ORIGINAL RESEARCH

Decontamination of Human and Rabbit Skin Experimentally Contaminated with ^{99m}Tc Radionuclide Using the Active Components of "Shudhika"—a Skin Decontamination Kit

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Abbreviations:
DF: Decontamination Factor
RM: Radioactive Material

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Abstract

Introduction: Radioactive contamination can occur as a result of accidental or intentional release of radioactive materials (RM) into the environment. RM may deposit on clothing, skin, or hair. Decontamination of contaminated persons should be done as soon as possible to minimize the deleterious health effects of radiation. The goal of this study was to evaluate the decontamination efficiency (for residual contaminant) of the active components of "Shudhika," an indigenously developed skin decontamination kit. The study kit is for external radioactive decontamination of intact skin.

Methods: Decontamination efficiency was evaluated on the skin surface of rabbit ($n = 6$) and human volunteers ($n = 13$). ^{99m}Tc sodium pertechnetate (200-250 μCi) was used as the radio-contaminant. Skin surface area (5×5 cm^2) of thoracic abdominal region of the rabbit and the forearm and the palm of human volunteers were used for the study. Decontamination was performed by using cotton swabs soaked with chemical decontamination agents of the kit.

Results: Decontamination efficiency (% of the contaminant removed) was calculated for each component of the study. Overall effectiveness of the kit was calculated to be 85% ± 5% in animal and 92% ± 3% in human skin surfaces. Running water and liquid soap with water was able to decontaminate volunteers' hand and animal skin up to 70% ± 5%. Chemical decontamination agents were applied only for trace residues (30% ± 5%). Efficiency of all the kit components was found up to be 20% ± 3% (animal) and 28% ± 2 (human), respectively. Residual contamination after final decontamination attempt for both the models was observed to be 12% ± 3% and 5% ± 2%. After 24 and 48 hours of the decontamination procedure, skin was found to be normal (no redness, erythema and edema were observed).

Conclusion: Decontaminants of the study kit were effective in removal of localized radioactive skin contamination when water is ineffective for further decontamination. By using the chemical decontaminants of the study kit, the use of water and radioactive waste generation could be reduced. Cross-contamination could also be avoided. During radiologic emergencies where water may be radioactively contaminated, the study kit could be used.

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Introduction

Radioactive contamination can occur if radioactive materials (RM) are released into the environment. Such release can expose people and contaminate the surrounding environment. There also exists an occupational risk of exposure and contamination during handling, storage, or processing of radio-nuclides. Radioactive contamination occurs when radioactive materials are deposited on or in the living organism.[1-3] External contamination occurs when radioactive material in the form of dust, powder, or liquid, comes into contact with a person's clothing, hair, or skin. Internal contamination occurs when people swallow or breathe in radioactive materials. Radiation can also enter into the body through intact or broken skin. Various radioisotopes of Technetium, Iodine, and Fluorine are used in small doses in nuclear medicine for diagnosis and therapy of diseases, but can also cause accidental large-dose contamination.[4-6] Radioactive materials have been used in weaponry and stockpiled by different nations, and there is a risk that an incident involving these stockpiles during storage, transportation, or malevolent use can lead to mass-casualty events.[7]

Contamination includes the deposition of the RM on the skin and surface of the body and can cause harmful effects of radiation until removed. A contaminated individual carrying RM may cross-contaminate other persons or non-living surfaces through contact.[8,9] The detection and removal of radioactive skin contamination should be undertaken quickly both for the protection of the individual concerned and the community.[10-12] RMs can emit alpha and beta particles. Alpha particles do not penetrate the horny outer layer of the skin, and can be removed by disposing the outer layer of clothing and washing all the exposed parts of the body. If internalized, alpha emitters can cause organ damage.[13-15] Beta particles penetrate the full thickness of the skin, and to a certain extent, the subcutaneous tissues and cause radiological damage.[16] The acceptable levels of radio-nuclide particle contamination should be averaged over $10^{-2}\,m^2$ in the case of skin generally, or over $3 \times 10^{-2} m^2$ in the case of hands.[17-18]

Gamma (ionizing) radiation is most dangerous because of penetration of the whole body. This form of radiation leads to ionization of water and bio-molecules within cells. The severity of the effects depends on the length of the exposure and degree of contamination.[19-22]

This study was designed to evaluate the efficiency of the active components of "Shudhika," which is an indigenously developed skin radiation decontamination kit.

Methods

This study used an experimental model designed to evaluate (in term of the relative efficacy) removal from skin of traces of a radioactive contaminant that was not removed with water and liquid soap. The study included both rabbit and human skin surface models. An animal (rabbit) model was used to observe the effect of dense hair, and soft and leathery skin. Contamination was done with ^{99m}Tc-sodium pertechnetate (a gamma emitter, 140 KeV), which is the most commonly used radionuclide in nuclear medicine imaging because of its short half-life (6 hours). Gamma scintigraphy technique was used for acquiring static counts and image generation after each successive step of decontamination.

Efficiency of each chemical decontamination agent was the outcome measure of interest. Length of contaminant exposure ranged from 0-3 hours to observe the effect of time on decontamination efficiency. Standardized conditions of the experiments were volume of water (0.5, 1.0, 1.5, 2.0, 2.5, 3.0 liters), radio-contaminant (200-250 μCi), decontamination attempt (60 seconds for each step), and length of exposure (0-3 hours). Skin toxicity, in terms of erythema and edema, was visually observed for the studied decontamination agents by using the method of Draize et al.[23]

For this study, a "Shudhika" kit was obtained from M/s Raksha Polycoats, Pune, India. The following components of the kit were used for the study:

- Ethylene diamine tetraacetic acid solution (10%)
- Oxalic acid solution (2%)
- Sodium bisulphate solution (5%)
- Hydrochloric acid solution (*p*H-1)
- Diethylene triamine pentaacetic acid solution (5%)
- Potassium permanganate solution (7%)
- Sodium bicarbonate solution (7.8%).

Radio-contaminate ^{99m}Tc separated from ^{99}Mo by solvent extraction method, was obtained as sodium pertechnetate from the Regional Centre for Radiopharmaceutical (Northern Region), Board of Radiation and Isotope Technology, Delhi, India.

Quantitative nuclear imaging was done using the scintigraphy technique for static counts calculated as kilo counts per seconds (kcps). Hawkeye Millennium, VG and Symbia True point SPECT-CT gamma cameras were used. Region-of-interest software was used for count statistics. Image and residual counts running time was kept to 180 seconds. This time period was optimized to acquire good images and static counts with the applied radioactivity used.

Six adult New Zealand rabbits (two to three months) weighing 2.25 ± 0.25 kg were used as the experimental model after obtaining Institutional Animal Ethics Committee approval. All animals were given normal feed *ad libitum*, and filtered drinking water. Rabbits were kept at normal room temperature of 22 ± 3° and in 12 hours each of dark and light periods. The thoraco-abdominal area of each rabbit was studied for decontamination. Hairs were clipped off with scissors one day before the experiment to contaminate the skin properly.

With Human Ethical Committee approval, 13 healthy volunteers 21-45 years of age were recruited for study after informed consent. The forearms and palms of the volunteers' hands were the surface areas used for the study.

Freshly prepared ^{99m}Tc (200-250 μCi), appropriately mixed in 0.1 ml saline (0.9%), was used for contamination of the skin surface area ($5 \times 5\,cm^2$). This solution was evenly spread over the skin with a syringe plunger. The contaminated skin surface was left for 0-3 hours, and subsequently decontaminated.

For decontamination, 0.5, 1.0, 1.5, 2.0, 2.5, and 3 liters of running water were used repeatedly to remove the contaminant (without the use of washcloth or brush) for 20 seconds. Decontamination agents of the "Shudhika" kit were applied to remove residual contaminant that was not removed further by using water and soap. The decontamination agents (4-5 ml), soaked in standard size cotton swabs (7.5 cm × 7.5 cm), were applied serially using a swirling motion (from periphery towards center) in clockwise direction. Each step was done for 20 seconds. Decontamination was started at different time periods to evaluate the time effect on the residual and adhered radio-nuclide on the skin. The length of exposure for the contaminant over the applied area was 0 to 30 minutes for the animal model and 0-3 hours for humans.

Radiation measurements were corrected for radioisotope decay so that decontamination data could be compared to initial contamination levels. Times of contamination and measurements were recorded to ensure that the measurements could be referred back to the initial contamination levels. Corrections were applied for background levels of radiation. Multiple readings were taken

Decontaminating agents	Residual ^{99m}Tc activty (Mean ± SD)	
	Human (N = 13)	Rabbit (N = 6)
Liquid Soap + water	65 ± 2.8	60 ± 5.0
Ethylene diaminetetraacetic acid	10 ± 2	8.7 ± 1.3
Oxalic Acid	6.0 ± 0.4	4.3 ± 2.3
Sodium bicarbonate	4 ± 0.9	5.4 ± 3.6
Hydrochloric acid (pH-1)	3.2 ± 1	3.7 ± 2.0
Diethylene triamine pentacetic acid	3.0 ± 1	5.9 ± 1.5
Potassium permanganate, sodium bisulphite	4.1 ± 2	3 ± 0.4

Table 1. Decontamination efficiency of "Shudika" kit components

and the average was used as the background level and subtracted from all measurements.

Results, expressed as a percentage of residual contamination, were calculated as follows:

$$DF = \frac{C_o}{C_t}$$

where DF denotes Decontamination Factor, C_0 = Measurement of the initial contamination counts, and C_t = Measurement of counts following decontamination attempt.

Evaluation of the efficiency of a particular agent for decontamination was accomplished by determining the differential mean reduction of contamination from a radionuclide relative to the original contamination. Decontamination efficacy was expressed in terms of a percentage of the remaining contamination, and was arrived at by using the following formula:

$$D = (1 - 1/DF) \times 100,$$

where D = decontamination efficiency and the other variables are the same as noted above.

Decontamination studies for each chemical agent against ^{99m}Tc radionuclide were performed in triplicate. The mean for each data point was calculated and the error bars calculated from the standard deviations of the distributions. In each case, data are presented as mean ± standard deviation. Data were analyzed by two-way analysis of variance (ANOVA) with post test to assess the differences between experimental groups using PASW Statistics 18 software (Chicago, Illinois USA). The P value was calculated at <.002 for both the experimental models.

Results

Water irrigation was used in series (0.5, 1.5, 1.5, 2.0, 2.5, 3.0 liter) and it was found that the first wash is the most effective. Decontamination efficiency for the traces of the contaminant (30% ± 5%), in both the models, animal and volunteers skin surface was calculated to be 70% ± 2% and 80% ± 1%, respectively. A significant difference was observed for washing contaminated surfaces with and without rubbing. Rubbing washing was more effective and reduced the contaminant burden from the forearm by >75%. Gentle washing without rubbing removed only up to 65% of contaminant. Palm skin surface without hair and pores washed in running water resulted in removal of most of the radio-contaminant. Palm skin contamination level followed by water decontamination was observed to be at the background level (Table 1). The leathery and soft skin of the rabbit had more persistence of the contaminant over the contaminant applied area when compared to the human forearm.

As shown in Table 1, EDTA solution was the most effective agent of the kit and able to remove up to 10% ± 2% of the residual contaminant. Approximate individual efficiency of other components of the kit were:

- Oxalic acid solution—6% ± 1%
- Sodium bicarbonate solution—4% ± 1%
- Hydrochloric acid solution—3% ± 1%
- DTPA solution—3% ± 1%
- Potassium permanganate + sodium bisulphite solution—4% ± 2%.

Discussion

Water followed with liquid soap and a water bath is used as a universal radiation decontamination agent. Chemical decontamination agents are based on the oxidation and reduction reactions that make contaminants soluble and easily removable from the body. Chelating agents form complexes with radioisotopes to facilitate removal. Various protocols and formulations for skin decontamination have been proposed for the removal of the radioactive contamination from skin. A number of chemical decontaminants have been advocated by the International Atomic Energy Agency and Atomic Energy Regulatory Board of India. The "Shudhika" skin decontamination kit contains all these recommended chemical decontamination agents and needed medical supplies (surgical mask, eye pads, water proof bandages, cotton swabs, nasal catheters, potassium iodide tablets, and nail cutter). Water decontamination along with liquid soap leaves trace residues of radiation contaminants that are difficult and sometimes impossible to remove.

The standard radiation decontamination process starts with tepid water for diluting and dispersing the RM. This by itself is not fully effective in removing traces of leftover contaminants.

First water wash results in reducing by 50-75% the contaminant body burden, but subsequent washes show little effect.[4] Intact skin layers are a barrier to radioactive nuclei penetration; therefore scrubbing is best avoided during decontamination process to avoid damage to skin. Decontamination studies have shown that skin moistening agents could reduce skin abrasion that to some extent may result in increased radioactive permeability. Immediate decontamination with commercially available skin cleaners have shown 99% removal of ^{132}I and ^{32}P.[18] Other skin decontamination studies using different decontaminating agents such as kaolin paste, titanium dioxide paste, potassium permanganate, and hydrochloric acid have found none of these to be highly effective or ideal. These agents also were reported to cause skin roughening, which results in more absorption of the contaminant, making it difficult to remove. Decontamination of the ^{99m}Tc with a saturated solution of potassium permanganate along with other commercially available agents was found to be effective for long-lived alpha emitters rather than gamma emitting radio-isotopes. The relative decontamination efficiency of the ^{99m}Tc radiopharmaceuticals, ^{131}I (as iodide and orthoiodohippurate), ^{67}Ga (as gallium citrate), and ^{111}In (as indium DTPA) with water, Radicawash and isoclean (see reference) found that removal of technetium is most difficult with residual contaminants of 7% for pertechnetate, 5% for the iodide and 1% or less for others left after 90 second decontamination attempts.[17]

Tepid water was used because cold or hot water affects the capillary blood flow and may alter absorption of the radionuclides. Plain water applied with cotton swabs can also remove contaminants in the same way as plain running water.

In the present study, the decontamination kit was applied after the water and liquid soap decontamination, and when further contaminant could not be removed. In both experimental models, approximately 30% of contaminants were left after applying water and liquid soap. The decontaminating agents were found to be effective in removing the persistent and adhered radio-contaminant from the skin. The chemical decontamination agents remove contaminants by oxidation, reduction, or chelation mechanisms. Sodium pertechnetate metal oxide (TcO_4^-) bonds are disrupted by attacking either the metal ion or the surface oxide group. Redox-based acid decontamination agents (oxalic acid, sodium bisulphate, hydrochloric acid) break the oxide lattice by proton (H^+) attack to form surface hydroxyl (OH^-) entities, allowing a hydrated metal ion to solubilize metals. These chemical reactions allow more effective removal of contaminates from the body. Hydrochloric acid solution acts as a strippable coating agent that makes a film, which is then stripped off, carrying with it contamination. Use of concentrated potassium permanganate and sodium bicarbonate solution oxidizes pertechnetates to a soluble form which loosen adhered contamination, resulting in leaching and simple removal.

Results of this study demonstrated the decontamination efficiency of the chemical components of the "Shudhika" kit. Potassium permanganate solution is specific for long-lived α-emitters, and sodium bicarbonate is specific for the uranium contamination, so these were not expected to be of much consequence in the present investigation. Other radiation sources are important radiological threats that terrorists may exploit. In such situations, this kit could be used for skin decontamination. Water is a universal decontamination agent along with liquid soap. The "Shudhika" kit is designed for decontamination of multiple contaminants or for decontamination of occupational workers and responders.

Conclusions and Recommendations

The "Shudhika" Kit consists of chemical decontamination agents that can applied for the decontamination of multiple radioactive isotopes including ^{137}Cs, ^{90}Sr, and ^{60}Co. Contamination which has not been removed from the skin with water irrigation and liquid soap can be reduced to within acceptable limits by using the kit decontamination agents. The kit is recommended for skin decontamination of occupational workers in nuclear medicine and radio-pharmaceutics. The "Shudhika" Kit can be used in multiple field settings for self- or buddy-decontamination. In this study, ^{99m}Tc provided base line data for evaluation of the Kit decontaminates that may be extrapolated to other radioisotopes such as ^{131}I and ^{92}Tl. It was also noted that use of cotton swabs soaked with the chemical decontamination agents allowed for avoiding spread and cross-contamination. It would also be appropriate to use the components of the study kit before decontaminating with water when the water supply is contaminated or water is in short supply.

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