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Administered Radiopharmaceutical Doses in Children: A Survey of 13 Pediatric Hospitals in North America

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Universally applied standards for administering radiopharmaceutical doses in children do not presently exist. Hence, pediatric radiopharmaceutical dosimetry varies considerably from institution to institution and is generally based on the recommended adult dose adjusted for body mass. **Methods:** We surveyed 13 pediatric hospitals in North America to obtain objective data on dosimetry practices for 16 pediatric nuclear medicine examinations, including the minimum total radiopharmaceutical administered dose per examination, the total administered dose based on body mass, and maximum total doses in children. **Results:** The reported administered doses of radiopharmaceuticals to children vary over a relatively large range, especially with respect to minimum total administered doses. **Conclusion:** This survey has identified a broad range of administered doses directly leading to variability in radiation-absorbed doses to patients. The nuclear medicine community should develop pediatric standards for radiopharmaceutical administered doses and reduce radiation exposure in children, such as through the use of modern software reconstruction techniques.

Key Words: pediatric radiopharmaceutical doses; children; pediatric nuclear medicine

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It is generally agreed that radiopharmaceutical administered doses in children should consist of the lowest activity that will result in a satisfactory examination. Activities that are too high and do not add diagnostic information deliver unnecessary radiation exposure. Conversely, activities that are too low may result in inadequate studies and cause unnecessary radiation exposure.

Over the past 3 decades, administered doses in pediatric nuclear medicine have evolved through clinical experience, taking into account the radiation-absorbed dose to the patient, the type of study required, available photon flux, instrumentation, and amount of time needed to perform the examination. Estimates of administered activities for children older than 1 y have typically been based on the recommended adult dose, corrected for body mass or body surface area.

The concept of minimum total administered radiopharmaceutical activity is understood as the activity needed to achieve an adequate examination regardless of the patient's body mass or surface area. This is of particular importance when imaging premature infants and newborns. Several factors should be considered when determining the minimum total dose. For example, rapid dynamic studies require a higher administered activity than do static studies (*1*). Most radiopharmaceutical package inserts, however, do not provide guidelines on administered doses for pediatric patients.

In the absence of universally accepted standards on pediatric radiopharmaceutical administered doses, practice varies widely across institutions. To obtain objective data on such variations, we surveyed 15 North American pediatric institutions, 13 of which (including Children's Hospital Boston) responded to our queries. Survey results are summarized below.

MATERIALS AND METHODS

Fifteen pediatric institutions in North America were contacted and asked to provide information on their respective approaches to administered radiopharmaceutical doses for children. They were asked to complete a survey for 16 pediatric nuclear medicine examinations. The data requested for these procedures included the minimum and maximum administered activities, the schedule used in determining the appropriate administered activity as a function of patient size, and the corresponding factor that is applied (e.g., activity per kg [MBq/kg] or activity per body surface area [MBq/m^2]). The data received were tabulated and summarized. The specific dose schedules of individual institutions are considered confidential and have been purposely omitted in this analysis.

RESULTS

The 13 institutions that responded to our survey provided information on their respective radiopharmaceutical administered dose schedules (see "Acknowledgments"). These

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TABLE 1
Study Data

Radiopharmaceutical	Parameter	Number of respondents	Minimum	Maximum	Median	Mean
^{99m}Tc-dimercaptosuccinic acid (DMSA)	Activity/mass, MBq/kg (mCi/kg)	8	1.11 (0.030)	3.70 (0.100)	2.22 (0.060)	2.35 (0.064)
	Minimum activity, MBq (mCi)	11	5.55 (0.150)	74.00 (2.000)	18.50 (0.500)	26.40 (0.714)
	Maximum activity, MBq (mCi)	11	74.00 (2.00)	222.00 (6.000)	185.00 (5.000)	151.36 (4.091)
^{99m}Tc-mercaptoacetyltriglycine (MAG3)	Activity/mass, MBq/kg (mCi/kg)	8	1.85 (0.050)	10.36 (0.280)	5.55 (0.150)	5.69 (0.154)
	Minimum activity, MBq (mCi)	12	18.50 (0.500)	148.00 (4.000)	37.00 (1.000)	53.96 (1.458)
	Maximum activity, MBq (mCi)	13	111.00 (3.000)	370.00 (10.000)	370.00 (10.000)	278.92 (7.538)
^{99m}Tc-methylene diphosphate (MDP)	Activity/mass, MBq/kg (mCi/kg)	8	7.40 (0.200)	13.32 (0.360)	11.10 (0.300)	10.87 (0.294)
	Minimum activity, MBq (mCi)	13	22.20 (0.600)	185.00 (5.000)	92.50 (2.500)	99.90 (2.700)
	Maximum activity, MBq (mCi)	13	666.00 (18.000)	925.00 (25.000)	740.00 (20.000)	819.69 (22.154)
^{99m}Tc-diisopropyl iminodiacetic acid (DISIDA)	Activity/mass, MBq/kg (mCi/kg)	7	1.85 (0.050)	3.70 (0.100)	2.78 (0.075)	2.97 (0.080)
	Minimum activity, MBq (mCi)	13	14.80 (0.400)	74.00 (2.000)	37.00 (1.000)	36.17 (0.978)
	Maximum activity, MBq (mCi)	13	92.50 (2.500)	370.00 (10.000)	185.00 (5.000)	200.65 (5.423)
^{123}I-metaiodobenzylguanidine (MIBG)	Activity/mass, MBq/kg (mCi/kg)	7	5.18 (0.140)	7.40 (0.200)	5.55 (0.150)	5.45 (0.147)
	Minimum activity, MBq (mCi)	11	37.00 (1.000)	185.00 (5.000)	37.00 (1.000)	75.68 (2.045)
	Maximum activity, MBq (mCi)	13	296.00 (8.000)	370.00 (10.000)	370.00 (10.000)	360.04 (9.731)
^{99m}Tc-$NaTcO_4$ (for Meckel's diverticulum)	Activity/mass, MBq/kg (mCi/kg)	7	1.63 (0.044)	5.92 (0.160)	5.18 (0.140)	4.46 (0.121)
	Minimum activity, MBq (mCi)	12	7.40 (0.200)	148.00 (4.000)	37.00 (1.000)	49.27 (1.332)
	Maximum activity, MBq (mCi)	12	111.00 (3.000)	555.00 (15.000)	370.00 (10.000)	348.42 (9.417)
^{123}I (NaI) (for the thyroid)	Activity/mass, MBq/kg (mCi/kg)	4	0.06 (0.0015)	0.22 (0.0060)	0.10 (0.0028)	0.12 (0.0033)
	Minimum activity, MBq (mCi)	10	0.56 (0.0150)	11.10 (0.3000)	3.70 (0.1000)	3.76 (0.1015)
	Maximum activity, MBq (mCi)	11	3.70 (0.1000)	19.98 (0.5400)	8.14 (0.2200)	9.45 (0.2555)
^{99m}Tc-ethylcysteinate dimer (ECD) or ^{99m}Tc-exametazime (HMPAO)	Activity/mass, MBq/kg (mCi/kg)	7	1.85 (0.050)	15.73 (0.425)	10.55 (0.285)	10.81 (0.292)
	Minimum activity, MBq (mCi)	11	18.50 (0.500)	370.00 (10.000)	185.00 (5.000)	174.91 (4.727)
	Maximum activity, MBq (mCi)	12	370.00 (10.000)	1110.00 (30.000)	740.00 (20.000)	810.92 (21.917)
^{99m}Tc-sestamibi (MIBI)	Activity/mass, MBq/kg (mCi/kg)	7	5.70 (0.154)	18.50 (0.500)	12.95 (0.350)	11.97 (0.323)
	Minimum activity, MBq (mCi)	10	37.00 (1.000)	518.00 (14.000)	148.00 (4.000)	210.90 (5.700)
	Maximum activity, MBq (mCi)	12	370.00 (10.000)	1110.00 (30.000)	777.00 (21.000)	792.42 (21.417)
^{99m}Tc-macroaggregated albumin (MAA)	Activity/mass, MBq/kg (mCi/kg)	7	1.11 (0.030)	4.88 (0.132)	1.85 (0.050)	2.31 (0.062)
	Minimum activity, MBq (mCi)	12	7.40 (0.200)	37.00 (1.000)	18.50 (0.500)	21.40 (0.578)
	Maximum activity, MBq (mCi)	12	111.00 (3.000)	222.00 (6.000)	138.75 (3.750)	143.99 (3.892)
^{99m}Tc-Ultratag (Mallinckrodt) (for gastrointestinal bleeding)	Activity/mass, MBq/kg (mCi/kg)	6	3.70 (0.100)	11.10 (0.300)	8.33 (0.225)	7.92 (0.214)
	Minimum activity, MBq (mCi)	9	37.00 (1.000)	148.00 (4.000)	74.00 (2.000)	78.11 (2.111)
	Maximum activity, MBq (mCi)	11	185.00 (5.000)	740.00 (20.000)	740.00 (20.000)	615.55 (16.636)
^{99m}Tc-denatured RBCs (for the spleen)	Activity/mass, MBq/kg (mCi/kg)	2	1.85 (0.050)	2.59 (0.070)	2.22 (0.060)	2.22 (0.060)
	Minimum Activity MBq (mCi)	6	18.50 (0.500)	92.50 (2.500)	37.00 (1.000)	40.08 (1.083)
	Maximum Activity MBq (mCi)	6	74.00 (2.000)	740.00 (20.000)	111.00 (3.000)	215.83 (5.833)
^{99m}Tc-Ultratag (Mallinckrodt) (for multiple gated acquisitions)	Activity/Mass MBq/kg (mCi/kg)	5	7.40 (0.200)	14.80 (0.400)	8.14 (0.220)	9.69 (0.262)
	Minimum Activity MBq (mCi)	10	44.40 (1.200)	370.00 (10.000)	101.75 (2.750)	132.09 (3.570)
	Maximum Activity MBq (mCi)	11	555.00 (15.000)	925.00 (25.000)	740.00 (20.000)	733.27 (19.818)
^{67}Ga (for inflammatory disease)	Activity/Mass MBq/kg (mCi/kg)	5	1.48 (0.040)	2.59 (0.070)	1.85 (0.050)	1.90 (0.051)
	Minimum Activity MBq (mCi)	4	9.25 (0.250)	74.00 (2.000)	27.75 (0.750)	34.69 (0.938)
	Maximum Activity MBq (mCi)	6	111.00 (3.000)	185.00 (5.000)	166.50 (4.500)	154.17 (4.167)
^{67}Ga (for tumor imaging)	Activity/Mass MBq/kg (mCi/kg)	5	2.96 (0.080)	5.25 (0.142)	4.07 (0.110)	3.90 (0.105)
	Minimum Activity MBq (mCi)	10	9.25 (0.250)	111.00 (3.000)	37.00 (1.000)	41.07 (1.110)
	Maximum Activity MBq (mCi)	12	222.00 (6.000)	370.00 (10.000)	333.00 (9.000)	312.96 (8.458)
^{18}F-fluorodeoxyglucose (FDG)	Activity/Mass MBq/kg (mCi/kg)	6	5.18 (0.140)	7.40 (0.200)	5.37 (0.145)	5.67 (0.153)
	Minimum Activity MBq (mCi)	6	18.50 (0.500)	74.00 (2.000)	37.00 (1.000)	46.25 (1.250)
	Maximum Activity MBq (mCi)	8	370.00 (10.000)	555.00 (15.000)	407.00 (11.000)	430.13 (11.625)

[**Table 1**] data, summarized in Table 1, include the minimum and maximum administered doses for each of the 16 procedures. In a few cases, institutions provided a schedule based on activity per body surface area or another method. However, because most sites reported using the activity per unit body mass (MBq/kg or mCi/kg), only this is reported in Table 1. For each of these parameters, we also report the number of institutions that responded for that parameter as well as the minimum, maximum, median, and mean values for each parameter. The range of responses for each parameter is defined as minimum and maximum response.

DISCUSSION

In most cases, the reported values for maximum activity and activity per mass varied within a factor of 2, although for some procedures, they varied by as much as a factor of 10. On the other hand, the reported values of minimum activity demonstrated substantially wider variation, by as much as a factor of 20 for some procedures. There are several examples of this wider variation: ^{99m}Tc-dimercaptosuccinic acid (DMSA) minimum total doses varied from 5.55 to 74.0 MBq, whereas the activity per kilogram varied from 1.11 to 3.70 MBq/kg and the maximum dose varied from 74.0 to 222.0 MBq. ^{99m}Tc-mercaptoacetyltriglycine (MAG3) minimum total doses varied from 18.5 to 148 MBq, whereas the activity per kilogram varied from 1.85 to 10.36 MBq/kg and the maximum dose varied from 111.0 to 370.0 MBq. ^{99m}Tc-methylene diphosphate (MDP) minimum doses varied from 22.2 to 185.0 MBq, whereas the activity per kilogram varied from 7.4 to 13.3 MBq/kg and the maximum dose varied from 666 to 925 MBq. ^{99m}Tc-diisopropyl iminodiacetic acid (or Choletec; Bracco Diagnostics) minimum doses varied from 14.8 to 74.0 MBq, whereas the activity per kilogram varied from 1.85 to 3.70 MBq/kg and the maximum total administered dose varied from 92.5 to 370.0 MBq. ^{123}I-NaI minimum doses varied from 0.56 to 11.10 MBq, whereas the activity per kilogram varied from 0.06 to 0.22 MBq/kg and the maximum dose varied from 3.70 to 19.98 MBq. Similar variations in the dose ranges for other radiopharmaceuticals are seen in Table 1. This survey involved many of the premiere pediatric nuclear medicine clinics in North America, where access to current imaging technologies is excellent and understanding of the pediatric patient is refined. Yet, as this report shows, even under the best of medical circumstances, administered dose ranges vary widely. It is therefore tempting to speculate that the variations in the general nuclear medicine community would be greater. Nowhere is a customized approach to dosimetry more urgently needed than in neonates and infants whose extremely small size demands the utmost caution in optimizing minimum dosing activity without sacrificing image quality.

As demonstrated by the results of this survey, the levels for minimum activity applied in the pediatric nuclear medicine community are substantially more variable than those for maximum activity or activity per body mass. This finding is most likely due to the fact that these latter parameters are typically based on the values prescribed for adult nuclear medicine, whereas the minimum total administered activity is a concept unique to pediatric nuclear medicine. In many cases, these minimum values were defined historically. In some cases, the assumptions used in applying a given level of activity, although appropriate at the time, may have been rendered obsolete by subsequent changes or upgrades in instrumentation and data-processing capabilities. For example, large multidetector SPECT cameras and advanced iterative reconstruction algorithms can now generate high-quality, diagnostic image data using only a fraction of the radiopharmaceutical doses that are typically administered in most nuclear medicine settings. The variations among administered radiopharmaceutical activities obviously result in a corresponding variation in the patient radiation-absorbed doses (*2,3*).

CONCLUSION

Our survey shows that rather large variations exist in administered radiopharmaceutical dose schedules among the surveyed pediatric sites. This is particularly true for the minimum activity values indicated in Table 1, for which a study would be considered inadequate irrespective of patient size. It is not our intention to evaluate whether the doses, as reported by the 13 respondents, are too small or too large for the individual practices included in this survey. What our findings do suggest, however, is a clear need to achieve some level of standardization by reaching a broader consensus on pediatric radiopharmaceutical activity schedules. Moreover, the pediatric nuclear medicine community and nuclear medicine professional organizations should promote a dialogue aimed at developing guidelines for administered radiopharmaceutical activities in children. Efforts within the nuclear medicine community to ensure the highest levels of pediatric patient care should be directed at achieving superior image quality while using the minimum dose necessary to produce successful studies (and the smaller or younger the child, the more critical the dose becomes) and exploring the utility of new technology, including instrumentation and reconstruction software, as a means of reducing radiation exposure while maintaining diagnostic accuracy.

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