Radiation exposure of the families of outpatients treated with radioiodine (iodine-131) for hyperthyroidism

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Abstract. Patients who receive radioiodine (iodine-131) treatment for hyperthyroidism (195–800 MBq) emit radiation and represent a potential hazard to other individuals. Critical groups amongst the public are fellow travellers on the patient's journey home from hospital and members of the patient's family, particularly young children. The dose which members of the public are allowed to receive as a result of a patient's treatment has been reduced in Europe following recently revised recommendations from ICRP. The annual public dose limit is 1 mSv, though adult members of the patient's family are allowed to receive higher doses, with the proviso that a limit of 5 mSv should not be exceeded over 5 years. Unless the doses received during out-patient administration of radioiodine can be demonstrated to comply with these new limits, hospitalisation of patients will be necessary. The radiation doses received by family members (35 adults and 87 children) of patients treated with radioiodine at five UK hospitals were measured using thermoluminescent dosimeters mounted in wrist bands. Families were given advice (according to current practice) from their treatment centre about limiting close contact with the patient for a period of time after treatment. Doses measured over 3–6 weeks were adjusted to give an estimate of values which might have been expected if the dosimeters had been worn indefinitely. Thirty-five passengers accompanying patients home after treatment also recorded the dose received during the journey using electronic (digital) personal dosimeters. For the "adjusted" doses to infinity, 97% of adults complied with a 5-mSv dose limit (range:0.2–5.8 mSv) and 89% of children with a 1-mSv limit (range: 0.2–7.2 mSv). However 6 of 17 children aged 3 years or less had an adjusted dose which exceeded this 1 mSv limit. The dose received by adults during travel was small in comparison with the total dose received. The median travel dose was 0.03 mSv for 1 h travel (range: 2 μSv-0.52 mSv for 1 h of travel time). These data suggest that hyperthyroid patients can continue to be treated with radioiodine on an out-patient basis, if given appropriate radiation protection advice. However, particular consideration needs to be given to children aged 3 years or younger. Admission to hospital is not warranted on radiation protection grounds.

Key words: Radiation protection – radioiodine – thyrotoxicosis

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Introduction

Radioiodine (iodine-131) is the safest and most effective long-term treatment for hyperthyroidism [1]. There are, however, significant radiation protection issues associated with the treatment. These include emitted radiation and the loss of radioiodine in urine, sweat, saliva and breast milk**.** Those at potential risk of being irradiated are members of the public with whom the patient may come into close proximity. Children are regarded as being at greatest risk because they have a longer life expectancy than adults, growing tissues are more radiosensitive [2] and close contact between young children and their parents may be difficult to avoid. Contamination by radioactive secretions/excretions can usually be prevented by avoiding physical contact with the patient in the first few days after treatment, and any dose received is small in comparison to that which may be received through emitted radiation [3–5].

Legislation requiring the dose received by the public to be limited has recently been revised following recom-

mendations by the International Commission on Radiological Protection (ICRP) to reduce the annual dose to a member of the public from 5 mSv to 1 mSv [6]. Radiation exposure in excess of this limit may, however, be considered acceptable provided it is received by individuals "knowingly and willingly helping in the support and comfort of individuals undergoing medical exposure (comforters and carers)" [7–9]. The Basic Safety Standard (BSS) issued by the European Commission (EC) permits the dose limit of 1 mSv to be exceeded in 1 year, provided the average over 5 years does not exceed 5 mSv [8]. However, to keep the dose as low as reasonably achievable for these individuals, it suggests that "dose constraints should be used, where appropriate". Dose constraints are intended to act as ceiling levels, which are not expected to be exceeded, but which are not legally binding. The dose constraints suggested in a recent EC guidance document are linked to age and are aimed at taking into account radiation received from other man-made sources [10]. A dose constraint of 3 mSv per treatment has been proposed for relatives, including children, over the age of 10 years, with a higher dose constraint of 15 mSv for relatives over the age of 60. The dose constraint for children under 10 years is set at 1 mSv. A dose constraint of 0.3-mSv for members of the general public such as fellow passengers has been proposed.

There are considerable differences as to how these dose limits are enforced in Europe at present [11]. Guidelines in some countries such as Germany, Switzerland and the Czech Republic mean hyperthyroid patients receive radioiodine as in-patients; other European countries and the United States offer out-patient treatment with advice given to minimise subsequent close contact with other individuals. If revised lower dose limits cannot be achieved during out-patient therapy, admission will result in a significant increase in hospital expenditure for those countries currently offering out-patient treatment.

The data available on which to base unified European advice and restrictions are inadequate [11, 12]. The current UK guidelines impose restrictions based on arbitrary amounts of radioactivity retained within the patient which bear little relation to the dose received by other individuals [5, 12, 13]. Guidelines in the United States assume continuous exposure to a radioactive source at a constant distance over time [9] and take no account of the biological behaviour of radioiodine. Individual investigators have attempted to improve on the current UK guidance, combining the fall in external dose-rate from treated patients with different models of social behaviour to give an estimate of the integral dose [5, 14]. However, measurements of the actual dose received over time from treated patients by a large number of members of the public would provide a more substantive basis on which to formulate appropriate guidance. Monsieurs et al. [15] have attempted to ascertain the integral dose to family members by performing dose measurements over a limited period of 1–2 weeks. However, they did not investigate travel doses to members of the public nor the doses to young children (the mean age of their "children" was 18 years).

The purpose of this study was to measure the doses received by fellow travellers and family members of hyperthyroid patients treated with radioiodine as out-patients, including children, while following existing UK guidelines, to determine wheter these doses complied with revised European Community limits [2, 8].

Materials and methods

Families of out-patients receiving ^{131}I for hyperthyroidism were recruited at five UK centres (North Staffordshire Hospital, Stoke-on-Trent; the City and the Queen Elizabeth Hospitals, Birmingham; St. Thomas' Hospital, London and the Kent and Canterbury Hospital, Canterbury).

Family members wore hospital name bands on both wrists containing a lithium fluoride thermoluminescent dosimeter (TLD) which has a uniform energy response for the energies of ^{131}I. Some very young children wore the bands on their ankles so that they could not get their fingers caught in the wrist band. The bands were worn continuously after treatment for a period of 3–6 weeks.

Patients were given advice about restricting close contact with other individuals following the standard procedure for the individual centre. The advice given by centres 1–3 was based on UK national guidelines derived from measurements of the rate of clearance of radioiodine from the patient after treatment and is shown in Tables 1, 2 (advice A) [13, 16, 17]. These guidelines consist of the times for which the patient has to adhere to certain restrictions [16]. These times depend on the administered activity, the levels of retained radioactivity above which the patient has to restrict his or her behaviour [13], and the effective half-life assumed for the retained radioactivity [16]. Advice A was intended to comply with a dose limit of 5 mSv for adults and 1 mSv for children. The advice given by centres 4 and 5 was based on an earlier dosimetry study and is shown in Tables 1, 2 (advice B) [5]. This advice was designed to combine measurements of dose rates from patients with social behaviour models. Advice B was intended to comply with a dose limit of 1 mSv for both adults and children and tended to be more restrictive on contact with adults but less restrictive on contact with older children. It should be noted that for very young children, under the age of 3 years, the advice did not really differ between centres.

The TLDs were analysed by an Approved Dosimetry Service (ADS) independent of the recruiting centres**.** The dose received by an individual was taken as the higher of the two doses recorded on each wrist (or ankle). Each individual was assumed to have received at least 0.2 mSv as this is the minimum dose that can be recorded on the TLD. Doses received were adjusted for the time period the TLD was worn to give an estimate of the expected values had the TLDs been worn indefinitely (i.e. dose to infinity). All doses given in this paper refer to this "adjusted absorbed dose". An effective half-life of 5.8 days was used to describe the decrease in dose rate [5].

The adjusted absorbed dose was calculated according to the following equation:

$$D_2 = -D_1 / (e^{-\lambda x} - 1),$$

Table 1. Different advice given to patients to restrict behaviour with adults after administration of radioiodine. advice A was offered by centres 1–3 and advice B was offered by centres 4 and 5. Length of restrictions applied is shown in whole days [5, 13, 16]

Activity of ^{131}I (MBq)	Avoid work if time spent in close proximity (closer than 1 m) to one individual		Avoid visiting places of entertainment or journeys on public transport >1hour		Time patient should sleep alone in separate bed	
	A	B	A	B	A	B
200	1	0	1	0	1	15
400	5	3	5	0	5	20
600	9	6	9	7	9	24
800	12	8	12	7	12	26

Table 2. Different advice given to patients to restrict behaviour with children after administration of radioiodine. advice A was offered by centres 1–3 and advice B was offered by centres 4 and 5. Length of restrictions applied is shown in days [5, 13, 16]

Activity of I-131 (MBq)	Avoid close contact with children (closer than 1 m)		
	A (advice given irrespective of child's age)	B (advice given dependent on child's age in years)	
200	14	Less than 2	15
		2–5	11
		Over 5	5
400	21	Less than 2	21
		2–5	16
		Over 5	11
600	24	Less than 2	25
		2–5	20
		Over 5	14
800	27	Less than 2	27
		2–5	22
		Over 5	16

where D_2 is the absorbed adjusted dose, D_1 is the absorbed measured dose during the number of whole days (x) for which the TLD was worn, λ is the dose rate constant and $\lambda=0.693/t_{1/2}$.

Relatives accompanying patients for treatment were also asked to wear electronic digital personal dosimeters on the journey home (all Aloka PDM 102 calibrated by one centre against ^{131}I). The doses were scaled to take account of the position of the patient and accompanying person in the car and converted from a surface entry dose to a mean whole-body dose using an attenuation factor determined experimentally as follows:

A tissue-equivalent anthropomorphic Rando phantom was positioned 1 m from a ^{131}I point source (activity 1.7 GBq) to represent a driver or a relative accompanying a patient home in a car. Two electronic (digital) personal dosimeters (EPDs) were placed on the Rando phantom (a) at the posterior midline and (b) posteriorly to the left of the spine nearest the source position, and exposed to the source for 30 min. The mean of these readings was taken as an entrance dose estimate. The exit dose was measured simultaneously with an EPD on the anterior midline of the phantom. Three readings were taken and the ratio of the exit to mean entrance doses was estimated at 0.20, 0.20 and 0.22, giving a mean exit to entrance dose ratio of 0.21.

The mean whole-body dose was estimated with reference to the entrance dose by assuming that the dose decreased exponentially and according to the inverse square law as it traversed the driver's body, and that the integral dose below this profile could be used to approximate the mean whole-body dose. Using this simple approach, the effective dose was approximately 0.50 of the entrance dose, and 2.4 times the exit dose.

Statistical analysis. Analysis of the differences in activity of radioiodine administered and age of the children between centres offering advice A and those offering advice B was done using Wilcoxon rank sum tests. As the doses had an approximate log-normal distribution, linear regression on the log of the doses was used to determine the ratio of doses between the centres offering advice A and those offering advice B. As doses were measured to an accuracy of 0.1 mSv, interval regression [18] was used with robust standard errors [19].

Results

Fifty-one families participated in the study, comprising 35 adults and 87 children. Children ranged in age from 5 months to 17 years (mean=8 years). In some families, there was uncertainty as to the exact date when TLDs were removed and these measurements were excluded when the dose to infinity was calculated. There were no significant differences in the activity of radioiodine administered to patients, or in the age of the children recruited, between centres offering advice A or B.

The doses received by the adults are shown in Table 3 and graphically in Fig. 1. With a single exception, all the adults received less than the proposed European dose constraint for adults of 3 mSv.

Table 3. Doses received by adult family members (n=31) related to the number of whole days during which the TLDs were worn and the activity of radioiodine administered to the patient

	Activity (MBq)	Days TLDs worn	Dose (mSv)
Minimum	200	9	0.2
Maximum	608	42	5.8
Median	388	21	0.5

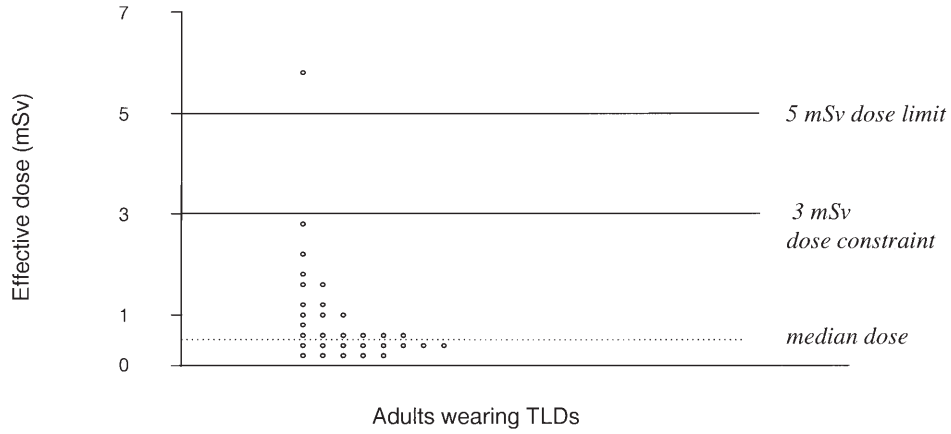

Fig. 1. Dot-plot showing the radiation doses received by the adults relative to revised dose limits. The median dose received is shown by the *dotted line*

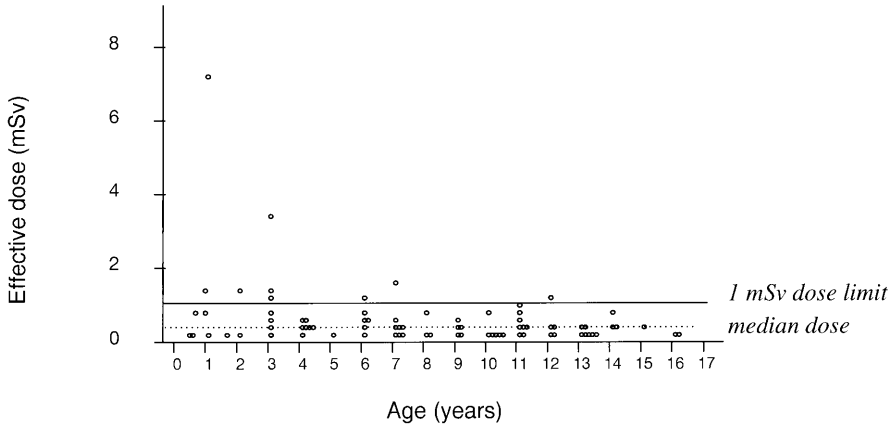

Fig. 2. Dot-plot showing the radiation doses received by the children relative to revised dose limits. The median dose received is shown by the *dotted line*. The children's ages are shown in years

Table 4. Doses received by children (n=79) related to the number of whole days during which the TLDs were worn, the children's ages and the activity of radioiodine administered to the parent

	Activity (MBq)	Days TLDs worn	Age (years)	Dose (mSv)
Minimum	195	6	0.4	0.2
Maximum	800	47	17	5.8
Median	377	21	8	0.5

The doses received by children are shown in Table 4 and according to age in Fig. 2. Eighty-nine percent of children complied with the 1-mSv dose limit, but 6 of the 17 children aged 3 years or younger received more than 1 mSv. If children over 3 years only are considered, 94% received 1 mSv or less.

Adults at centres offering advice B (which was more restrictive and aimed at a 1-mSv dose limit) received lower doses than those at centres offering advice A. The median adult dose at centres offering advice B was 32% of the dose at centres offering advice A (95% confidence interval: 20%–52%, P<0.0001). Children at centres offering advice B (which was less restrictive on children over 2 years) also received lower doses than those at centres offering advice A. The median dose to the children at centres offering advice B was 63% of the dose at centres offering advice A (95% confidence interval: 46%–88%, P=0.007). If, however, children over the age of 3 years only are considered in the analysis, then there was no significant difference in the median doses between centres.

Travel data were obtained from 35 passengers. Thirty-three travelled in private cars, one by taxi and one by train. The median activity administered to patients whose relatives accompanied them home was 400 MBq (range: 195–800 MBq). The median journey time was 30 min (range: 6–125 min). The median whole-body dose recorded was 0.03 mSv during the first hour of the journey (range: 2–520 μSv). The maximum dose received was recorded by a passenger in a car where the maximum distance between seating was only 71 cm (diagonal distance between the driver and the patient in the near-side back seat), whereas a typical distance between these seats in a modern car is 115 cm. The next highest dose recorded was 0.25 mSv.

Discussion

Ninety-seven percent (30/31) of "comforters and carers" and 89% (70/79) of children in our study received "adjusted" doses of less than 3 mSv and 1 mSv respectively. This was achieved despite adopting a conservative approach to the analysis of the data, with the higher of two

wrist TLD readings being taken in all cases and a minimum recordable value of 0.2 mSv assumed. It is possible that wearing the wrist bands may have heightened the awareness of the study population to the need for radiation protection, but it is difficult to see how measurements can be performed in social situations without the knowledge of those taking part. Even if wearing the TLDs did affect the magnitude of the doses, the study still demonstrated that family members who comply with restrictions can reduce their dose to less than 1 mSv in the case of children and 3 mSv in the case of adults.

We cannot explain satisfactorily why two children in the study received high doses of 3.3 mSv and 7.2 mSv respectively. However, it can be seen from Fig. 2 that these two doses lay well above the rest of the measurements. Both were young children (aged 1 and 3 years respectively) and were likely to have spent more time in close contact with their mothers than was recommended. However, the mothers did not report any deviations from the advice about restricting close contact despite requestioning after the results were known. Six of the nine children who exceeded the 1 mSv dose limit were also 3 years of age or younger. Parents of two of the nine recorded deviations from advice. The mother of a 7-year-old child who received an adjusted dose of 1.6 mSv slept alongside the child in the same bed on two nights, 12 and 21 days after treatment. The father of a 2-year-old child who received an adjusted dose of 1.4 mSv carried the baby for prolonged periods on family outings for the 2 days immediately after treatment and recommenced bathing and dressing the child from 13 days after treatment onwards. Despite having a diary in which to record episodes of close contact, the parents of the other children did not report any such episodes. This suggested that any such "close" periods were probably brief and part of a normal daily contact, but they were clearly sufficient to increase the radiation dose. Treatment of parents with very young children, perhaps aged 3 years or under, might be best delayed or alternative treatments considered.

The doses received during travel in a private car were small in comparison to the total dose received by adults, and well within the proposed European dose constraint for members of the general public of 0.3 mSv. However, the time of hospital discharge in the United Kingdom is based purely on the potential exposure of fellow passengers, whereas the majority of the dose received is likely to be from partners sleeping together [5, 15]. These findings indicate that restrictions are unnecessary for private transport although the closer seating of public transport might require some restriction.

This study was not designed to test which of two sets of advice should be applied. The institutions involved each felt comfortable with the advice they were offering and how that advice had been formulated. There was also a difference in ethos, with centres offering advice B wishing to comply with a 1-mSv limit for all family members, rather than accepting a higher limit for adults. It was therefore felt to be neither reasonable nor ethical to change the practice of the individual institutions for the purpose of this study and to insist on the same advice. Nevertheless, certain observations may be made from the data. advice B to adults was more restrictive than advice A and adults given advice B received statistically lower doses. Overall, children received statistically lower doses at centres offering advice B, which was less restrictive for older children. However, when children of 3 years or younger were excluded from the analysis, no difference was observed according to advice. As the advice differed very little in this younger age group between centres, it is likely that the reason why there was a difference in the doses received, related to problems with compliance rather than the advice given. It may be that at centres offering advice B, where the advice was specifically tailored to the age of the child, more emphasis was placed on stressing the length of restrictions necessary when there were very young children in the family. Five of the six children (under the age of 3 years) who exceeded the 1-mSv dose limit came from centres giving advice A, but one of the outliers who received 3.2 mSv came from a centre offering advice B.

Our results indicate that a 3-mSv dose constraint for adults and a 1-mSv dose limit for children over the age of 3 years can be successfully complied with whichever set of advice is used, and the less restrictive of the two options could be given.

Patients receiving administered activities of 200 MBq, 400 MBq, 600 MBq or 800 MBq should be advised to sleep alone for 1, 5, 9 or 12 days for their partners to comply with a 3-mSv dose constraint. Patients with children receiving 200 MBq, 400 MBq, 600 MBq or 800 MBq should be advised to avoid contact closer than 1 m with children aged over 3 years but under 5 years for 11, 16, 20 or 22 days respectively or with children aged over 5 years for 5, 11, 14 or 16 days respectively.

Compliance with these restrictions would ensure that nearly all children would receive less than 1 mSv as a result of a single treatment to a parent. This assumes that the dose limit of 1 mSv is applied to all children under 16 years of age, rather than 10 years as proposed in European Commission guidance [10]. Authors of this study feel that it is inappropriate to apply the term "knowingly and willingly", as used in the ICRP recommendations, to children as young as 11 years [6].

If a subsequent treatment were to be required within 1 year, then the proposals in the Basic Safety Standard for an average dose of 5 mSv over 5 years would still allow further treatment in the majority of patients [8]. advice would need to be sought from a Radiation Protection Advisor to comply with the 5-mSv limit.

The doses recorded in our study for adults are similar to those reported in other studies [15, 20, 21]. Monsieurs et al. recently reported median "adjusted" doses to partners of out-patients of 0.78 mSv (range: 0.00–6.00 mSv)

and 0.80 mSv (range: 0.07–2.11 mSv) (groups distinguished according to duration of separate sleeping) where the patient was hospitalised for 2–5 days [15]. The patients in their study came from several centres in Belgium where different restrictions applied, and at least three sets of different advice were given to hyperthyroid patients and their families. advice was not tailored according to the activity administered. As might be expected, there was a trend for the doses received to be lower in relatives of patients who observed longer restrictions. The only group that complied with a 1-mSv limit avoided close contact for 21 days. The variety of restrictions applied to the patients in the study of Monsieurs et al. is likely to make it difficult to formulate comprehensive guidelines for patients treated with radioiodine without resorting to lengthy restrictions. However, the difficulty in applying identical restrictions across several institutions, as discussed above in our study, is acknowledged. Monsieurs et al. felt that period of restriction of 7 days for "comforters and carers" is too short while a period of 21 days is too long; a compromise of 14 days was proposed. This recommendation was offered irrespective of the activity of ^{131}I, provided 200 MBq or over was administered to the patient. Our results indicate that this proposal is excessive, and that close contact between adults including separate sleeping arrangements could range from as little as 1 day for 200 MBq to up to 12 days for 800 MBq. There was no difference in the dose received by partners of out-patients compared with partners of in-patients in the study of Monsieurs et al. [15]. This supports our findings that the partners of patients treated as out-patients can successfully comply with a 3-mSv dose constraint and that hospitalisation is not warranted on radiation protection grounds. It is surprising, therefore, that a period of hospitalisation of up to 3 days is included in the recommendations by Monsieurs et al.

It is difficult to compare the doses received by the "children" in Monsieur's paper with our own who are probably a different study population. "Grown-up" sons and daughters, provided they were members of the patients' household, were included as "children" by Monsieurs et al. The mean age of the 27 "children" of hyperthyroid patients studied was 18 years. This suggests a significant proportion were over 18 years and therefore this was not a true paediatric population. Children younger than 7 years were advised to stay with relatives for a minimum of 5 days. In our study, the mean age of the 89 children was 8 years and 17 children were aged 3 years or younger. Older children should be able to understand the need to limit close contact with a parent and may spend a considerable time away from home at school. We were concerned, therefore, to recruit as many families with very young children as possible. The conclusion drawn by Monsieurs et al. that "advising children under the age of 7 to spend 5 days at family or friends leads to a significant dose reduction" is not supported by the data presented in their paper, although we would prefer not to treat as out-patients parents of children of 3 years or younger unless arrangements can be made for the children to stay with other relatives after treatment. Apart from the paper by Monsieurs et al., only two studies have reported measurements on children under 18 years where close contact with parents was restricted. In these two studies, from a total of 26 children, the maximum dose recorded (observing 3 weeks' restriction on close contact) was 0.9 mSv [20, 21].

Conclusions

It is concluded that:

1. Patients receiving radioiodine for hyperthyroidism may be safely treated as out-patients with activities up to 800 MBq provided they follow sensible advice about limiting close contact with other individuals without exceeding the revised lower ICRP dose limits.
2. Patients receiving administered activities of 200 MBq, 400 MBq, 600 MBq or 800 MBq should be advised to sleep alone for 1, 5, 9 or 12 days for their partners to comply with a 3-mSv dose constraint.
3. Parents receiving 200 MBq, 400 MBq, 600 MBq or 800 MBq should be advised to deliberately avoid contact closer than 1 m with children aged 3–5 years for 11, 16, 20 or 22 days respectively or with children aged over 5 years for 5, 11, 14 or 16 days respectively in order to comply with a 1-mSv limit.
4. Admission to hospital may only need to be considered when patients have children aged 3 years or younger, and arrangements cannot be made for an alternative carer for the child. Such patients should not pose a radiation risk to other members of their family.
5. This study has demonstrated that the UK restrictions used for the current higher activity limits can be relaxed for passengers using private transport and for older children without exceeding the lower dose limits.

Countries should consider these conclusions when formulating new guidelines to comply with statutory requirements based on the revised ICRP limits.

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