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LEACHING OF RADIONUCLIDES FROM NEUTRON-ACTIVATED TALC IN SERUM AND IN DILUTE HYDROCHLORIC ACID

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Abstract—When neutron-activated talc was suspended in bovine serum, 0·5% of the ^{60}Co and 3·1% of the ^{46}Sc occurring in the sample was found in the supernatant of the centrifuged and filtered suspension. A maximum of about 0·5% of each radionuclide can be attributed to small particles passing through the filter. This indicates that very little ^{60}Co and about 2·5% ^{46}Sc leached from the talc. The findings indicate that from the pulmonary talc burden of about 45 μg observed in a previously conducted pulmonary deposition, translocation and clearance study, the equivalent of about 0·2 or 1·1 μg talc may have leached, depending on whether ^{60}Co or ^{46}Sc data were used for this computation. Leaching effects on the lung burden thus appear to be negligible. When neutron-activated talc was suspended in 2 N-HCl, from 2 to 5% of the induced ^{60}Co, ^{51}Cr, ^{59}Fe and ^{46}Sc was removed, primarily by leaching. This suggests that leaching of radionuclides from talc may take place in the acid environment of the stomach. This leaching and the subsequent absorption of the radionuclide in the intestinal tract could account for the quantities of ^{60}Co found in the urine of the hamsters in the earlier study.

INTRODUCTION

In a pulmonary deposition, translocation and clearance study previously conducted in these laboratories, neutron-activated talc was used to determine talc burdens in hamster tissues and excreta following a single 2-hr inhalation exposure (Wehner, Wilkerson, Cannon, Buschbom & Tanner, 1977). Reported talc burdens were based on direct instrumental measurements of ^{60}Co tracers and, in a number of cases, also of ^{46}Sc tracers, induced in talc prior to the inhalation exposure. A fundamental presumption relevant to the validity of this technique is a direct quantitative correlation between measured radionuclides and talc particles. However, following contact with biological fluids, the tracers may leach from the talc and thus compromise this correlation.

Direct instrumental measurements made in the pulmonary deposition, translocation and clearance study indicated that from 20 to 80 μg talc was retained in hamster lungs and, following mucociliary clearance and subsequent swallowing, from 220 to 940 μg passed through the gastro-intestinal tract and was eliminated in the faeces. If significant leaching from talc occurs in the lung and gastro-intestinal tract, soluble ^{60}Co and/or ^{46}Sc may be absorbed and translocated to other organs or to the urine. If it does represent translocated talc, a calculated talc burden should be similar whether it is based on measurements of ^{60}Co or ^{46}Sc. Since this definitive verification was not always possible due to ^{46}Sc decay, and since without verification measured radionuclide activities due to leaching may be incorrectly interpreted as translocated talc particles, the extent and significance of tracer leaching into body fluids needed to be determined.

The objectives of the experiment were to estimate leaching of selected radionuclides (^{60}Co, ^{51}Cr, ^{59}Fe and ^{46}Sc) from neutron-activated talc and to evaluate the effect of such leaching on the estimated talc burdens reported for the pulmonary deposition, translocation and clearance study.

EXPERIMENTAL

A 3-g sample of Johnson's Baby Powder®, subsequently called 'talc', was irradiated to an integrated neutron exposure of $1·4 \times 10^{17}$ n/cm^2. Following a decay period of 3 wk, the irradiated talc was thoroughly mixed to provide a homogeneous specific γ-ray activity. Several 0·1-g aliquots were then weighed into 1·4 ml polyethylene vials. Three randomly selected talc-containing vials were subjected to γ-ray analysis on a solid-state Ge(Li) detector to determine the specific counting activities of the radionuclides ^{60}Co, ^{51}Cr, ^{59}Fe and ^{46}Sc.

Solutions of bovine serum (Grand Island Biological Company, Santa Clara, Cal.) and of 2 N-HCl were prepared, and 100-ml aliquots of each were poured into separate 250-ml polyethylene bottles. The pH of the serum was 8 and that of the dilute HCl was 1·8. The serum was treated with sodium azide (0·1 g/litre) immediately after thawing to inhibit bacterial growth during the experiment. Aliquots containing 0·1 g of neutron-activated talc were suspended in the prepared solutions. The suspensions were then placed in a sample-agitating water-bath maintained at 37°C. It was assumed that the solution-to-talc ratio of 100 ml:0·1 g was adequate to make the experiment independent of solution equilibrium effects, and would thus allow maximal leaching of the radionuclides of interest.

The extent of radionuclide leaching into bovine

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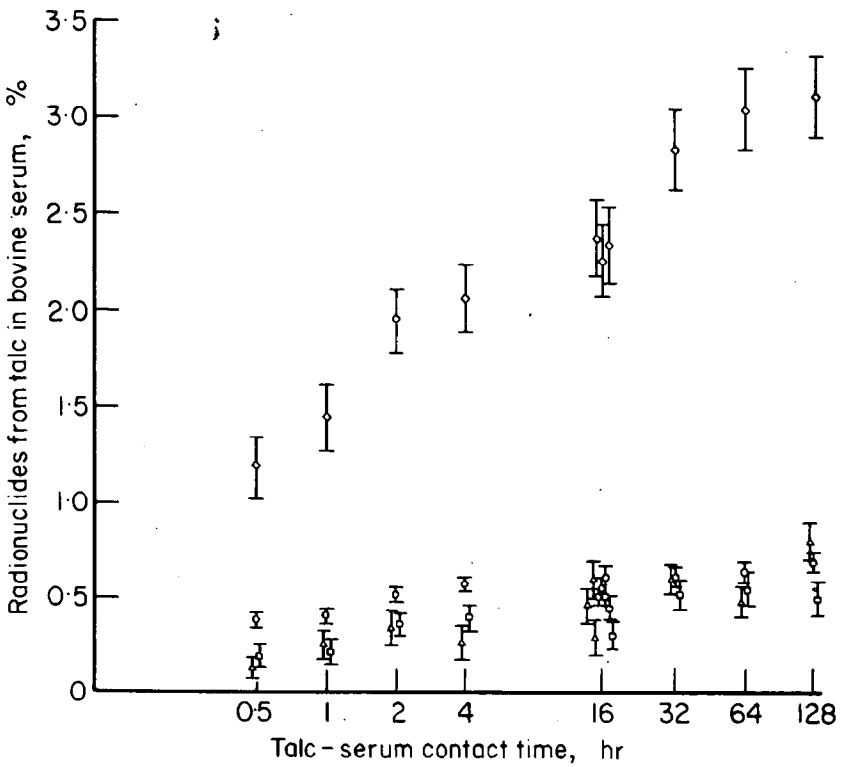

Fig. 1. Removal of ^{46}Sc (◇), ^{60}Co (○), ^{59}Fe (□) and ^{51}Cr (△) from talc suspended in bovine serum (pH 8) in a concentration of 0·1 g/100 ml. Error bars represent the combined error of the standards (mean ± 1s) and supernatant counting errors (1s).

serum or 2 N-HCl as a function of time was investigated by controlling the period of contact between each solution and the talc. Periods for contacting a total of ten aliquots of neutron-activated talc with bovine serum were 0·5, 1, 2, 4, 16, 32, 64 and 128 hr, aliquots for the 16-hr contact time being measured in triplicate to determine experimental precision. Contact periods for a total of three aliquots of neutron-activated talc with dilute HCl were 1, 4 and 128 hr.

At the end of each contact period, the appropriate suspension was removed from the water-bath and centrifuged. A 50-ml aliquot of the supernatant was removed by pipette and filtered through a glass-fibre filter (Gelman Type E) with a rated filtration efficiency of >99% for particle sizes ≥0·3 μm. The filtered 50 ml of supernatant was analysed on the Ge(Li) detector used previously. After application of appropriate radioactive-decay and counting-geometry corrections, the fraction of each radionuclide that had leached from the talc was determined.

RESULTS AND DISCUSSION

The corrected specific counting activities of the radionuclides ^{60}Co, ^{51}Cr, ^{59}Fe and ^{46}Sc in talc, and in the filtered supernatant solutions of bovine serum and 2 N-HCl are shown in Table 1. Measured specific counting activities for the three randomly selected aliquots of irradiated talc showed close agreement and served as standards.

Computed fractions of each radionuclide removed from neutron-activated talc as a function of the period of contact with bovine serum or 2 N-HCl are shown in Figs 1 and 2, respectively.

Results of contacting neutron-activated talc with bovine serum (Fig. 1) indicate that ^{60}Co, ^{51}Cr, ^{59}Fe and ^{46}Sc were essentially retained by the irradiated talc particles. Retained fractions were >96% for ^{46}Sc and >99% for ^{60}Co, ^{51}Cr and ^{59}Fe, as measured over the entire contact period. Removed fractions of ^{60}Co, ^{51}Cr and ^{59}Fe were within a narrow range around 0·5%. Considering experimental precision and accuracy, the close agreement between these three radionuclide fractions suggests that the removed fraction represents small talc particles which may have escaped filtration. This assumption is in good agreement with the rated >99% efficiency of the glass-fibre filter for particle sizes ≥0·3 μm. In view of these observations, it is reasonable to conclude that measured fractions of ^{60}Co, ^{51}Cr and ^{59}Fe in filtered bovine serum represented talc particles. Leached fractions of these three radionuclides can be considered negligible.

Preferential removal of ^{46}Sc was observed for all talc-serum exposures. The gradual increase in removed ^{46}Sc as a function of time suggests that leaching effects contributed to the measured ^{46}Sc activities. The observed maximal fraction of ^{46}Sc removed was 3·1% after the 128-hr contact period. Assuming that this value represents maximally extractable ^{46}Sc, and assuming a 0·5% contribution from small talc particles, an estimated fraction of 2·6% represents leached ^{46}Sc.

Alternative explanations for the raised ^{46}Sc levels in the serum supernatant involve the fast neutron

Table 1. *Specific activities for neutron-activated talc and filtered supernatants of bovine serum and dilute HCl*

Sample	Contact time (hr)	Radionuclide activity (cpm/g talc)*						
		^{60}Co		^{51}Cr	^{59}Fe		^{46}Sc	
		1·17 MeVγ	1·33 MeVγ	0·32 MeVγ	1·10 MeVγ	1·29 MeVγ	0·89 MeVγ	1·12 MeVγ
Talc (0·1 g) in vial no. 1	—	2173 ± 12†	1929 ± 11	1597 ± 10	1024 ± 8	671 ± 6	588 ± 6	484 ± 5
2	—	2253 ± 12	1990 ± 11	1677 ± 10	1066 ± 8	695 ± 7	628 ± 6	496 ± 6
3	—	2211 ± 12	1955 ± 11	1607 ± 10	1017 ± 8	681 ± 6	602 ± 6	484 ± 5
Talc (mean ± 1s)	—	2212 ± 40	1958 ± 31	1627 ± 44	1036 ± 27	682 ± 12	606 ± 20	488 ± 7
Bovine serum supernatant	0·5	7·8 ± 0·8	7·8 ± 0·8	2·2 ± 1·0	2·3 ± 0·6	1·3 ± 0·4	5·2 ± 0·6	7·4 ± 0·8
	1	9·4 ± 0·8	7·1 ± 0·8	4·2 ± 1·3	3·1 ± 0·7	0·9 ± 0·4	7·7 ± 0·8	7·9 ± 0·8
	2	10·5 ± 0·8	10·7 ± 0·8	5·7 ± 1·4	3·8 ± 0·7	2·4 ± 0·5	10·1 ± 0·9	11·0 ± 0·9
	4	12·2 ± 1·0	11·2 ± 0·8	4·4 ± 1·4	4·1 ± 0·7	2·7 ± 0·5	12·1 ± 1·0	10·4 ± 0·8
	16‡ (1)	12·5 ± 1·0	10·9 ± 0·8	9·8 ± 1·5	5·2 ± 0·7	2·7 ± 0·5	14·6 ± 1·1	11·4 ± 0·9
	(2)	14·5 ± 1·0	10·8 ± 0·8	7·7 ± 1·5	4·2 ± 0·7	1·2 ± 0·5	13·7 ± 1·1	11·9 ± 0·9
	(3)	10·8 ± 0·8	10·4 ± 0·8	4·6 ± 1·4	4·6 ± 0·7	3·9 ± 0·7	12·5 ± 1·1	12·1 ± 0·9
	32	14·9 ± 1·0	10·5 ± 0·8	9·8 ± 1·6	4·7 ± 0·6	3·9 ± 0·6	16·5 ± 1·0	14·4 ± 1·0
	64	13·7 ± 1·0	13·0 ± 1·0	7·8 ± 1·2	6·4 ± 0·9	3·4 ± 0·6	16·8 ± 1·0	16·2 ± 1·0
	128	16·4 ± 1·0	12·6 ± 1·0	13·1 ± 1·6	4·9 ± 0·7	3·6 ± 0·7	17·8 ± 1·1	16·1 ± 1·1
Dilute HCl supernatant	1	20·6 ± 1·3	20·6 ± 1·0	6·5 ± 2·0	16·4 ± 1·5	12·5 ± 1·2	25·8 ± 1·5	22·3 ± 1·5
	4	24·7 ± 1·3	20·1 ± 1·1	17·1 ± 2·2	25·9 ± 1·6	16·2 ± 1·4	29·6 ± 1·6	27·6 ± 1·4
	128	44·9 ± 1·8	39·8 ± 1·6	33·9 ± 3·0	45·1 ± 2·1	25·7 ± 1·5	30·3 ± 1·7	25·6 ± 1·5

*All values are corrected for radioactive decay and counting geometry. Supernatant solution activities have been converted to cpm/g talc by multiplying with appropriate solution-to-talc ratios.
†Counting error (1s).
‡Determined in triplicate.

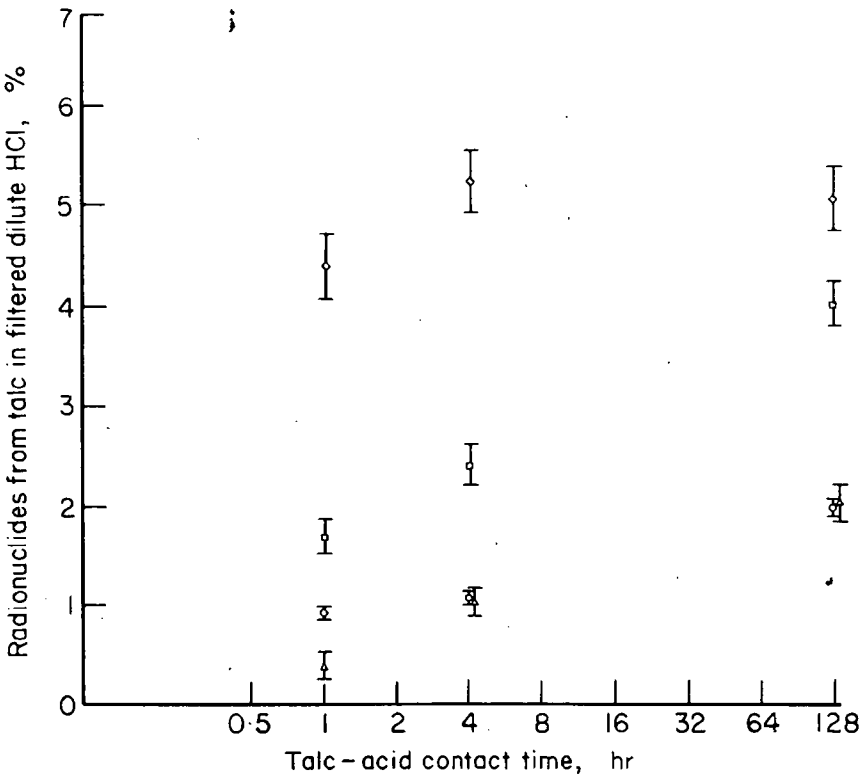

Fig. 2. Removal of ^{46}Sc (◇), ^{60}Co (○), ^{59}Fe (□) and ^{51}Cr (△) from talc suspended in dilute HCl (pH 1·8) in a concentration of 0·1 g/100 ml. Errors bars represent the combined error of the standards (mean ± 1s) and supernatant counting errors (1s).

reaction $^{46}_{22}Ti(n,p)^{46}_{21}Sc$. If significant, this reaction could result in recoiled atoms of ^{46}Sc which might become highly soluble following contact of the irradiated talc with the solution. However, this possibility appears unlikely due to the unfavourable production parameters of ^{46}Ti atomic abundance (8%) and the Ti concentration in this talc (< 200 ppm), as measured by neutron-activation analysis in our laboratory. Also, if recoiled ^{46}Sc atoms were responsible for the increased ^{46}Sc levels in the filtered serum supernatants, the expected fractional removal curve in Fig. 1 would rise sharply within a short exposure time and then level off asymptotically. The data represented by the gradually increasing curve illustrated in Fig. 1 do not support this hypothesis. A second possibility is that the talc contains a high Sc-bearing mineral of small particle size which could preferentially escape the filter or leach.

Assuming a maximal leaching of 0·5% for ^{60}Co and 2·5% for ^{46}Sc, the maximal fraction of these tracers which may have leached from the talc in the hamster lung can be estimated. Using the mean talc burden for hamster lungs (45 μg) demonstrated in the pulmonary deposition, translocation and clearance study (Wehner *et al.* 1977), the fraction of potentially leached ^{60}Co and ^{46}Sc would be equivalent to about 0·2 and 1·1 μg talc, respectively. The estimated quantities of elemental Co and Sc leached from the above talc burden may be calculated from the elemental concentration of Co and Sc in the talc. As measured in our laboratory by instrumental neutron-activation analysis, these values were 64 and 1 ppm for Co and Sc, respectively. The estimated quantities of elemental Co and Sc leached were thus $14·4 \times 10^{-12}$ g Co (from 45×10^{-6} g talc, 64×10^{-6} g Co/g talc and 0·5%) and $1·1 \times 10^{-12}$ g Sc (from 45×10^{-6} g talc, 1×10^{-6} g Sc/g talc and 2·5%).

Table 2 shows the average values for background γ-ray counts with twice the standard deviation for ^{60}Co and ^{46}Sc in various tissues and excreta from control animals, expressed as μg equivalents of talc. It can readily be observed that the estimated quantities of leached ^{60}Co and ^{46}Sc (equivalent to 0·2 and 1·1 μg talc, respectively) are negligible. Thus, quantities of ^{60}Co and ^{46}Sc that may have leached and translocated from the hamster lung would also be negligible and would not affect the results of the pulmonary deposition, translocation and clearance study.

Results of the serum-leaching study suggest that a maximum of 0·5% of the induced radionuclides may have passed into the supernatant as unfiltered talc particles. Contacting neutron-activated talc with 2 N-HCl resulted in greater removals, namely 2–5%. This indicates that all four radionuclides were removed from talc primarily by leaching (Fig. 2). The maximal fraction of ^{46}Sc removed was 5·3%; this was recorded after the 4-hr contact time and appears to be the upper limit of extractable ^{46}Sc. Removed fractions of ^{59}Fe measured in filtered 2 N-HCl supernatants increased linearly as a function of contact time. The maximal fraction removed was 4·1% after 128 hr. Removal of the radionuclides ^{60}Co and ^{51}Cr also showed a linear increase with contact time, the maximal fraction removed from the talc being 2·1% after

Table 2. *Mean γ-ray counts for tissues and excreta of control hamsters, based on ^{60}Co and ^{46}Sc data and expressed in talc equivalents*

Sample	Talc equivalent* (μg)	
	^{60}Co	^{46}Sc
Lung	2·1 ± 0·9	7·0 ± 5·8
Liver	2·5 ± 1·4	4·6 ± 2·1
Kidneys	2·1 ± 1·7	7·1 ± 2·2
Ovaries	2·2 ± 1·0	5·0 ± 3·8
Carcass	3·0 ± 1·8	8·8 ± 6·8
Urine	1·5 ± 0·4	4·4 ± 2·0
Faeces	4·8 ± 3·4	5·8 ± 2·6

*Values are expressed as means ± 2 SD and are based on ^{60}Co and ^{46}Sc data for the control animals in a pulmonary deposition, translocation and clearance study on talc (Wehner *et al.* 1977).

Table 3. *Estimated quantities of Co and Sc translocated to blood of exposed animals following absorption from gastro-intestinal tract*

Parameter	Co	Sc
Concn of element in talc (ppm)	64	1
Mean quantity (Q) of talc passing through gut* (μg)	455	455
Estimated fraction (f_1) leached in upper gut†	0·01	0·045
Estimated fraction (f_2) absorbed in gut‡	0·3	0·0001
Estimated quantity (T) of element transferred to blood ($\times 10^{-12}$ g)	90	0·002
Equivalent quantity of talc (μg)	1·4	0·002

*Determined by Wehner *et al.* 1977.
†Determined experimentally using ^{60}Co and ^{46}Sc tracers.
‡From report of ICRP Committee II (1960).

128 hr in both cases. The complex behaviour of the ^{46}Sc removal curve, which reaches a maximum after 4 hr, supports a mechanism of removal independent of that of Fe, Co and Cr. The independent behaviour of Sc could be due to the reduction of particles containing high concentrations of Sc to smaller particle sizes or to the leaching of particles containing readily depletable quantities of Sc.

To estimate the leaching effects of the acid environment of the stomach on ^{60}Co and ^{46}Sc, the 1-hr contact data were used. During this contact period, 1% ^{60}Co and 4·5% ^{46}Sc were removed from the talc (Fig. 2). On the basis of the data for gastro-intestinal absorption reported in 1959 by Committee II of the International Commission on Radiological Protection (ICRP), the total quantity of Co and Sc that may have leached from talc and translocated to blood by gastro-intestinal absorption can be estimated using the general equation: $T = Q.f_1.f_2.C$ where T is the estimated quantity of stable element translocated, Q is the estimated quantity of talc passing through the gastro-intestinal tract, f_1 is the estimated fraction of the element (or radionuclide tracer) leached during passage through the gastro-intestinal tract, f_2 is the estimated fraction of the element (or radio nuclide tracer) absorbed from the gastro-intestinal tract and C is the concentration of the element in this sample of talc.

Using the average talc burden for hamster carcasses (455 μg) determined in the pulmonary deposition, translocation and clearance study (Wehner *et al.* 1977), the corresponding equivalent fraction of talc potentially translocated, calculated on the basis of leached ^{46}Sc, is only 0·002 μg (Table 3). This value is far below the levels demonstrated for the control animals in that study (Table 2) and would thus be undetectable. Leaching, therefore, would have had no effect on the ^{46}Sc-determined talc burdens in the pulmonary deposition, translocation and clearance study.

The data on ^{60}Co in Table 3 show that about 90 pg Co may translocate. The corresponding talc equivalent, based on the measurement of ^{60}Co, is about 1·4 μg. Assuming that leached Co translocating to blood would mainly be excreted in the urine, one would expect that the ^{60}Co leached from talc could be measured in the hamster urine. This contention is supported by a comparison of ^{60}Co determinations in the urines of control and exposed animals. The average value for control urines (Table 2) is equivalent to 1·5 ± 0·4 μg talc. The estimated translocation of leached ^{60}Co to blood following gastro-intestinal absorption (Table 3) resulted in a talc burden equivalent of 1·4 μg. Adding the average urine value for the controls (1·5 μg) to that of the experimentally determined equivalent quantity of talc represented by leached ^{60}Co (1·4 μg) yields approximately the values (about 3·5 μg) found in the urine of the exposed animals (Wehner *et al.* 1977). This suggests that leached ^{60}Co accounts to a large extent for the γ-ray counts recorded for the urine of exposed animals.

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