Adjustment to Radionuclide Angiogram Dose Based upon Patient's Physical Parameters

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Objective: The standard 30-mCi technetium-99m (^{99m}Tc) equilibrium radionuclide angiogram (RNA) dose for evaluating cardiac function has long been a problem in two respects: (1) unnecessarily high doses in smaller patients and (2) poor count statistics in larger patients. To rectify these problems, a dose chart was created based on height, weight, and gender to assist in the dispensing of an appropriate RNA dose. ***Methods:*** The chart created is based on the 1983 Metropolitan Weight & Height Tables, which state the normal ranges of weight for men and women according to their respective heights. The 30-mCi dose was used for this normal range, and 1 mCi was added or subtracted for every 10-pound deviation from this range. We prospectively applied our chart to 91 patients and calculated the counts/pixel within the left ventricular region. The study group was divided into three groups: (Group A) patients who received 30 mCi (52 ± 11 counts/pixel, n = 32), (Group B) patients who received less than 30 mCi (56 ± 8 counts/pixel, n = 28), and (Group C) patients who received greater than 30 mCi (54 ± 12 counts/pixel, n = 31). We retrospectively identified 12 patients (Group D) who received the standard 30-mCi dose, but would have received a reduced dose if our chart had been used. ***Results:*** There was no significant difference (p = 0.22) in counts/pixel among these three groups despite a very significant difference (p = 0.001) in weight. Image quality remained consistently good throughout the study. In contrast, Group D had significantly higher counts per pixel (78 ± 17 counts/pixel, p = 0.001) when compared to the other groups, indicating a need for dose reduction. ***Conclusions:*** These data clearly demonstrate that dosage adjustment by our chart avoided excess radiation in thin patients and ensured adequate counting statistics in heavy patients.
Key Words: Radionuclide angiogram dose (RNA), dose chart, dose adjustment by weight.

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The equilibrium radionuclide angiogram (RNA) has always been a reliable means of evaluating cardiac function. However, the standard 30-mCi dose (*1*) used in this diagnostic tool has been problematic in two respects: (1) unnecessarily high doses in thin patients and (2) poor count statistics in heavy patients. The higher doses in thin patients lead to unnecessary radiation exposure, which is in contrast to the "as low as reasonably achievable" (ALARA) principle. In heavy patients, poor count statistics lead to inferior image quality, especially on exercise studies when images are acquired for a short period of time. This leads to a suboptimal patient study.

The solution to these problems seems straightforward: decrease the doses in thin patients and increase the doses in heavy patients. There are two commonly used theories on which to base the dosage adjustments. One is the body mass index (BMI), which is based upon body weight and height (W/H^2) (*2*), where W represents body weight in kg and H is body height in m. BMI or Quetelet's index (*2*) is used in epidemiology as a measure of body fatness. This approach does not consider important differences in body habitus between males and females. The other approach is to consider only body weight. This approach does not consider important differences in height or gender differences in body habitus.

The 1983 Metropolitan Weight & Height Tables (MWHTs) (*3*) state the normal ranges of weight for men and women according to their respective heights. The MWHTs were developed by the Health and Safety Education Division of the Metropolitan Life Insurance Company as an aid to predict optimal weight for longevity of life and are considered the standard among insurance companies. These tables are used as the basis of the dosage chart for this study. The purpose of this study was to determine if consistently adequate counting statistics would be obtained when dosage adjustments were made based upon the dosage adjustment chart that we developed.

MATERIALS AND METHODS

Patient data from 240 RNA studies were accumulated over approximately a five-month period using the RNA dosage

TABLE 1. Radionuclide Angiogram (RNA) Dose Chart Sample for Male Patients

Height	28 mCi	29 mCi	30 mCi	31 mCi	32 mCi
5′9″	151–160 lb	161–170 lb	171–180 lb	181–190 lb	191–200 lb
5′10″	155–164 lb	165–174 lb	175–184 lb	185–194 lb	195–204 lb
5′11″	159–168 lb	169–178 lb	179–188 lb	189–198 lb	199–208 lb

Note: The height and weight measurements in this table are based upon subjects wearing indoor clothing with no shoes.

adjustment chart. The relevant information recorded for each patient included gender, height, weight, and the calculated dose using the RNA dosage adjustment chart. The MHWTs list normal weights for each specific height. The difference between the lower and upper limits can range from 22 lb to 45 lb. A more consistent width of the normal range was necessary to develop the dosage adjustment chart. Therefore, the upper 10 lb of the quoted normal range was designated as the "normal range" for the dosage adjustment chart, and permission has been granted to us by the Metropolitan Life Insurance Company, Aurora, Illinois, (G. Brower, Metropolitan Life Insurance Company, Aurora, IL, personal communication) to modify the MHWTs in order to establish the "normal range" body weight. The RNA dosage adjustment chart was then developed based on these "normal ranges."

Table 1 shows some dosage samples from the proposed dosage chart. Permission was obtained from the prescribing physicians and our Radiation Safety Committee to increase the RNA dose, when necessary, to a maximum of 40 mCi.

Dosage Determination

The calculated dose was derived using the new dosage chart, which determines an adjusted dose based on the patient's gender, height, and weight. The standard 30-mCi dose was used for the normal range, and 1 mCi was added or subtracted for every 10-lb deviation from this normal range.

If the RNA dosage adjustment chart (Table 1) is used, a 5′11″, 200-lb male patient will receive a 32-mCi dose of sodium [^{99m}Tc]pertechnetate ($Na^{99m}TcO_4$). This male patient is 20 lb above the normal range of weight for a man of his height and is therefore given 2 mCi of additional $Na^{99m}TcO_4$ to compensate for the 20 lb that he is above the normal range.

Patient Groups

From the original 240 RNA studies, 91 patient studies (71 male and 20 female) were randomly selected to form three groups (Groups A–C) of approximately 30 patients each; the three groups received 30 mCi, less than 30 mCi, or more than 30 mCi, respectively. The three groups were as follows: Group A: Patients who received 30 mCi (n = 32); Group B: Patients who received less than 30 mCi (n = 28); and Group C: Patients who received greater than 30 mCi (n = 31).

We retrospectively identified an additional group of 12 patients (Group D) who received the standard 30-mCi dose prior to the initiation of this study but who would have received a reduced dose if our new chart had been used.

Imaging Protocol

Each of the patient studies was handled in the same manner. Red blood cells were labeled with the chart-adjusted $Na^{99m}TcO_4$ dose using the modified in vivo technique (*4*). The patients were imaged in the supine position with a small field of view mobile gamma camera (Picker Dynamo, Picker Corp., Highland Heights, OH) equipped with a low-energy all-purpose collimator and minicomputer (Medasys Pinnacle, Medasys, Ann Arbor, MI), which divided the cardiac cycle into 16 frames using an electrocardiogram R-wave gating circuit. The image set chosen for analysis was the supine left anterior oblique (LAO) image, taken prior to exercise, with the patient's feet in the bicycle ergometer pedals. This image was acquired for 120 sec in a 64 × 64 matrix; the LAO angle was determined by the nuclear medicine technologist in order to obtain the best separation of the right and left ventricles.

Each of the patient's resting LAO feet-up images was processed on the computer using the threshold and second-derivative edge detection method to determine the ejection fraction as previously described (*5*). The processing program also indicated the background-corrected end diastolic counts and the number of end diastolic pixels within the left ventricular region of interest. From these data, counts/pixel within the left ventricle were calculated.

Statistical Analysis

Data are expressed as the mean ± 1 s.d. The Turkey-Kramer method was used for multiple group comparisons.

RESULTS

Results of the calculations of left ventricular average counts/pixel from all four groups of patient studies are shown in Table 2. There was no significant difference ($p = 0.22$) in counts/pixel among Groups A–C (Fig. 1) despite a very significant difference ($p = 0.001$) in weight (Fig. 2).

TABLE 2. Count-Rate Comparisons Among Different Patient Groups

Patient Group	Number of Patients	Counts/Pixel
A	32	52 ± 11
B	28	56 ± 8
C	31	54 ± 12
D	12	78 ± 17

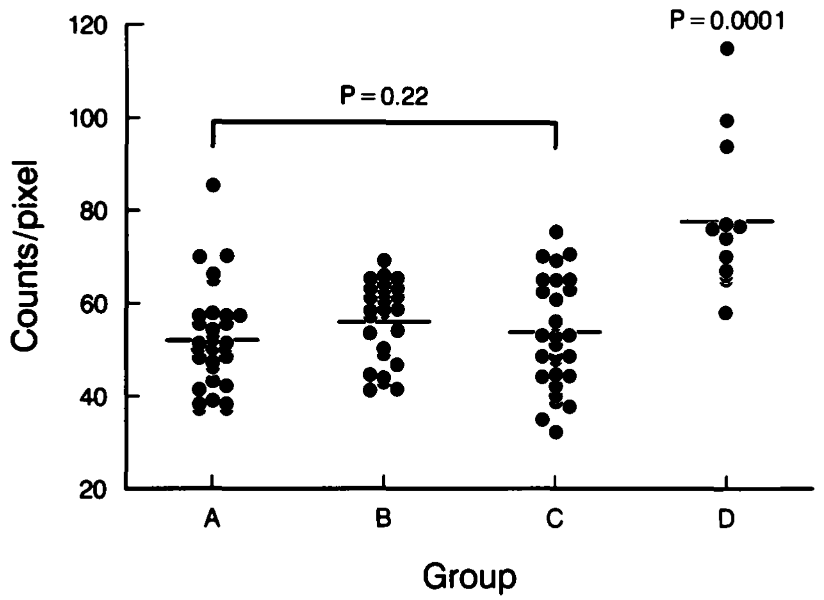

FIG. 1. Comparison of counts/pixel from four different groups of patients. Using RNA dosage adjustment chart, Groups A, B, and C showed no significant difference (p = 0.22). Group D, which did not receive adjusted doses, had significantly higher counts/pixel and revealed a very significant difference (p = 0.0001) when compared to the other groups.

Image quality remained consistently good throughout the study. In contrast, Group D, which received a dose of 30 mCi, but according to the dosage chart should have received a lesser dose, had significantly higher counts/pixel (Table 2) than the other groups (p = 0.0001) (Fig. 1), indicating a need for dose reduction.

DISCUSSION

The idea of adjusting patient doses is used in other areas of nuclear medicine, such as kidney scanning and pediatric imaging. For these two types of tests, weight is generally used to determine dosage, either by giving a certain amount of activity for each lb or kg of body weight or by proportionally adjusting the dosage compared to a standard 154 lb (70 kg) patient. Applying this method of dosage adjustment to the RNA appeared to be the logical solution when the problem was first considered. Using 154 lb as the standard weight for a standard 30-mCi dose, 0.19 mCi/lb would be the dosage increment. According to this method, a 222-lb patient would receive a 42-mCi dose and a 112-lb patient would receive a dose of 21 mCi, regardless of the patient's height. In contrast, using our dosage adjustment chart, a 6′2″, 222-lb

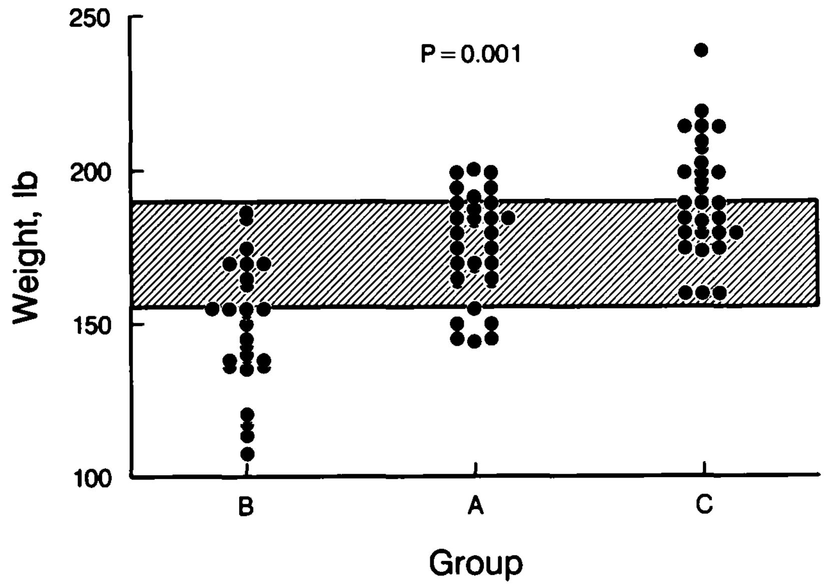

FIG. 2. Body weight distribution among three different groups of patients. There was a significant difference (p = 0.001) in weight among these three patient groups. The shaded region represents a range of weight that was common to Groups A, B, and C.

TABLE 3. Three Different Theories for Determining Radionuclide Angiogram (RNA) Dose

Height	Sex	Weight (lb)	Authors' RNA Chart (mCi)	Weight (mCi)	Body Mass Index (BMI) (mCi)
5'3"	F	112	30	21	24
6'2"	M	222	32	42	34
5'5"	M	194	33	37	39
5'10"	F	125	25	24	21

Note: F = female, M = male.

male would receive a dose of 32 mCi, and a 5'3", 112-lb female, a dose of 30 mCi (Table 3).

Another theory used to adjust dosage is the BMI, which considers both body weight and height. As shown by the four examples in Table 3, the dosages derived using the BMI theory varied by approximately ± 6 mCi when compared to those of our RNA dosage adjustment chart. Many other examples were compared, with similar results.

The adjustments using these two theories (i.e., body weight adjustment method and BMI) seemed to be inconsistent and extreme in certain situations. We also believed that patient gender was an important factor that should be considered along with height and weight. It was for these reasons that the RNA dosage adjustment chart was developed. Our chart lists different schedules for both male and female patients and allows for a more gradual adjustment of patient doses. Table 3 displays a comparison of our proposed dosage chart method versus the other two methods of dosage adjustment for four sample patients.

Our data demonstrate that consistent count statistics were attained in all three groups (A, B, and C) with the use of the dosage adjustment chart (Table 2 and Fig. 1). Thin patients were able to receive a smaller RNA dose, thus giving them less radiation exposure, while continuing to maintain good counting statistics. Heavy patients received a larger dose, also maintaining good counting statistics that were similar to those of the thinner patients. The data from retrospective Group D show clearly that thinner patients were receiving unnecessarily high doses of approximately 30 mCi prior to the introduction of our adjustment (Fig. 1). Data were not available for heavier patients given the standard 30-mCi RNA dose, but it does seem obvious that the counting statistics would be considerably lower and the quality of the images would be inferior.

Figure 2 demonstrates that different dosages are given to patients within a common range of weight. Thus, patients of similar weight are receiving different dosages, but have similar counting statistics. It is obviously necessary to consider not only weight, but height and gender as well, when determining dosage.

Other problems exist, such as patient attenuation. While some of the patients' physical parameters are being addressed, it is difficult to take into account the distribution of a patient's weight on his or her body. Large-breasted women and men with large, thick chests may have less than optimal counting statistics. None of the available dosage adjustment methods, including our proposed method, are able to solve this problem. One other potential weak point in our dosage adjustment method may be the lack of a simple formula which can be used to determine the patient dose. It is not possible to enter the patients' physical parameters into a formula and calculate the appropriate dosage. The actual RNA dosage adjustment chart must be available.

The RNA dosage adjustment chart would seem to be a very helpful tool, with the patient as the major benefactor. Following the ALARA principle, patients are receiving the lowest dose necessary to provide quality patient studies on a consistent basis. The methods and principles employed in dosage adjustment could possibly be used in other areas of nuclear medicine studies, such as bone scanning, where relatively large standard doses are given to all patients regardless of the patient's physical parameters.

In conclusion, the RNA dosage adjustment chart adjusts the patient dose appropriately to ensure the safest possible test, while also providing consistently good quality images, which are necessary for an optimal RNA study.

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