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Practical Aspects of ^{18}F-FDG PET When Receiving ^{18}F-FDG from a Distant Supplier

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With PET becoming more widely used, there is an increase in the number of imaging centers being forced to rely on distant suppliers of ^{18}F-FDG. Because of the large distances between major urban centers, this is particularly true for PET centers in Canada. **Methods:** Our PET center, located in Winnipeg, Manitoba, Canada, currently purchases ^{18}F-FDG from a commercial vendor located more than 1,000 km from Winnipeg, necessitating transport by commercial airline cargo. This dependence on air transport and a distant supplier creates a situation in which our ^{18}F-FDG supply is less reliable than it would be with onsite production. In this article, we offer insight into the obstacles we have encountered in imaging with a distant supplier of ^{18}F-FDG and the solutions we have implemented to minimize the disruption to our patients and maximize the number of scans performed each year. **Results:** The development of contingency plans and protocols designed to suit our operating environment has allowed us to increase the number of patient scans obtained from 659 in year 1 to 993 in year 3, an increase of 51%, despite an increase in our actual number of scan days of only 24%. ^{18}F-FDG injection timetables are presented for a variety of scenarios including normal delivery, low shipped activity, and delayed delivery. **Conclusion:** Through the careful establishment of contingency protocols and management of ^{18}F-FDG shipments, patient throughput can be increased and disruptions minimized.

Key Words: positron emission tomography; organizational efficiency; ^{18}F-FDG; radioisotope transportation; patient scheduling

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In the last few decades, clinical PET has progressed from being used at a few select sites to becoming a standard of patient care, especially in oncology (*1*). A key factor in the phenomenal growth of clinical PET has been the availability of commercial sources of ^{18}F-FDG for patient imaging. Purchasing ^{18}F-FDG from a commercial vendor can represent a cost-effective alternative to in-house production (*2*), which requires the operation and maintenance of a medical cyclotron and a PET radiochemistry department. This is particularly true for smaller centers with limited patient throughput, for which the operating costs of a cyclotron and ^{18}F-FDG synthesis facility can be prohibitively high when calculated on a per-patient scan basis (*3,4*). As the use of PET has grown, PET and PET/CT cameras have been installed at centers that are increasingly distant from a production source of PET radiotracers. The short 110-min half-life of ^{18}F means that any increase in distance from supplier to imaging center increases the complexity of ^{18}F-FDG shipping, patient scheduling, PET suite staffing logistics, and scanning protocols.

Canada lags behind the United States and Europe in the widespread adoption of PET/CT and medical cyclotron technologies (*5,6*). In addition, Canada has a significantly lower population density (one tenth) than the United States, having approximately one tenth the population but slightly more land mass than the United States. The lower population density reduces the incentive for commercial medical cyclotrons, which commonly operate in a hub-and-spoke fashion in the United States because of adequate population density, market demand, and transportation infrastructure.

At the present time, our PET/CT center, The Winnipeg Great-West Life PET/CT Imaging Centre, purchases ^{18}F-FDG from a production site that is located 1,200 km away, with a backup supplier located 1,800 km away. Currently, ^{18}F-FDG is undergoing clinical trials in Canada, necessitating a Canadian supplier of the tracer. As a result, our choice of ^{18}F-FDG vendor is constrained by regulatory requirements, with secondary considerations given to geographic realities. Although closer manufacturers of ^{18}F-FDG exist across the border in the United States, under the conditions of our Clinical Trial Application (CTA) we could get ^{18}F-FDG only from Health Canada–approved suppliers.

The purpose of this article was to share our insights into the practical aspects of operating a PET center 1,200–1,800 km from the ^{18}F-FDG production site, a transport distance that translates into greater than 3 half-lives of ^{18}F. The sometimes-tenuous nature of cyclotron production, ^{18}F-FDG synthesis, and transport logistics have required the development of contingency plans, with the goal of preventing wasted time and travel miles for our patients and optimizing the use of the shipments that we receive.

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MATERIALS AND METHODS

PET Center Location and Catchment Area

The Winnipeg Great-West Life PET/CT Imaging Centre (hereafter referred to as the PET/CT Centre) is located at the Health Sciences Centre in Winnipeg, a city of approximately 700,000 people located in the province of Manitoba, Canada. The population of the province of Manitoba is 1.2 million. Winnipeg is close to the geographic center of Canada and is roughly a 1-h drive from the U.S. border with the states of North Dakota and Minnesota. Our PET/CT center, the only one in the province, services all of Manitoba plus regions of the neighboring provinces of Saskatchewan and Ontario and the Canadian Territory of Nunavut. This amounts to a region of coverage greater than 700,000 km^2, an area comparable in size to California and Nevada combined (710,000 km^2) (*7,8*) or an area larger than the entire country of France (643,427 km^2) (*9*). As a consequence of this large regional coverage, it is not uncommon for patients to travel a considerable distance for a PET scan. Rescheduling these patients at the last minute is a difficult and frustrating experience for patients and PET/CT staff alike. Our PET/CT center is a self-contained outpatient imaging facility, with a single clinical PET/CT camera, 3 patient injection bays, a hot laboratory for dose dispensing, a physician reading room, a clinical trials coordinator workstation, and a reception area.

Patient Load and Scan Cancellations

As of July 2008, our PET/CT center has been in operation for 36 mo, in which time 2,559 patients have been imaged. Excluding the initial month of operation (start-up and learning-curve issues), the monthly average number of patient scans has been 72.7 ± 18.6 (mean ± SD; maximum, 110; minimum, 28). The monthly PET/CT scan totals and statistics for the first 3 y of operation are shown [**Table 1**] in Table 1. The number of patient scans obtained has significantly increased, and the month-to-month fluctuation in scan numbers over this 3-y period has decreased. This increase in patient throughput is due to the rise in clinical demand, the optimization of patient scheduling, and the contracting of a backup supplier of ^{18}F-FDG to cover intervals when our main supplier is offline for either scheduled preventive maintenance (~4 wk/y) or unscheduled repair of its cyclotron.

As the patient volume has increased, there has been a corresponding increase in the number of patient scans that have [**Table 2**] been cancelled because of various reasons. Table 2 summarizes the number of scheduled and actual scan days, total number of scans, and percentage of scans cancelled by year for the first 3 y of [**Table 3**] our center's operation. Table 3 stratifies reasons for cancelled scans by year. Cancellations are grouped into 4 categories: ^{18}F-FDG production problems, including both complete production failure and low production; transport problems, including both complete transport failure (i.e., ^{18}F-FDG not delivered) and delayed transport; PET/CT camera unscheduled downtime; and cancellations due to patient no-shows or medical issues (e.g., blood glucose elevated above our upper threshold for imaging). Problems with ^{18}F-FDG production have been the largest reason for cancelled scans in each year of operation, and the number of scans cancelled because of them has doubled in each year of operation. Although the exact causes for ^{18}F-FDG production problems are unknown, they are likely due to a combination of booking patients to near our maximum scan capacity and increasing demands on our ^{18}F-FDG suppliers, because the number of clients they serve has also increased in the same time.

TABLE 1
PET/CT Scan Totals by Year

Year	Average no. of scans/mo	SD of average	Minimum no./mo	Maximum no./mo
2005–2006	54.9	24.3	15	86
2006–2007	75.6	12.3	54	89
2007–2008	82.8	12.8	63	110

^{18}F-FDG Production and Transport

Two vendors synthesize ^{18}F-FDG for our facility. The primary vendor is located in Edmonton, Alberta, 1,200 km from our PET/CT center, and the secondary vendor is in Montréal, Québec, located 1,800 km away. Because of the large distances from production facility to imaging center, the only practical option for transport is by air. At the present time, there is only 1 Canadian commercial airline, Air Canada, that will transport radioactive substances and that flies between Edmonton or Montréal and Winnipeg. As a result, the ^{18}F-FDG production schedule is closely tied to airline schedules. For shipments originating in Edmonton, the flight time is 1 h 50 min, and for shipments from Montréal it is 3 h. In addition, ^{18}F-FDG must arrive at the airport at least 1–2 h before flight departure to be cleared by Transport of Dangerous Goods (TDG) inspectors. ^{18}F-FDG quality assurance is performed at the supplier's location. A private ground courier delivers ^{18}F-FDG to the PET center within approximately 30 min of its arrival at the airport in Winnipeg. Typically, the total door-to-door shipping time will be 5–6 h, or 2.7−3.3 half-lives of ^{18}F, meaning that if 100 GBq was produced, we will take delivery of roughly 10 GBq. Because of uncertainties in both actual activities produced and delivery timing, the ^{18}F-FDG is shipped in bulk form rather than unit doses.

An additional consideration when transporting ^{18}F-FDG is that the shelf life of the product is limited. In our case, the expiration time for both of our products is 12 h from preparation. If our

TABLE 2
PET/CT Scheduled and Actual Scan Numbers by Year

Year	Scheduled scan days	Actual scan days	Scheduled scans	Actual scans	Percentage of scans cancelled	^{18}F-FDG production problems (d)	Transport problems (d)
2005–2006	134	123	755	659	12.7	13	13
2006–2007	171	155	1,049	907	13.5	18	8
2007–2008	183	153	1,249	993	20.5	37	12

TABLE 3
Reasons for PET/CT Scan Cancellations by Year

Year	Scans cancelled because of ^{18}F-FDG production problems	Scans cancelled because of transport problems	Scans cancelled because of PET system downtime	Scans cancelled by patient
2005–2006	45	32	3	16
2006–2007	84	28	0	30
2007–2008	165	57	10	24

product delivery is substantially delayed, we may physically have enough radioactivity to inject and scan a patient, but we will be unable to inject because of the expiration of our product. In such a situation, we have adopted the procedure of batching the injection of patients (i.e., injecting multiple patients in a short period of time), to ensure that the available activity is used before expiration. This is part of our low-activity contingency plans.

From production through injection, the ^{18}F-FDG passes through numerous hands including the production staff at the cyclotron, a private courier at the origin and destination sites, an airline TDG officer, cargo personnel at the source and destination, and a nuclear medicine (NM) technologist in Winnipeg. The short half-life of ^{18}F means that rerouting shipments on nondirect flights results in cancelled patient scans. If there is an indirect flight involving a transfer of cargo, the air carrier also requires 3–4 h to transfer dangerous goods from plane to plane. This makes the efficient transfer between each of these handlers critical for ensuring the delivery of ^{18}F-FDG. In addition, proper education of the transport personnel as to the nature of a product with less than a 2-h half-life is critical to ensuring that the product will not be held and put on a later or alternative flight.

RESULTS

Minimizing Disruptions to PET/CT Appointments

Over the course of operating a PET/CT center for 3 y, in an environment of potentially unstable ^{18}F-FDG supply, we have learned the following key lessons regarding minimizing disruptions to patient scheduling and maximizing patient throughput.

Prescreening Patients

Before their scheduled scan day, the patient is telephoned by one of the NM technologists or our study coordinator and asked to provide prescan screening information. During the screening process, the patient is informed of what to expect, and all patient questions and concerns are addressed. The patient is also questioned regarding diabetic status, chemotherapy schedules, radiation therapy, recent infections, and recent or upcoming surgeries; several other prescribed questions related to conditions or circumstances that may affect the PET scan are also asked. These prescan screening questions reduce unnecessary delays due to unexpected issues and questions on the patient scan day. On the basis of predefined criteria, the screener will seek direction from the NM physician when needed. For example, if the patient has a history of recent infection, the physician will review the request to determine the potential impact of such on the scan results. If the site of infection will not significantly affect the interpretation of the scan, relative to the clinical question being posed, then the scan will proceed. If not, the NM physician will contact the referring physicians to further discuss the case. These procedures will all take place before the scan day. Prescreening our patients reduces cancellations or rebookings due to poor patient preparations or other interfering factors and helps us to obtain optimal image quality.

We also obtain any relevant contact information from the patient including cell phone, hotel, and local contact numbers or other medical appointments booked for that day. This information allows us to contact the patient easily if we have any issues with ^{18}F-FDG delivery that may require adjustment of the patient schedule.

In addition, patients are prioritized when the PET NM physicians review their requisitions and categorized as priority (emergency slots), urgent (within a week), or elective (next available regular slot). We rarely have a waiting period of more than 2 wk for the next available regular slot.

Avoiding Overbooking Patient Scan Slots

We book a maximum of 7 patients each day, which is a number that can be comfortably managed on the basis of the expectation of receiving 10 GBq of ^{18}F-FDG. An eighth patient scanning slot is usually held open for urgent cases and can be filled on short notice if sufficient activity is anticipated. By not overbooking patient scan slots, we do not use all of the ^{18}F-FDG that is shipped to us on a day with full production, but this does allow us to have a reasonable expectation of scanning our scheduled patients, even when low-activity shipments are received. The decision to not overbook patients was made early in the operation of our PET/CT center, to minimize the number of patients that need to be rebooked. Rebooking is a particular concern for our center, given the number of patients who travel from out of town for the scan. We also try not to book patients from out of town at the end of a week. Most patients who travel from a great distance are willing to stay overnight if we are able to reschedule their scan for the next day. If we book them on a Friday, however, and are unable to scan them on that day, we may not be able to scan them until Tuesday.

Timely Communication of Expected Shipped Activity

We ask that both of our ^{18}F-FDG vendors send e-mails to designated staff as early as possible in the morning so that we can plan accordingly if there is a problem with shipment. As our PET/CT staff starts work later in the day, we have designated other NM technologists to receive this information in the morning. On the basis of the activity shipped, these technologists are prepared to act accordingly; this is all captured on a table, with available time slots dependent on [**Table 4**] shipped activity (Table 4). Patients should be phoned as soon as possible to let them know the study has been cancelled and that they will be contacted later in the day to rebook, which allows the patients to stop their prescan fasting or, in the case of diabetic patients, to resume their normal insulin use. Notification of an expected delay in the delivery of ^{18}F-FDG triggers the same action mechanisms.

If there is significantly low activity, some patients will be rebooked. The NM technologists who receive the information in the morning are aware that imaging priority is given to out-of-town patients and to patients whose scan day is time-sensitive because of mitigating factors such as where they are in their chemotherapy cycle. The patients with imaging priority are indicated with an asterisk on the day sheet, to alert the staff who will be making the decisions on who is scanned.

Contingency Plans for Low ^{18}F-FDG Activity

Our normal injected ^{18}F-FDG activity, for adult whole- or near-whole-body scanning, is 444 MBq, increasing to 555 MBq for patients with mass over 100 kg and decreasing to 370 MBq for those with mass less than 45.5 kg. We have developed a simple Microsoft Excel–based spreadsheet to optimally organize the timing of the patient injections relative to received activity. The spreadsheet automatically calculates residual activity, taking into account received activity, physical decay, and injected doses. For a full shipment of 10 GBq on receipt, delivered on time, no modifications to the injection schedule are required. Alternative injection and scanning schedules can be constructed on the fly for both receipt of a low amount of ^{18}F-FDG on time and late receipt of ^{18}F-FDG.

When we receive a low-activity shipment, we are generally more tolerant of delayed imaging (e.g., 1.5–2 h after full-dose injection) rather than rigidly following our normal uptake period of 1 h. The 1-h uptake gives us good target-to-nontarget imaging ratios and is respectful of our patients' time. If we wait to 2 h, the target-to-nontarget ratio may be better, but we may have to increase the imaging time to produce good-quality count statistics, which is physically demanding for some patients and increases the total time a patient is in our department. For example, we will simultaneously inject up to 3 patients at the start of the imaging day to maximize available activity. In addition, multiple-patient injections ensure that there will be minimal delay between patient scans because the next patient will automatically be ready for scanning. Because all our ^{18}F-FDG PET scans are performed under a Health Canada CTA that specifies what our injected dose must be, we were unable to consider implementing a reduction in the injected dose as part of our low-activity contingency plans.

TABLE 4
Alternative Scanning Schedules Based on Amount of ^{18}F-FDG Shipped (Standard Dose, 444 MBq)

Scanning schedule	Patient no.	Time slot	Injection time	Shipped activity required (GBq) to inject all patients up to and including that slot
Routine	1	12:00	12:30	3
	2	12:25	12:55	6
	3	12:50	13:20	10
	4	13:40	14:15	18
	5	14:15	14:45	25
	6	14:45	15:15	34
	7	15:20	15:50	45
	8	15:45	16:25	60
Delayed shipment to 16:00 h arrival	1	15:10	16:00	13.4
	2	15:25	16:05	28.8
	3	15:40	16:10	42.4
	4	16:15	17:00	63.6
	5	16:45	17:25	84.8
	6	17:15	18:00	106
Emergency low shipment	1	11:30	12:15	3
	2	11:50	12:20	6
	3	12:10	12:40	10
	4	12:45	13:15	15
	5	13:15	13:45	21
	6	13:45	14:15	28
	7	14:15	14:45	34
	8	14:45	15:15	45

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TABLE 5
Patient Injection Calculator for 10-GBq-Activity ^{18}F-FDG Shipment

Patient no.	Time since previous injection (min)	Injection time	Activity available (MBq)	Injected dose (MBq)	Residual activity (MBq)
1	0	13:00	10,000	444	9,556
2	15	13:15	8,694	444	8,250
3	30	13:45	6,829	444	6,385
4	60	14:45	4,375	444	3,931
5	35	15:20	3,153	444	2,709
6	35	15:55	2,173	444	1,729
7	40	16:35	1,344	444	900
8	75	17:50	561	444	117
9	30	18:20	97	444	−347

[**Table 5**] [**Table 6**] Tables 5 and 6 illustrate how our simple spreadsheet program guides our practice when we receive low activity. We normally plan to image 7 patients. If we receive a full-activity shipment of 10 GBq, we can comfortably image 7 patients and have room for an eighth patient if need be. Table 5 illustrates how many patients can be imaged relative to received activity, with the normal injected dose of 444 MBq, remaining activity, and our usual schedule of time between injections. The schedule of time between injections is not a consistent time because the schedule for patient injection and imaging is designed to allow for staff breaks. We currently only have 2 full-time technologists who must be able to relieve each other throughout the day because we have no coverage during breaks. An electronic version of Table 5 in Microsoft Excel format is available as Supplemental Table 1 (supplemental materials are available online only at http://jnm.snmjournals.org). Table 6 shows that if we receive only 5 GBq, or half the expected activity, we would not be able to image 7 patients following the normal injection schedule. As shown in the table, only 54 MBq of ^{18}F-FDG would remain after the sixth patient was imaged. However, as illustrated in the alternative injection schedule in Table 6, if we injected the first 3 patients simultaneously (the maximum number of injection bays we have) and moved up the injection of the third patient (i.e., from 60 to 45 min) we would have adequate activity for all 7 patients. This simple spreadsheet tool allows technologists to quickly, and simply, manipulate several variables (injection times, injected doses, received activity) on a day-to-day basis to make the best use of received ^{18}F-FDG activity.

Networking

It is important to have good relationships with the multiple parties whose efforts eventually result in the ^{18}F-FDG arriving at the PET/CT Centre. We have personal relationships with the ^{18}F-FDG production facilities, airline TDG personnel, and courier personnel. By maintaining regular communication with these personnel, we have avoided many hardships for our center. For example, it is not uncommon for TDG personnel to batch items to be

TABLE 6
Patient Injection Calculators for 5-GBq-Activity ^{18}F-FDG Shipment

Injection schedule	Patient no.	Time since previous injection (min)	Injection time	Activity available (MBq)	Injected dose (MBq)	Residual activity (MBq)
Normal	1	0	13:00	5,000	444	4,556
	2	15	13:15	4,145	444	3,701
	3	30	13:45	3,064	444	2,620
	4	60	14:45	1,795	444	1,351
	5	35	15:20	1,084	444	640
	6	35	15:55	513	444	69
	7	40	16:35	54	444	−390
Alternative	1	0	13:00	5,000	444	4,556
	2	0	13:00	4,556	444	4,112
	3	0	13:00	4,112	444	3,668
	4	45	13:45	2,762	444	2,318
	5	35	14:20	1,860	444	1,416
	6	35	14:55	1,135	444	691
	7	40	15:35	537	444	93
	8	75	16:50	58	444	−386

inspected later in the day, especially if they are short-staffed during holidays. After not receiving our product a few times because of lack of available TDG officers, we spent the time to impress on the TDG officers that ^{18}F-FDG should be considered a perishable substance (i.e., short half-life) and must go out on the morning direct flight or patient care will suffer. Now we find the TDG staff to be accommodating, and we rarely run into such problems.

Teamwork

Last, but by far not least, it is essential that staff work as a team to solve problems on the fly, with an aim that all scheduled patients get imaged. This requires not only a clear identification of the roles and responsibilities of all team members but also clear communication trees and a determination of how responsibilities should be delegated. Given the number of variables that can negatively affect whether adequate ^{18}F-FDG activity is received, staff must be flexible, resourceful, and creative. It is not uncommon to hear staff say that "Every day is an adventure in the PET suite!" We have excellent staff working in our PET/CT center who take responsibility and personal pride in doing what is necessary to accommodate patients, many times going above and beyond the call of duty.

CONCLUSION

The key to operating a PET/CT program and using a product shipped daily from 1,200 to 1,800 km away is communication and flexibility. We routinely balance injection times, uptake period, and the number of patients injected in a given period according to the shipment we receive and the best images we can produce. The communication systems that we have did not develop overnight but rather evolved in an iterative process requiring trial and error. The key to our plan is that all members of the team know what their jobs are, at what level they need to intervene, and whom they need to call. One person alone is not responsible for the entire plan, and we use simple methods to communicate with all members of our team. By avoiding overbooking patients, we are able to rebook in a timely manner if necessary and with ease to both our staff and patients. Patients are assigned a scanning priority so that we know who needs to be scanned and who could wait if needed. A simple daily worksheet enables us to contact patients wherever they may be. Everyone within our system plays an important role in our daily dance of product receipt. Organized chaos or a well-rehearsed dance: you be the judge.

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