeller et al. (ref. 4) reported that the strontium-90 content of human hair seemed to correlate with the levels of the radionuclide in the diet. This initial report was expanded by Magno et al. (ref. 5), who showed that there were some irregularities between the mean levels of strontium-90 in the diet, and in the hair collected from children living in five installations participating in U.S. Public Health Service Institutional Diet Sampling Program.

The accumulation of other radioisotopes in the hair of several species has been studied by various investigators. Cesium-137 (ref. 6) has been shown to be present in Alaskan Eskimo hair as a result of fallout, but correlation with body burden has not been definitely established. Iron-59 (ref. 7), sulphur-35 (ref. 8), and zinc-65 (ref. 9) have also been shown to accumulate in human hair. Among the first radioisotopes to be studied in this way, were selenium-75 in dog hair (ref. 10), and iodine-131 (ref. 11,12) in rat hair. Other radioisotopes investigated in rat hair include cobalt-58 (ref. 13), vanadium-48 (ref. 14), and zinc-65 (ref. 15,16).

The mechanisms by which radioisotopes, especially of trace elements, accumulate in hair and other tissues are important to us. We are investigating the metabolism of trace elements with radioisotopes to develop new diagnostic procedures, to evaluate tissue damage from toxic excesses, to develop new therapies for burn and wound healing, and to study particulate pollutants. Accordingly, we have explicated the tropism of various radionuclides for rat hair by comparing the radioactivity of clipped with plucked hair at various time

intervals after intravenous injection of ecologically important radioisotopes. The plucked hair includes the hair follicle where important biochemical transformations are taking place. The radionuclides employed were iodine-131 ($T/2, 8D$), manganese-54 ($T/2, 300D$), strontium-85 ($T/2, 64D$), and zinc-65 ($T/2, 245D$).

METHODS AND RESULTS

The procedure used for measuring the accumulation of radioisotopes in rat hair was an elaboration of a previously described method (ref. 17). The radionuclides studied included sodium iodide-I-131, manganous-Mn-54 chloride, strontium-Sr-85 chloride, and zinc-Zn-65 chloride. Commercial preparations of these radioisotopes with high specific activity were diluted with normal saline so that 1.0 ml of each solution contained ca 5 μ Ci. Both young adult and old retired breeder male Sprague-Dawley rats were used, so that age effects could be investigated. Eight rats were injected in a tail vein with 1.0 ml of each radioisotope, and then divided into two groups of four animals each so that adequate quantities of hair could be harvested. Samples of hair ranging in weight from 0.20 to 0.50 mg were plucked with tweezers or shaved with animal clippers from the back of each rat at intervals of 1,2,4,6,12, or 24 hrs. These hair samples were weighed to 1 mgm, counted in a deep-well gamma scintillation counter, and the specific activity calculated. Between intervals of sample collection, the rats were housed individually in stainless steel cages provided with food and water ad lib. A 1.0 ml aliquot of each radioisotope solution was diluted to 100 ml, and 1.0 ml of this diluted solution was counted simultaneously with the hair samples to

provide a standard that was corrected for decay to calculate retention of injected dose per gram of hair.

The results are shown graphically in figures 1-5, in which the mean values and range of the percent retention of each radioisotope per gram of hair are plotted against time on semilogarithmic paper. As is evident from these graphic representations, the patterns of accumulation are similar for all radionuclides. The plucked hair with follicle always retained a higher percent of radioisotope per gram of hair than the shaved hair. The effect of age is to reduce slightly the rate of accumulation of each radioisotope in hair, as is illustrated by the comparison of data on the accumulation of strontium-85 in shaved hair of young adult and old breeder male rats, in figure 5. Standard errors and analyses of significance have not been included because these values probably cannot be applied to the hair samples, and would mask certain peculiarities if they were routinely used.

^{131}I ACCUMULATION IN HAIR

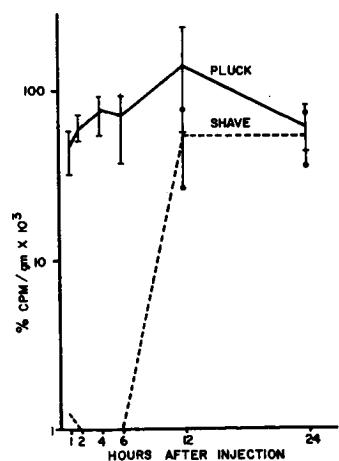


Figure 1. Comparison of iodine-131 retention in plucked and shaved rat hair following intravenous injection of ca 5 μCi of sodium iodide- ^{131}I in normal saline. The large differences between the radioactivity of plucked and shaved hair suggest that radioiodine accumulates rapidly in the hair follicle, and enters the hair shaft slowly from the follicle.

^{54}Mn ACCUMULATION IN HAIR

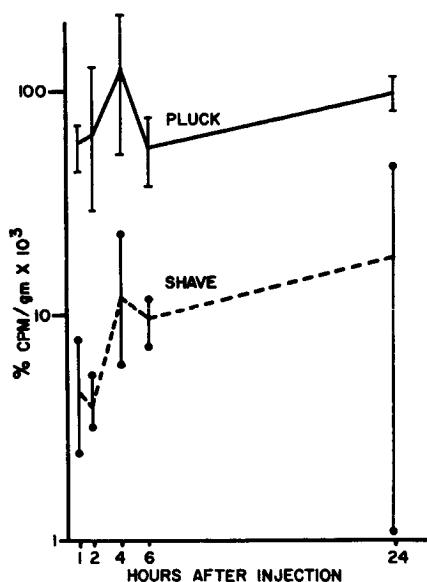


Figure 2. Accumulation of manganese-54 in plucked vs. shaved hair, following intravenous injection of ca 5 μCi of manganese- ^{54}Mn chloride, shows an initial slight surge of the radioisotope into both kinds of hair.

^{85}Sr ACCUMULATION IN HAIR

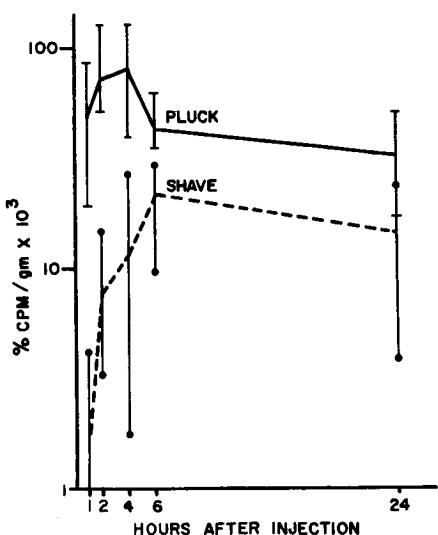


Figure 3. After intravenous injection of ca 5 μCi of strontium- ^{85}Sr chloride into rats, plucked hair shows a surge of the radioisotope, but shaved hair does not. This suggests that the radionuclide accumulates rapidly in the hair follicle, and passes slowly into the hair shaft from the follicle.

^{65}Zn ACCUMULATION IN HAIR

DISCUSSION

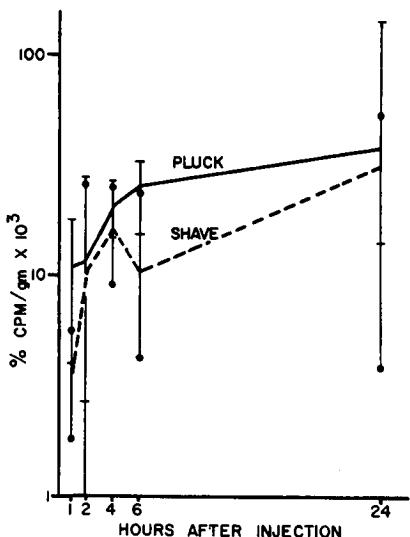


Figure 4. The accumulation of radioactivity in rat hair after intravenous injection of ca 5 μCi of zinc-Zn-65 chloride is slower than of the other radioisotopes, and the difference in radioactivity of plucked and shaved hair is small. Although the rate of accumulation of zinc-65 is slow initially, hair and bone become, and remain, the tissues with the highest specific activity after eight days.

^{85}Sr ACCUMULATION IN HAIR (PLUCKED)

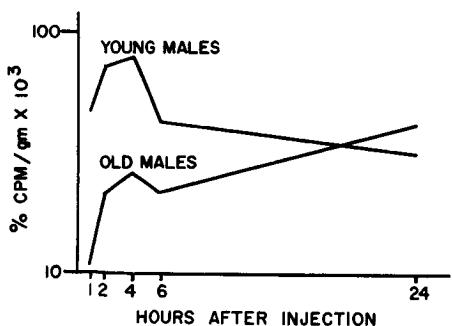


Figure 5. Comparison of uptake of strontium-85 in plucked hair from young adults and old retired male breeder rats indicates a faster rate of accumulation of radioisotope in the hair by the younger animals.

The curves showing the large ranges and mean values for the accumulation of the four radionuclides in plucked and shaved hair bring out similarities and differences. The large ranges probably relate to the mixture of hair in growing, transitional, and resting stages which are obtained by the sampling procedure. Iodine-131, manganese-54, and strontium-85, but not zinc-65, show a surge of radioactivity into the hair immediately after injection. This surge is followed by an ebbing out from the hair tissue which suggests that the hair levels reflect both the rise and fall in blood levels and something about the biochemistry of the hair follicle. There are significant differences in the retention patterns of manganese-54 (figure 2) and strontium-85 (figure 3) between plucked and shaved hair which indicate that the rate of uptake is much greater for strontium-85 than for manganese-54. As shown by the differences in the curves for the radioactivity of plucked and shaved hair in figure 1, iodine-131 seems to accumulate rapidly in the hair follicle and is then slowly transferred to the hair shaft. Zinc-65, in contrast, enters the hair follicle less rapidly than the other radioisotopes, and, apparently, is transferred rapidly to the hair itself, as shown in figure 4. The absence of a surge and ebb response may be related to the information of stable ligands of zinc with the sulphydryl groups which are abundant in hair.

The effect of age on the uptake of radioisotopes is brought out in figure 5 which shows a comparison of uptake of strontium-85 by the hair of younger adult with that of old retired breeder male rats. Strontium-85 is particularly suitable

for this comparison since it is the only radionuclide of the four which seems to be transferred easily from hair follicle to hair shaft. As is evident from the two curves, the accumulation of strontium-85 is much less in the hair of the older than of the younger animals.

Hair growth proceeds through three stages designated as anagenesis, catagenesis, and telogenensis (ref. 18). In anagenesis, there is active growth of hair from the follicle, but there is little information on the biomechanisms for producing keratin, the protein of hair which has such a high sulfur content. Keratin synthesis presumably takes place in the hair follicle, and incorporation of labeled sulfur amino acids, such as cysteine-S-35, in hair is so prompt that injection of small amounts of this radiolabeled amino acid into an animal provides a way of measuring hair growth (ref. 19). The incorporation of most inorganic elements in hair is usually explained as an excretion, but there is no real information on possible mechanisms of the excretion. Presumably, the excretion takes place in the hair follicle, where some of these elements from ligands with sulphydryl and other chelating groupings of keratin. The iodine content of hair, however, is the highest of any body tissue other than thyroid, and, apparently, the iodine is present entirely as inorganic iodide (ref. 11,12).

Determination of hair radioactivity has potential as a method of diagnosing inadvertent exposure to radioisotopes or radiation which produces radioisotopes in the body (ref. 20,21). Additional investigations are needed to establish the best methods of sampling and handling hair and related tissues, and of developing statistical relationship. Statistical analysis does not seem appropriate for the present studies because of the short cycle of hair growth in the rat of about 28 days. It is difficult to distinguish the stage of a cycle without a biopsy of the skin which would invalidate further work. Since the hair cycle is very much longer in man, as much as three years, and some head hairs persist for many years, hair analysis seems much more appropriate for man.

Exposure to high levels of radionuclides usually produces burns and traumatic injuries. The specialized tissues of the hair follicle and sebaceous glands are stimulated by injury to form migrating epithelium which will cover the injured surface (ref. 22). Since we (ref. 23) and others (ref. 24,25) have found that oral zinc therapy promotes healing of burns and wounds in man, there is need for an understanding of the biochemistry of hair follicles and hair formation. Accordingly, investigations on the accumulation of stable and radioactive forms of the elements in hair may provide additional information for the repair of burns, trauma, and critical injuries. These studies are sorely needed because of the lack of programs to furnish such basic information.

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