RESEARCH ARTICLE

Low dose radioiodine therapy: A review of dosimetry and evaluation of potential shielding materials for neck collars

S Mubarak¹, D Nanayakkara², C Jayalath¹ and V Sivakumar^{1*}

¹ Department of Physics, Faculty of Science, University of Peradeniya, Peradeniya.

² Nuclear Medicine Unit, Faculty of Medicine, University of Peradeniya, Peradeniya.

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Abstract: Radioactive Iodine (¹³¹I) has become the most widely used radionuclide for the treatment of patients with thyroid cancer in Sri Lanka. This study aims to measure radiation dose rate emitted from the ¹³¹I treated patients at the Nuclear Medicine Unit (NMU), University of Peradeniya, Sri Lanka and synthesise a lead-free material to be used as a shielding collar to minimize the radiation exposure to the family members and the general public. Routinely, an average activity of 1110 MBq (30 mCi) is administered orally to thyroid cancer patients following a thyroidectomy. A total number of 40 patients including 17.5% males and 82.5% females were monitored for radiation dose rate after administering the radioiodine. The dose rate was measured at 1.0 m distance from the patient's neck, after 1 hour of ¹³¹I administration. The results showed moderately high dose rates (mean $50.01 \pm 11.50 \mu\text{Sv h}^{-1}$) from these patients when compared to permissible dose rates to the general public in other countries. Hence, measures should be taken to reduce the dose rates at the releasing time of the patients. Four types of shielding materials were synthesised to make a collar. The best shielding material identified was iodine incorporated silicon-based rubber with a reduction percentage of 38.48%.

Keywords: ¹³¹I treatment, nuclear medicine, radiation protection, shielding materials, thyroid cancer.

INTRODUCTION

According to the World Health Organization (WHO), cancer is the second leading cause of death globally and is responsible for an estimated 9.6 million deaths in 2018

(Bangkok Post, 2019; Ulinskiene *et al.*, 2019; Sharma *et al.*, 2020; WHO report, 2020). Approximately 70% of the deaths from cancer occur in low and middle-income countries (Sloan & Gelband, 2007; GHEC, 2008; Bray *et al.*, 2018; Knaul *et al.*, 2018; WHO report, 2020). According to the American Cancer Society (ACS), thyroid cancer has seized the ninth place in worldwide rankings for incidence (Bray *et al.*, 2018). As claimed by the International Agency for Research on Cancer under the supervision of WHO, thyroid cancer is the fifth most common cancer among Sri Lankans in 2018 (GLOBOCAN, 2018; Gunasekera *et al.*, 2018). Also, it is the second most common cancer among women in Sri Lanka (NCCP, 2014; GLOBOCAN, 2018; Jayarajah *et al.*, 2018).

Radioactive iodine (RAI) therapy for thyroid cancer is widely accepted and is the most frequently used treatment modality in the world (Muhammad *et al.*, 2006). ¹³¹I is administered to patients with thyroid carcinoma to ablate residual functioning thyroid tissues as well as to destroy the residual cancer cells after completion of (total or near-total) thyroidectomy (Hackshaw *et al.*, 2007). The administered RAI is absorbed mainly by the thyroid tissues and later excreted by the renal system (Pashnehsaz *et al.*, 2016; Haghighatafshar *et al.*, 2018). The absorbed dose and radiation emission (dose rate) by the thyroid tissues might differ from person to person depending on many factors (Hewamanna *et al.*, 2014).

* Corresponding author (vsiva@sci.pdn.ac.lk; <https://orcid.org/0000-0002-8473-767X>)

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The administration of low dose RAI is relatively inexpensive and convenient for the patient with minimum side effects (Muhammad *et al.*, 2006). However, one of the risks of using ^{131}I to treat thyroid cancer is that the patients may act as a mobile radiation source. If precautions were not taken, radiation exposure to family members, caregivers and the general public is inevitable. Thus, standard regulations are made when releasing those patients from the hospital. According to the International Atomic Energy Agency (IAEA) Safety Series No. 63 (IAEA, 2009; HERCA, 2010), patients should not be discharged from the hospital unless the ^{131}I activity is less than or equal to 1100 MBq (~ 30 mCi). At the same time, some countries follow the safety level of 400 MBq (~ 11 mCi) as a measure of good practice (IAEA, 2009). Table 1 gives a list of some countries, that discharge RAI administered patients on activity basis (Brian, 2014).

Table 1: Activity based release criteria followed by some countries after RAI administration

Country	Activity at the time of release [MBq (mCi)]
China	400 (10.8)
France, United Kingdom, Poland, Spain, New Zealand	800 (21.6)
Germany	250 (6.8)
Malaysia, Bangladesh	1100 (29.7)

Some countries use the dose rate measured at a fixed distance as a criterion for releasing patients (Zanzonico *et al.*, 2000; Hewamanna *et al.*, 2014). The fixed distance may vary from 1–2 m away from the patient, e.g. Poland measures the dose rate at 1.0 m from the patient whereas Germany measures at 2.0 m distance (Brian, 2014). However, in any case, at the time of release, ^{131}I treated patients are strictly advised on necessary precautions to be taken for the protection of whom they may come in contact with, especially pregnant women and children.

The radiation exposure to the general public from a ^{131}I administered patient mainly depends on the patient's behaviour and understanding of radiation effects as the public is not necessarily aware of the patient's status. Considering the socio-economic conditions, extended family system, nature of the job, mode of transportation, and cultural bindings, releasing ^{131}I treated patients is a common problem in this part of the world. Currently, many countries have formed their own criteria for

releasing patients after RAI therapy according to their own necessities (Brian, 2014).

Sri Lanka Atomic Energy Board (SLAEB), the regulatory body of radiation protection in Sri Lanka in compliance with the IAEA recommendations has imposed an activity-based limit of 1100 MBq (~ 30 mCi) at the discharge of ^{131}I administered patients from the hospitals (AEA, 1996). The Nuclear Medicine Unit (NMU) of the University of Peradeniya, which treats only out-patients in concurrence with the regulations of the recently established regulatory council, Sri Lanka Atomic Energy Regulatory Council (SLARC) and treats with an average ^{131}I activity of 1110 MBq (30 mCi).

According to de Klerk (2000), there is a possibility for the caregivers and family members, especially toddlers and pre-schoolers, to exceed the annual maximum dose limit (Radiation Protection 97, 1998) from ^{131}I treated patients during their stay at home. For example, family members can be exposed to radiation by cross contamination while using the same bathroom or washing facilities. Usually, before Iodine administration, the patients are advised on their behaviour during the time of their isolated stay at home. While following these instructions a feasible precaution that could be taken to reduce the exposure risk is covering the neck area of the patient using a suitable shielding material.

Usage of lead collars by radioactive patients has been a known practice in developed countries over the past years, owing to the high blocking ability of lead from gamma radiation. However, due to the disadvantages such as high cost, cumbersomeness, disposal difficulties, lead toxicity, etc. currently, the usage of lead for radiation protection is replaced by other materials (Nambiar & Yeow, 2012; Nambiar *et al.*, 2012; Ambika & Nagaiah, 2017). The main aspects expected in synthesising shielding materials are to be more flexible, comfortable, cost-efficient and non-toxic, so that it could be easily disposed.

In this study, an effort has been made to analyse the measured radiation dose rate at the releasing time of ^{131}I treated patients administered with an activity of 1110 MBq (30 mCi). Moreover, an attempt has been made to synthesise a cost-effective, affordable and lead-free shielding material, which can be used as a collar by the patient. This collar can be used as a radiation protection shield by the ^{131}I treated patients at the releasing time in order to minimize the exposure to the caregivers, family members and the general public.

METHODOLOGY

Dose measurement

Ethics approval was not obtained for this study, as it does not require any extra data other than the regular data collected by the NMU, University of Peradeniya for clinical and other safety purposes. Data did not contain any identifiers, which can reveal the personal identity of the subjects. No changes in protocols were adopted for the benefit of this study.

The study used secondary data of 40 thyroid cancer patients (17.5% males and 82.5% females) who have undergone a total or near-total thyroidectomy and were referred to the NMU of the University of Peradeniya. Patients had been administered with radioactive Iodine (^{131}I) having a mean activity of 1043.4 MBq (28.2 mCi) and a median of 1036 MBq (28 mCi) with a standard deviation (SD) of 61.42 MBq (1.66 mCi).

Dose rates emitted from each patient after 1 hour had been recorded at 1.0 m distance away from the neck,

Figure 1: The figure shows the arrangement to take dose rates at the neck area

while the patient was in a standing position (Figure 1), according to the IAEA protocol (IAEA, 2009). Calibrated, portable dose rate meter type - RadEye™ PRD was used to measure the dose rate in $\mu\text{Sv h}^{-1}$. Here, the readings of the RadEye were cross-checked with a dose rate meter (Nuclear Enterprises Portable Dose Rate Meter Type PDR 1) available at the NMU. The dose rate meter at the NMU is calibrated annually at the SLAEB. Background radiation was subtracted from the measurements.

According to the protocol followed by the NMU, patients are allowed to go home after 1 hour from the time of administration.

Collar material

Polyethylene glycol, ethylene glycol and rubber were used as matrix media for the protective collar. Locally available fillers such as bone powder, calcium and phosphate compounds and elements such as Iodine were systematically incorporated into the matrix media.

The alumina incorporated polymer sample was prepared as follows. Alumina (Sigma-Aldrich) (1.28 g) was vacuum dried using the vacuum oven at a temperature of 50 °C for 2 h and was ground well using an agate mortar and pestle. Polyethylene glycol (Sigma-Aldrich) (5.12 g) and ethylene glycol (Sigma-Aldrich) (1.28 g) dissolved in ethanol was added to a beaker along with the ground alumina and DI water. The mixture was thoroughly mixed using a magnetic stir for 2 h to ensure uniform dispersion of alumina in the mixture and was poured into a mold.

In order to prepare the samples with bone powder, first the chloroprene rubber (commercially available) was mixed with dichloromethane (to reduce the thickness) and a small volume was poured into a Perspex mold to get a thin layer. Then to get a composition ratio

Figure 2: Experimental setup used to calculate the dose rate reduction of the shielding materials prepared

of Ca:P:S:C equals to 6:2:1:1 (wt%), bone powder was dusted upon the chloroprene rubber layer using a metal sieve and allowed to dry. The above-mentioned layers were repeated one after the other until the thickness of 5.0 mm was obtained. The bones were purchased from the local market and were powdered using a laboratory ball mill and sieved using a sieve shaker machine.

To prepare the iodine incorporated silicon rubber (Dow Corning) sample, 20 mL of slime-6178 base and 0.30 mL of catalyst-9600 (1.5% volume of the slime) were mixed in a beaker. Iodine crystals (5 g) (99%, C&G chemicals) were powdered and added to the beaker. The mixture was poured into a Perspex mold and allowed to dry. In all the samples the filler to matrix medium weight ratio was maintained around 1:4 ratio.

Out of the material combinations used, silicon-rubber-based media incorporated with iodine powder (I_2 , 99%, C&G chemicals) and bone powder (purchased from the local market) gave the best shielding ability. The collar was tested using a ^{131}I source while keeping the collar very close to the source and measuring the dose rate at 1.0 m away from the collar using the same dosimeter (Figure 2).

Figure 3: Prototype collar prepared from iodine incorporated Si-rubber

Usage of collar

Figure 3 depicts the usage of a collar (not with a real patient) that contains the shielding material to cover the thyroid gland. In this prototype, the material blocks the radiation emitted from the front part of the neck. However, it is possible to make the entire collar using the same material so that it can cover the entire neck region. It must be noted that, similar to previously reported studies (Grigsby *et al.*, 2000; Loutfi *et al.*, 2003), testing the collar with real patients and exposure to caregivers

and household members were not undertaken as it required ethical approval.

RESULTS AND DISCUSSION

Dose rate readings

Forty patients were included in the study. The study population consisted of 17.5% males and 82.5% females, ranging in age from 17 to 71 years (mean 40.3 ± 13.16 years). Mean activity of 1043.4 MBq (28.2 mCi) [SD 61.42 MBq (1.66 mCi)] ^{131}I was administered to the patients. The mean dose rate measured at a 1.0 m distance from the patient's neck area after 1 hour of ^{131}I administration was $50.01 \mu Sv h^{-1}$ (SD $11.50 \mu Sv h^{-1}$) with the range 37.3–80.0 $\mu Sv h^{-1}$. By using the reported effective half-life of 5.5 days for ^{131}I by Hewamanna *et al.* (2014), the calculated mean activity after 1 hour of post administration was 1037.94 MBq (28.05 mCi).

A histogram of the normalized dose rate ($\mu Sv /h$ MBq) of each patient at 1.0 m distance at the time of discharge is given in Figure 4. The histogram shown in Figure 5 represents the fluctuation of the dose rate values ($\mu Sv h^{-1}$) at the time of discharge, measured at 1 m distance along with dose rate limits at the discharge practiced in some countries. Also, the figure shows the deviation of the above dose rate limits with respect to the mean value of our measured dose rates. These deviations show that the mean of dose rates measured at the release of the patients at the NMU of University of Peradeniya is moderately high.

Over the past decade, total or near-total surgical removal of the thyroid gland (thyroidectomy) followed by radioactive iodine therapy for ablation of remnant thyroid cells has been the standard treatment for differentiated thyroid cancer (Hewamanna *et al.*, 2014; Pacini *et al.*, 2015). The main concern of using RAI is the radiation exposure risk to the caregivers and the general public due to the ionizing radiation emitted from the ^{131}I administered patients.

Previous studies conducted in Sri Lanka on radiation dose rates emitted from the ^{131}I treated patients were on in-ward patients who received high dose RAI from 3700–11100 MBq (100–300 mCi) at various radiation therapy units (Hettiarachchi, 2008) and at the National Cancer Hospital in Sri Lanka (Hewamanna *et al.*, 2014). For the first time, this study reveals the dose rates emitted from the patients who received low dose 1100 MBq (30 mCi) RAI as out-patient basis at NMU, University of Peradeniya, Sri Lanka.

Figure 4: Histogram of the normalized dose rate ($\mu\text{Sv/h MBq}$) of each patient measured at 1.0 m distance at the time of release

Figure 5: Measured radiation dose rates ($\mu\text{Sv h}^{-1}$) emitted from each patient at 1.0 m distance at the time of release (on the left axis) and the percentage difference (%) of dose limits practiced in some countries with respect to the mean of the measured dose rate (on the right axis).

¹ Lee *et al.*, 2010; ² Nosheen *et al.*, 2016; ³ Zhang *et al.*, 2014; ⁴ Brian, 2014; ⁵ IAEA, 2009; ⁶ Muhammad *et al.*, 2006; ⁷ Al-Maskery & Bererhi, 2009

Figure 4 proclaims a histogram of the normalized dose rate ($\mu\text{Sv/h MBq}$) of each patient measured at 1.0 m distance at the time of release. Here, the emitted dose rate per unit of administered activity has been calculated for each patient involved in this study. Previous studies (Hewamanna *et al.*, 2014) have pointed out that many variables such as the administered ^{131}I activity, patient's gender, age, body weight, percentage of remnant thyroid cells, that differ from patient to patient affect the dose rates emitted from these patients. In our study too, one could observe the variation in the emitted dose rate from the ^{131}I treated patients. We did not excogitate the emitted dose rate dependency on them, as it was not the scope of this study. However, Figure 4 and 5 indicates important information on radiation protection purpose considering that it is directly linked to the risk of managing these ^{131}I treated patients.

According to Hewamanna *et al.* (2014) some studies conducted on discharged patients administered with more than 1110 MBq (30 mCi) ^{131}I have concluded that for most of the patients, 35–75% of the ^{131}I is cleared from the body within the first 24 hours. According to Memon *et al.* (2017), the recommended dose rate on discharging ^{131}I treated patients to avoid unwanted radiation exposure to family members was around 20–30 $\mu\text{Sv h}^{-1}$ at 1.0 m distance. Barrington *et al.* (1996) recommended that ^{131}I administered patients should be separated from children less than 2 years of age for at least 16 days. It has been calculated that the dose to such a child if the advice is not heeded, will be 33 mSv which is a considerably high value compared to the annual maximum dose limit for children (1 mSv y^{-1}) (Barrington *et al.*, 1996; Radiation Protection 97, 1998; Memon *et al.*, 2017). The same implies to the working staff and the caregivers who are being exposed, yet the maximum instructed limit for them is 5 mSv y^{-1} (Radiation Protection 97, 1998). According

to the protocols followed at the National Cancer Institute (NCI) of Sri Lanka, all the patients are discharged from the hospital only when the dose rate measured at 1.0 m from their bodies is less than 30 $\mu\text{Sv hr}^{-1}$ (Hewamanna *et al.*, 2014).

Complying with the regulations of SLARC, patients administered with ^{131}I are discharged with strict instructions only if the activity is less than or equal to 1110 MBq (30 mCi) (AEA, 1996). Moreover, ^{131}I administered patients are observed 1 hour after the administration as a routine practice at the NMU premises.

It is visible that the dose rate values emitted from the ^{131}I administered patients from NMU are greater than that of most countries recommended value on discharging the patients from the hospitals (Figure 5). Thus, as a precautionary measure to this problem; we have suggested using a protective collar by the patients to reduce the emitted dose rate to a certain extent. This is in addition to the radiation protection advice given to the patients at the time of discharge.

Shielding materials

The materials synthesized incorporating different kinds of composites are presented in Table 2. Here, these sample materials were tested using a ^{131}I source (~ 10 mCi) that emits gamma rays at an average photon energy of 360 keV. The prepared samples were categorised into 4 main types; alumina incorporated polymers, bone composition with chloroprene rubber, bone powder with chloroprene rubber, and iodine incorporated silicon rubber. The maximum reduction percentage of radiation (1) calculated for each type of sample using equation is also shown in Table 2. Here, the measurements were taken while using the materials as a shield in front of the source (Figure 2) and without using any shield.

$$\text{Reduction} = \frac{(\text{dose rate before shielding}) - (\text{dose rate after shielding})}{\text{dose rate before shielding}} \times 100\% \quad \dots(1)$$

Table 2: The maximum reduction percentage of different types of samples prepared

Material	Thickness (mm)	Maximum reduction (%)
lumina incorporated polymer	4.21	6.75
Bone composition with chloroprene rubber	4.21	22.79
Bone powder with chloroprene rubber	4.02	30.10
Iodine incorporated Si-rubber	5.21	38.48

In this study, the first collar material was prepared by incorporating alumina into a biocompatible polymer matrix where it gave a dose rate reduction of 6.75% while measuring at 1.0 m distance from the ^{131}I source (Figure 2). Commercially available chloroprene rubber incorporated with different compositions of calcium and phosphate (to obtain bone composition) gave reduction percentages that varied from 14% to 23%. The maximum reduction 22.79% was obtained while using Ca: P: S: C ratio 6: 2:1: 1 wt.% (bone composition) along with chloroprene rubber. Actual bone powder incorporated in chloroprene rubber gave a reduction percentage of 30.10%. However, the major drawback of using chloroprene rubber as the matrix medium was that it became harder and rigid when the thickness was increased.

Iodine incorporated silicon rubber-based sample displayed a reduction percentage up to a maximum of 38.48%. To have an inkling, the reduction percentage value was compared with the reported value of He *et al.* (2016), where an evaluation has been performed to find the shielding effectiveness of lead aprons used in nuclear medicine clinics. It has been concluded that depending on whether the aprons are really made of lead or lead equivalent thickness, the reduction percentage might vary between 19–24% for gamma rays with energy of 356 keV. Hence, considering these factors, the reduction percentage obtained for the iodine incorporated silicon rubber-based sample seems to be persuasive. This convincing reduction percentage may be due to the absorption edges of the iodine incorporated (Kane, 2009). In addition to this level of attenuating the radiation, the material is also flexible, and cost-efficient.

CONCLUSION

The results show emission of moderately high dose rates (mean $50.01 \mu\text{Sv h}^{-1}$ and median $47.65 \mu\text{Sv h}^{-1}$ with SD $11.50 \mu\text{Sv h}^{-1}$) from RAI treated patients at the time of discharge from the NMU, University of Peradeniya. In order to minimize the radiation exposure to the general public and caregivers, wearing a neck collar as a radiation shield by these patients is proposed. Among the four types of shielding materials synthesized with the aim of producing a lead-free, flexible and cost-effective collar, the best shielding material was the iodine incorporated silicon-based rubber with a reduction percentage of 38.48%.

Conflicts of interest

The authors have no conflict of interest to disclose.

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