A New Bolus-Injection System for the Performance of Dynamic Time-Function Studies—a Preliminary Investigation

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A new bolus-injection system was developed to reduce radiation exposure to nuclear medicine personnel performing dynamic time-function studies, specifically first-pass nuclear cardiology studies. In comparing the new system with the old, two additional parameters were measured: the bolus flow rate characteristics, and the residual activity in the apparatus.

In 1973, it was reported that nuclear medicine procedures were growing at a rate greater than 15% per year and that an average nuclear medicine facility would routinely handle 300–700 mCi of Tc-99m per day plus prepare Tc-99m coumpounds (*1*). Because of the increased number of static and dynamic imaging procedures performed in nuclear medicine laboratories and the use of higher dose radionuclides, unnecessary radiation exposure to personnel must be minimized.

One particular dynamic imaging procedure that has experienced tremendous growth since 1973 is quantitative first-pass radionuclide angiocardiography. The technique for this procedure employed by our laboratory is described by Berger et al (*2*). High-count, high-frequency time–activity curves are generated by this technique because it delivers an isolated, compact bolus of radioactivity very rapidly into a peripheral vein. These high-count, high-frequency time–activity curves are essential to derive valid clinical information. Unfortunately, the bolus of radioactivity is isolated in an unshielded length of polyethylene tubing, increasing the radiation exposure to imaging personnel (Fig. 1).

The new injection system isolated the bolus of radioactivity in a shielded environment, thereby decreasing exposure to imaging personnel (Fig. 2b). Nevertheless, it still had to be proven comparable to the tubing-injection system in generating high-count, high-frequency time-activity curves. Residual activity of both injection systems was also measured to find whether a significant difference existed in the measured patient dose and the delivered patient dose.

Materials and Methods

Eleven patients who had been routinely scheduled for dynamic first-pass cardiac studies were selected for the comparison of the bolus-injection systems. Two first-pass studies were performed on each patient. The first study was performed in the anterior position, and the second study in the 45° LAO position. Each patient received 15–20 mCi of Tc-99m DTPA and 15–20 mCi of Tc-99m pertechnetate for the first and second injections respectively, the total not to exceed 35 mCi.

Each patient had an 18g–2 in. iv teflon catheter (Jelco Laboratories, Raritan, NJ) inserted in either the cephalic or basilic vein of the right arm. Prior to the first injection, the patient was positioned under the camera and a transmission study performed to identify the cardiac silhouette (*3*).

The first injection was performed in the anterior position, using the tubing injection system (Fig. 1). A volume of radioactivity, not exceeding 0.5 ml, was introduced into the side arm of a NOVEX three-way stopcock with extension tubing (Pharmaseal, Inc., Toa Alta, PR) from a 1 ml tuberculin syringe and isolated in the tubing with 0.1 ml of air in front and behind the bolus (*4*). After the bolus of radioactivity was isolated in the tubing, the open end of the tubing system was inserted in the iv catheter, and by using a 20 ml saline flush and maximum manual power, the bolus of radioactivity was flushed into the arm.

The second injection was performed in the 45° LAO position using the new syringe-injection system composed of a 1 ml tuberculin syringe barrel coupled to a one-way stopcock with a Luer adapter (Pharmaseal, Inc.)(Fig. 2a).

To draw up the patient dose, a 5 ml syringe was attached to the stopcock with the Luer adapter. A 21g needle was attached to the 1 ml syringe barrel and the stopcock opened. The syringe was then inserted into a vented stock

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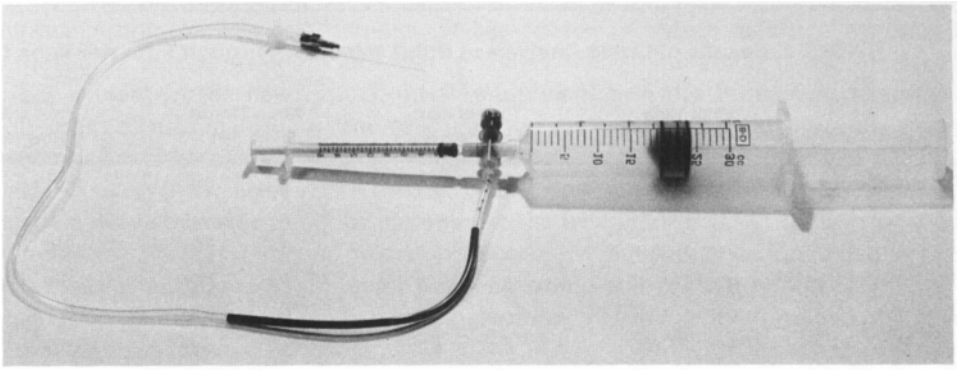

Fig. 1. The tubing-injection system with the bolus of radioactivity isolated in an unshielded environment.

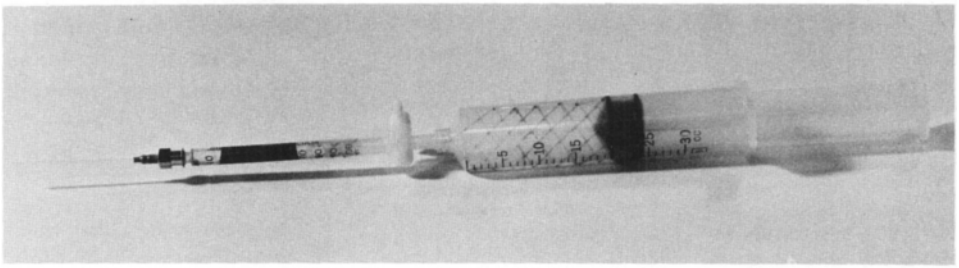

Fig. 2a. The syringe-injection system composed of a 1 ml tuberculin syringe barrel coupled to a one-way stopcock with a 20 ml saline flush attached.

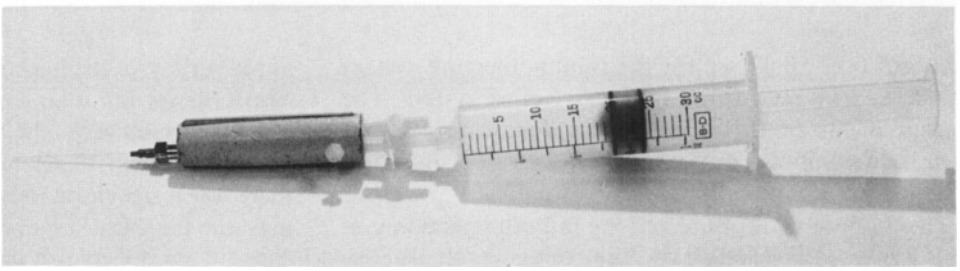

Fig. 2b. The syringe-injection system with a 1 ml lead syringe shield shielding the bolus of radioactivity.

closed, the 5 ml syringe removed, and a 20 ml saline flush attached to the Luer adapter. A lead shield was placed over the 1 ml syringe. The shielded injection system was inserted into the iv catheter and using maximum manual power, the bolus was flushed into the vein.

The information was recorded and stored at a rate of 1 frame/50 msec for 500 frames, using 1½ in. of parallel hole collimation with the Baird-Atomic System-77 Multicrystal Camera. (Baird Corp, Bedford, MA) Data were played back at twenty times acquisition and stored on disc memory. A summed frame was played back, displaying the superior vena cava. The region of the superior vena cava was flagged, and time-activity curves were generated for each injection system. These curves were then computer analyzed, and their data compared for bolus flow vial of Tc-99m sodium pertechnetate and a volume not exceeding 0.5 ml was withdrawn by drawing back the plunger of the attached 5 ml syringe. When the desired volume was delivered, the syringe was removed from the stock vial. Then by carefully drawing back the plunger of the attached 5 ml syringe, the volume of radiopharmaceutical was centered in the 1 ml syringe barrel, and the stopcock closed.

The volume was checked by reading directly from the 1 ml syringe, and the activity checked by placing the syringe system in the dose calibrator. The stopcock was rate characteristics. Results were stated as the mean±standard deviation using four parameters: peak time, mean transit time, pool transit time, and the time of maximum inflow rate. The data from both injection systems were compared using the paired t-test.

Exposure readings were taken with a calibrated laboratory survey meter immediately prior to injection. Readings were obtained at two distances from the injection systems: the first reading was taken at the surface, to approximate hand and finger exposure; and the second reading was taken at about six inches, to approximate body exposure.

Residual activity was measured immediately after the injection by placing the entire injection system into a dose calibrator and recording the reading.

Results

Data obtained in the first-pass studies using both injection systems are shown in Table I. Peak time averaged 0.58±0.02 sec for the tubing-injection system and 0.50 ±0.02 sec for the syringe-injection system. The mean transit time averaged 0.85±0.25 sec for the tubing-injection system and 0.78±0.26 sec for the syringe-injection system. The pool transit time averaged 0.53±0.25 sec for the tubing-injection system and 0.57±0.25 sec for the syringe- injection system. Finally, the time of maximum inflow rate

TABLE 1. Results of Curve Analysis of Bolus Injection Through Superior Vena Cava of 11 Patients

	Peak Time (sec)		Time of Max. Inflow Rate (sec)		Mean Transit Time (sec)		Pool Transit Time (sec)		Bolus Size (ml)	
Case No.	T-I*	S-I†	T-I	S-I	T-I	S-I	T-I	S-I	T-I	S-I
1.	0.4	0.3	0.1	0.1	0.5	0.4	0.5	0.3	0.5	0.5
2.	0.6	0.6	0.4	0.3	1.1	0.9	0.4	0.3	0.3	0.2
3.	0.6	0.3	0.2	0.1	0.5	0.5	0.4	0.5	0.5	0.5
4.	0.7	0.7	0.2	0.2	1.2	1.3	0.9	0.9	0.3	0.3
5.	0.9	0.5	0.2	0.3	0.8	0.9	0.8	0.9	0.3	0.2
6.	0.6	0.6	0.2	0.2	0.5	0.7	0.4	0.5	0.5	0.5
7.	0.5	0.6	0.2	0.1	1.3	1.0	0.5	1.0	0.5	0.5
8.	0.4	0.4	0.2	0.2	0.5	0.7	0.4	0.3	0.5	0.5
9.	0.5	0.5	0.3	0.2	1.2	0.9	0.4	0.6	0.5	0.4
10.	0.7	0.3	0.2	0.1	1.0	0.5	0.7	0.4	0.3	0.4
11.	0.5	0.7	0.2	0.2	0.7	0.8	0.4	0.6	0.5	0.5

*T-I: Tubing-injection system
†S-I: Syringe-injection system

averaged 0.22±0.07 sec for the tubing-injection system and 0.18±0.08 sec for the syringe-injection system. The measurements of these parameters demonstrated that there is no significant difference between the two injection systems ($P>0.05$).

The amount of residual activity in both injection systems was measured (Table II). The average residual activity in the tubing-injection system was 2.35±0.72 and 0.29 ±0.21 mCi in the syringe-injection system. This showed an average of eight times more residual activity in the tubing-injection system compared to the syringe-injection system

Exposure readings were taken at two positions with a calibrated laboratory survey meter. The first readings taken at the surface of the injection system were 440mR/hr and 50mR/hr for the tubing-injection and syringe-injection systems, respectively. The second readings showed 120mr/hr and less than 10mR/hr, respectively. This showed that there was a significant (ten fold) decrease in exposure readings with the shielded syringe-injection system.

TABLE 2. Residual Activity

Case No.	(mCi)	
	T-I*	S-I†
1.	2.5	0.2
2.	3.0	0.5
3.	1.8	0.7
4.	2.7	0.1
5.	1.9	0.4
6.	0.6	0.1
7.	2.8	0.1
8.	2.5	0.5
9.	3.1	0.2
10.	2.1	0.1
11.	2.8	0.3

*T-I: Tubing-injection system
†S-I: Syringe-injection system

Discussion

The primary motive for the development of the new injection system was the desire to isolate a small volume of radioactivity in a shielded environment in order to decrease radiation exposure to personnel performing dynamic time-function studies. Once we had solved the problem of shielding, we had to determine whether the bolus flow rate characteristics of the two injection systems were comparable. The results of the computer-analyzed data showed that the flow rate characteristics did not differ significantly. The four parameters measured were: 1) peak time, the time from the arrival of the head of the bolus into the region of interest (the superior vena cava) to the time of peak activity corresponding to the main body of the bolus; 2) time of maximum inflow rate, the time representing the largest change in activity under the region of interest (when this time parameter has a short interval, it indicates rapid delivery of the bolus of radioactivity into a region of interest); 3) mean transit time, the time calculated as the mathematically derived average time that a red cell is in the region of interest; and 4) pool transit time from the maximum rate of inflow to the time of the maximum rate of outflow. This last parameter measures the quality of the bolus' geometry. A short time interval indicates that a small, compact bolus of radioactivity was delivered to the region of interest.

We also measured the residual activity in the injection sys-

tem. The findings showed an average residual activity of 12-16% of the measured dose in the tubing–injection system. The average residual activity present in the new syringe–injection system was 4-5% of the measured dose. These percentages, based on a patient dose of 15-20 mCi, showed that there was 95% or greater delivery of the measured dose to the patient using the new system, compared to 84-88% of the measured dose delivered by the old system. The larger amount remaining in the tubing–injection system is due mainly to the dead space in the hub of the 1 ml syringe that delivers the volume of radioactivity to the 3-was stopcock and the dead space in the elbow of the stopcock itself. We postulated that if smaller volumes are used for clinical studies, there would be an even greater residual because the volume used would approach the volume of dead space in the old system.

Conclusion

The new bolus-injection system that we developed shields a small volume of radioactivity for rapid bolus injection in the performance of dynamic time-function studies. It has proven to reduce radiation exposure to imaging personnel, while maintaining technically superior bolus flow rate characteristics. We have also shown that the new injection system delivers a significantly greater percentage of the measured dose to the patient.

Because of the above findings, this laboratory has begun to incorporate the new syringe–injection system into all procedure protocols that require the rapid delivery of a small bolus of radioactivity into a region of interest to generate high-count, high-frequency time–activity curves.

References

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