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Exploring the feasibility of integrating barcode scanning technology into vaccine inventory recording in seasonal influenza vaccination clinics

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ABSTRACT

Background: In response to the need for improved quality of vaccine inventory and client immunization records, barcodes containing a unique identifier and lot number will be placed on all vaccine vials in Canada. We conducted feasibility studies to examine integration of barcode scanning into inventory recording workflow for mass immunization clinics.

Methods: During the 2010–2011 seasonal influenza vaccination campaign, Ontario public health units (PHUs) using an electronic immunization system were randomized to record clinic inventory data (including vaccine lot number and expiry date) through: (i) barcode scanning of vials; or (ii) drop-down menus. A third group of PHUs recording vaccine inventory on paper served as an observation arm. We visited a sample of clinics within each PHU to assess barcode readability, method efficiency and data quality. Clinic staff completed a survey examining method perceptions.

Results: We observed 20 clinics using barcode scanning to record inventory data (eight PHUs), 20 using drop-down menus (eight PHUs), and 21 using paper forms (five PHUs). Mean time spent recording data per vial was 4.3 s using barcode scanners with 1.3 scan attempts per vial, 0.5 s using drop-down menus, and 1.7 s using paper. Few errors were observed. Sixty-four perception surveys were completed by inventory staff; barcode scanning users indicated fairly strong overall satisfaction with the method (74%), and

Abbreviations: AIVP ATG, Automated Identification of Vaccines Project Advisory Task Group; CSUQ, Computer System Usability Questionnaire; GTIN, Global Trade Identification Number; NACI, National Advisory Committee on Immunization; PECS, Protocol for Electronic Clinic Systems; PHAC, Public Health Agency of Canada; PHU, public health unit; VIDS, Vaccine Identification Database System.

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the majority agreed that barcode scanning improved client safety (84%) and inventory record accuracy (77%). However, 38% of barcode scanning users felt that individually scanning vials took longer than the other approaches and 26% indicated that this increased time would discourage them from adopting the method. Our study demonstrated good readability of barcodes but scanning individual vials for high-volume clinics was time-consuming; modifying the process will improve feasibility to facilitate adoption in Canada, while serving as an example for other countries considering this technology.

1. Introduction

The implementation of barcode scanning technology in hospitals and healthcare institutions in the United States has been found to effectively reduce the rate of human errors associated with dispensing, transcribing and administering medications [1–3]. The benefits of automatic entry of scanned data may also apply to record-keeping for vaccines, as reliable immunization records are necessary for basic surveillance, and studies have shown that 10–60% of immunization records are missing important information or contain errors [4–6]. Inaccurate records can result in unnecessary re-immunizations, vaccine supply tracking issues, and delays in the follow-up of adverse events including those related to specific lots.

To reduce manual data entry errors on inventory and client records, Canada's National Advisory Committee on Immunization (NACI) issued a recommendation in 1999 that barcodes be placed on all vaccine products approved for use in Canada [7]. A pilot project was then implemented with front line immunizers in Alberta and Manitoba, demonstrating a 48–69% reduction in the time to record data and a 33% reduction in immunization record errors using peel-off, tagged and direct barcodes instead of manual entry [8]. In light of these findings and in support of NACI's recommendation, the Automated Identification of Vaccines Project Advisory Task Group (AIVP ATG) was founded, including representation from the vaccine and clinical software industries, healthcare professional organizations, and standard setting organizations [9]. In 2010, AIVP ATG reached a consensus on vaccine barcode standards in Canada, including the placement of a Global Trade Identification Number (GTIN, a unique product identifier) and lot number on primary packaging, with expiry date as an optional addition [9]. Canadian vaccine manufacturers have committed to adhering to these new standards over the next few years [9], and the Public Health Agency of Canada (PHAC) has developed the Vaccine Identification Database System (VIDS), a web-based repository of information on all vaccines approved in Canada [10]. Vaccine manufacturers provide data (including GTIN, lot number and expiry date) for all of their products to PHAC, who is responsible for entering this information into VIDS; thus, when a vaccine vial's barcode is scanned, the information is downloaded into the electronic immunization or inventory record [9], eliminating the need for manual entry or paper-based recording.

Previous studies implementing barcode scanning on medications have employed linear barcodes containing a product identifier only [1–3]. However, placing a vaccine's GTIN and variable data (lot number and expiry date) on the limited space of a vial can only be accomplished with a two-dimensional (2D) matrix barcode (Fig. 1a). To facilitate future adoption of barcode scanning, several unknowns such as the barcode's readability and the incorporation of scanning primary packaging into vaccination clinic workflow must be first explored. As adoption of a new system will be met with resistance if it is unable to integrate into user workflow [11,12], it is also important to understand how potential users perceive barcode scanning of vaccines and identify process components requiring modification before this technology is implemented in vaccination settings. Therefore, we examined the feasibility of integrating barcode scanning into the inventory recording process in public health mass influenza vaccination settings by assessing the readability of the barcodes (Fig. 1b) and comparing the efficiency, accuracy and user perceptions of this technology with more conventional methods.

2. Methodology

2.1. Study design

In support of barcode scanning feasibility studies, a collaborative was established among key stakeholders including AIVP ATG, the PHAC/Canadian Institutes of Health Research Influenza Research Network (PCIRN), PHAC, Niagara Region in Ontario and Sanofi Pasteur Ltd. We conducted primary and secondary studies in Ontario public health units (PHUs) during the 2010–2011 seasonal influenza vaccination campaign. The primary study was a multicentre randomized trial while the secondary study employed an observational design (study flowchart is presented in Fig. 2). These studies received approval from the Health Sciences Research Ethics Board at the University of Toronto, Canada.

(a)

(01)07612345678900(17)100503
(10)AC3453G3

(b)

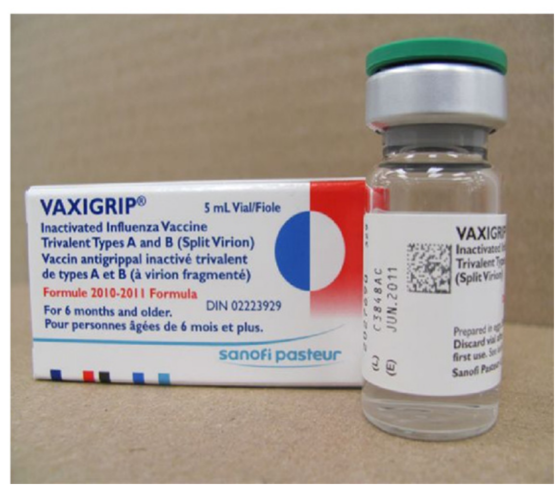

Fig. 1. (a) Example of a GS1 2D DataMatrix barcode: The barcode depicted includes a 14-digit Global Trade Identification Number (GTIN), lot number and expiry date and consists of printed squares or dots spiraling outwards from the centre of the symbol. (b) Ten-dose vial of influenza vaccine with a 2D matrix barcode including GTIN, lot number and expiry date (not the same barcode shown in Figure 1(a)): The product used in the study was commercially available, Canadian-labeled, Vaxigrip produced by Sanofi Pasteur Ltd. and licensed for distribution in Canada during the 2010/11 influenza season. Including the expiry date in the barcode is an optional labeling requirement as it can be determined through lot number. Lot number and expiry date will continue to appear in human readable form on vaccine primary packaging as per Canadian labeling requirements.

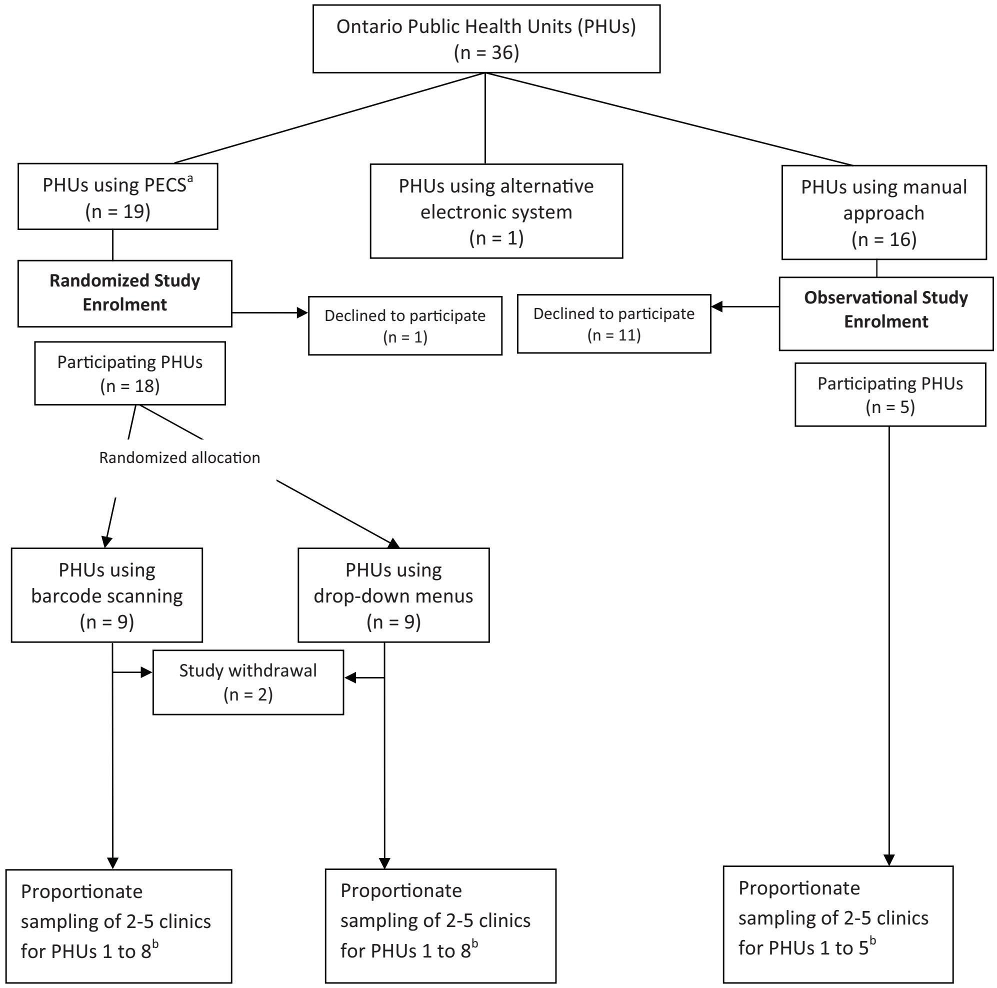

Fig. 2. Flowchart for randomized and observational studies. This figure depicts the study flow from recruitment to data collection. [a]PECS = Protocol for Electronic Clinic System (an electronic immunization data collection system) [b]Each of the barcode scanning and drop-down arms included six PHUs with populations < 200,000 (two clinic visits) and two PHUs with populations between 350,000-499,000 (four clinic visits); for the paper arm, there was one PHU with population < 200,000, two PHUs with populations between 350,000-499,000 and two PHUs with populations ≥ 500,000 (five clinic visits).

2.2. Primary study: site inclusion criteria and recruitment

All PHUs using Niagara Region's electronic immunization system, Protocol for Electronic Clinic Systems (PECS), who agreed to participate were randomized to either barcode scanning of vials or drop-down menu options to record vaccine inventory data (GTIN, lot number and expiry date).

PHUs randomized to the scanning arm were provided with scanners (PowerScan D8530 Handheld Scanner, Datalogic Mobile Inc.) and influenza vaccine packaged in vials that were compliant with the barcode standards: 2D matrix containing GTIN, lot number and expiry date (Fig. 1b).

Barcode scanning: Each vial was processed individually, which involved opening the outer box, removing and scanning the vial, and returning it to the box. When the vial was scanned, vaccine information was downloaded from VIDS into the inventory module of the PECS system (Fig. 3). After processing all vials, the inventory staff person clicked "submit".

Drop-down menu: All vials were sorted by vaccine name and lot number, and then counted; the inventory staff member selected the appropriate vaccine name, lot number and expiry date from a drop-down list which had been manually entered by a staff member when the PHU first received their vaccine shipment. After typing in the quantity of vaccine and selecting the vaccine name and lot number, the inventory staff person clicked "submit" (Fig. 3).

2.3. Primary study: data collection

For each participating PHU, we observed inventory recording for two to five immunization clinics, proportionate to the PHU's population size (<200,000 = 2 clinics; 200,000–349,999 = 3 clinics; 350,000–499,999 = 4 clinics; ≥500,000 = 5 clinics). After obtaining informed consent, we collected data on the following elements:

(i) *Efficiency*—Efficiency was defined as the time, in seconds, required to process clinic inventory. For PHUs randomized to barcode scanning, times measured included a total time (from start to end of inventory) and a batch time. Batch time was only recorded when inventory staff scanned two or more vials consecutively without completing other non-scanning tasks in between. Batch scan time consisted of the time to scan vials only and excluded the time spent performing other inventory-related tasks (opening vial boxes, returning vials to boxes after scanning, etc.). Total time for the drop-down menu method included the time to sort/count the vials and select the appropriate barcode(s) using the pre-populated drop-down menu.

(ii) *Vaccine inventory record quality*—We assessed the quality of the vaccine inventory record, as defined by the completeness and accuracy of data-fields including vaccine quantity, lot number and expiry date. Errors based on these measures were classified into two groups: *human error*s and *system errors*. Human

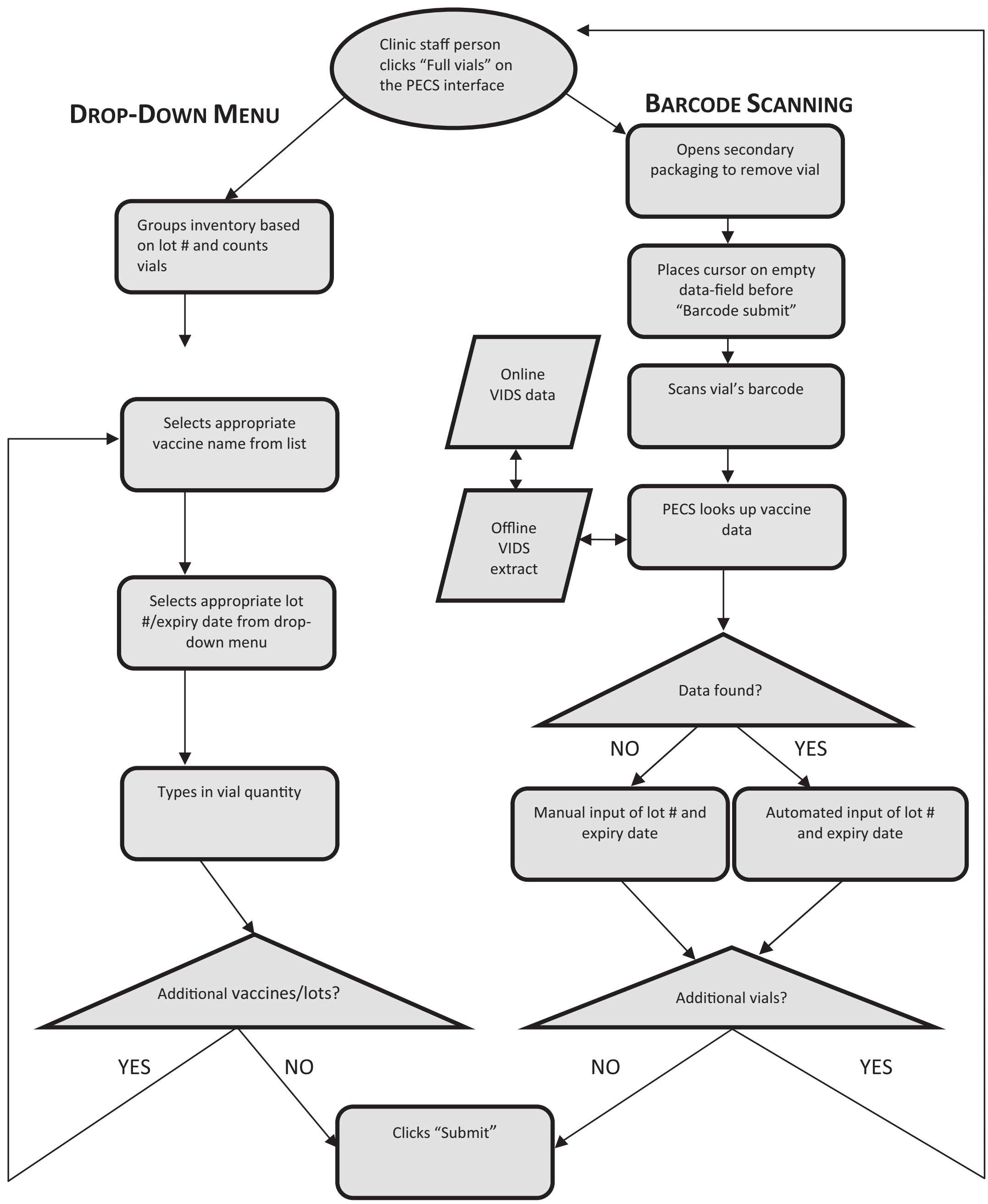

Fig. 3. Inventory method processes for the randomized study.

errors were inaccuracies caused by the staff member (e.g., miscounting the number of vials). System errors were caused by the computer application inaccurately recording the number of vials and/or lot numbers.

(iii) *Readability of barcodes*—For PHUs randomized to barcode scanning technology, we collected data on: (a) the number of scan attempts made for a given number of vials; (b) the number of vials for which manual entry of GTIN, lot number and expiry date was required, due to an unreadable barcode.

(iv) *User perceptions*—Inventory staff for each clinic completed a paper questionnaire, modified from the validated IBM Computer System Usability Questionnaire (CSUQ) [13]. Staff indicated their level of agreement using a 5-point Likert-like scale to statements regarding inventory recording applications: seven statements addressed the user's current method based on six key dimensions from the CSUQ (simplicity, speed, accuracy, satisfaction, ability to recover from mistakes and training); 12 statements asked barcode scanning users about logistical issues with the technology, and perceived benefits and detriments of the method; and five statements asked drop-down and paper users about their perceptions of barcode scanning. At the end of the vaccination campaign, an electronic version of the questionnaire was sent to staff that had been involved with inventory in at least one clinic that season, but had not yet completed the survey.

To assess whether readability and user perceptions were influenced by staff-specific factors, we recorded the number of staff involved with inventory at each clinic, the number of clinics for which the staff member had previously used the barcode scanner, and the staff member's self-reported comfort level (low/moderate/high) with computer applications.

Table 1a
Clinic site characteristics.

Characteristic	Randomized study ($n = 40$)		Observational study ($n = 21$)
	Barcode scanning: n (%)	Drop-down menu: n (%)	Paper form: n (%)
Number of clinic inventory sites ($N = 61$)	20 (32.8)	20 (32.8)	21 (34.4)
Location			
Public health unit	5 (25.0)	6 (30.0)	21 (100.0)
Community centre	14 (70.0)	9 (45.0)	0 (0)
School	1 (5.0)	1 (5.0)	0 (0)
Mall	0 (0)	2 (10.0)	0 (0)
Retirement/nursing home	0 (0)	2 (10.0)	0 (0)
Sites			
Urban	18 (90.0)	17 (85.0)	21 (100.0)
Rural	2 (10.0)	3 (15.0)	0 (0)
Week of site visit			
1st week of vaccine campaign	4 (20.0)	2 (10.0)	4 (19.0)
>1st week of vaccine campaign	16 (80.0)	18 (90.0)	17 (81.0)
Mean number of staff involved with inventory (range)	2 (1,4)	1	1
Number of sites >1 unique lot number	0 (0)	4 (20.0)	6 (28.6)
Number of clinics with ≥200 vials processed	2 (10)	0 (0)	7 (33.3)
Median number of vials processed per clinic (minimum, maximum)	30 (9250)	75.5 (40,150)	60 (30,343)

2.4. *Secondary study: site inclusion criteria, recruitment and data collection*

To complement the primary study, an observational study was conducted concurrently in a convenience sample of Ontario PHUs using paper-based approaches to data collection. The process generally involved the inventory staff person deciding on the number of vials to send to each clinic, counting the appropriate quantity, and recording vaccine name/lot number/expiry date and quantity on a paper form; in most settings, this information was then entered into a database.

All PHUs using paper-based data collection approaches to record vaccine inventory were invited to participate. As with the primary study, we visited two to five sites per PHU, and obtained written consent from the inventory staff before collecting data on efficiency, vaccine inventory record quality and user perceptions.

2.5. *Statistical analysis*

As it was unfeasible to accurately measure time and number of scans per vial, we used a weighted analysis method to estimate both average number of scans and time to scan one vial for all barcode scanning sites. Data collected were based on vial batches; to account for the varying levels of precision caused by the large range in batch size (1–240 vials), each batch was weighted by the number of vials in the batch. Two separate barcode scanning times were calculated, total time and batch time, with the latter excluding the amount of time required to open and close boxes as this step was not included in the drop-down menu and paper methods. For each inventory method, we examined histograms to assess the underlying distribution of mean time and calculated 95% confidence intervals from the weighted time data using normal approximation methods. We used an F-test to compare mean times across the three inventory methods. The bootstrap method was used to calculate confidence intervals for the average number of scans: we performed 10,000 bootstrapping replications to obtain robust non-parametric weighted estimates because the data were highly skewed, even after applying log and square root transformations.

We used the two-proportion z-test to compare the proportion of barcode scanning users with those of drop-down and paper users who agreed or strongly agreed to key statements in the user perceptions survey. To account for multiple comparisons, we adjusted the p values using Benjamini–Hochberg's method for controlling false discovery rates (FDR), which controls for the number of comparisons falsely declared significant.

As post-hoc analyses, we evaluated whether there were differences in responses between (i) respondents who were observed on-site and those who completed the survey after the vaccination campaign; (ii) a single health unit (Health Unit A) where barcode scanning was tested 3–4 weeks prior to implementation in the other PHUs, vs. the remainder of the PHUs using barcode scanning; and (iii) staff using barcode scanning for the first time and those users who had prior experience with this technology.

Data analysis was performed using STATA version 10.0 and the boots package in R Statistical Software.

3. Results

Sixteen of the 17 Ontario PHUs that used PECS for the 2010–2011 influenza campaign participated in the primary study, eight randomized to barcode scanning and eight randomized to the drop-down menu method (Table 1a). The secondary study comprised a convenience sample of five PHUs out of 18 (28%) recording inventory data on paper. From October to December 2010, we observed inventory recording for 20 clinics in each of the two primary study arms, and 21 clinics across the PHUs using paper. For 60% of the observed barcode scanning clinics, at least two staff members recorded inventory, compared to a single staff member per site for each of the other methods. Twenty-nine percent of clinics using paper and 20% of clinics using drop-down menus used two or three vaccine lots, while all barcode scanning sites had vaccine from a single lot.

Sixty-four staff members completed the user perceptions survey (Table 1b), representing 65% of all inventory staff members in 19 of the 21 participating PHUs; two small PHUs were excluded from the response rate because they did not provide information on the total number of staff who recorded inventory during their campaign. Among the surveyed staff, 31 (48%) used barcode scanners, 25 (39%) used drop-down menus and eight (13%) used paper to record inventory. The majority (97%) of respondents reported moderate to high levels of comfort using computer applications.

3.1. *Efficiency*

Mean time per vial was significantly faster using drop-down menus compared to paper and barcode scanning (drop-down menu = 0.5 s/vial, 95% CI: 0.3–0.7; paper = 1.7 s/vial, 95% CI: 1.5–2.3; barcode scanning = 4.3 s/vial, 95% CI: 3.5–5.2; p value < 0.01) (Table 2). When we factored in the time required for staff to open and close each vaccine vial box, the time increased considerably

Table 1b
Respondents' characteristics.

Characteristics	*N* (%)
Role of respondent	
Charge nurse	60 (93.8)
Support staff	4 (6.3)
Type of respondent	
Observed staff	38 (59.4)
Not observed staff	26 (40.6)
Number of years recording inventory	
≤1	22 (36.1)
2–5	22 (36.1)
>6	17 (27.8)
Current method for recording inventory	
Barcode scanning	31 (48.4)
Drop-down menu	25 (39.1)
Paper form	8 (12.5)
Method used in past vaccination campaigns	
Paper form	37 (59.7)
Drop-down menus	25 (40.3)
Typing data into an electronic system	41 (66.1)
Level of comfort using computer applications	
High	27 (42.2)
Moderate	35 (54.7)
Low	2 (3.1)

to 10.4 s/vial (95% CI: 6.7–14.0) for the barcode scanning arm. The minimum time to scan a barcode was 1 s/vial and the longest time was 64 s/vial. The median batch size was 10 vials (range: 1–240 vials). The results were similar when we excluded outliers three times longer than the mean.

3.2. Vaccine inventory record quality

Eleven inventory recording errors were observed during the study: five at barcode scanning clinics and six at paper clinics. Three of the errors at barcode scanning clinics were caused by a system malfunction (e.g., staff scanned the vials successfully, but the system did not update the number of vials accordingly) while the remaining two errors resulted from the inventory staff person neglecting to scan all vials. Four errors in paper clinics were due to inaccurately recording the number of vials, and two involved recording the wrong number of lots in inventory.

3.3. Readability of barcodes

The mean number of scans per vial was 1.34 (95% CI: 1.2–1.5) (Table 3). This was greater when observations were made at the first clinic using the vaccine inventory method compared to subsequent clinics (1st clinic = 1.5 scans/vial, 95% CI: 1.4–1.7; ≥2 clinics = 1.2 scans/vial, 95% CI: 1.1–1.4). No significant differences were observed based on staff's self-reported comfort level with computer technology nor when comparing single vs. multiple staff involvement with inventory processing.

As it was anticipated that scanning abilities might improve after the first batch of vials, we also plotted mean scans per vial for each staff person who scanned consistently-sized batches (between 5 and 20 vials in size) and examined this by date of observation; however, limited data were available for this analysis and no relationship was observed.

There were no vials which required manual entry of data due to an unreadable barcode.

Table 3
Readability of barcodes.

Factors	Average scans per vial (number of vials)	95% confidence intervals
Number of clinics in which staff member has used this inventory method, including current clinic		
1	1.5 (455)	1.4–1.7
2–5	1.2 (609)	1.1–1.3
>5	1.4 (65)	1.1–2.0
2 or more	1.2 (655)	1.1–1.4
Staff member's self-reported comfort level with computers		
High	1.3 (925)	1.2–1.4
Moderate	1.6 (149)	1.3–1.9
Low	1.3 (36)	1.1–1.5
Staff members involved with inventory per clinic		
Single	1.2 (394)	1.1–1.4
Multiple	1.4 (1011)	1.3–1.6

3.4. User perceptions

3.4.1. User perceptions of current vaccine inventory method

Respondents indicated favorable perceptions of their vaccine inventory method overall although some differences between approaches were evident (Table 4). A higher percentage of barcode scanning and drop-down menu users agreed that their method led to the recording of accurate vaccine information, compared to paper users (96% and 97% vs. 75% respectively). However, fewer barcode scanning users felt that it was easy to recover from a mistake, compared to the other inventory methods (barcode scanning = 57% vs. alternative methods = 88%). Drop-down menu users were more likely to agree that they could complete their tasks more quickly using their method (92%), compared to barcode scanning users and paper users (71% and 88%, respectively). After adjusting for multiple comparisons, drop-down menu users were significantly more satisfied with their method compared to barcode scanning users (100% vs. 74%, $p = 0.03$). No significant differences in response were observed between paper and barcode scanning users.

3.4.2. User perceptions of barcode scanning

Barcode scanning users demonstrated fairly strong acceptance of this method for every dimension other than speed: although the majority agreed that barcode scanning improved client safety (84%), nurse documentation (77%), and the accuracy of clinic inventory records (77%), nearly 40% of barcode scanning users felt that this process took longer than other methods for recording inventory and 26% of all respondents indicated that this increased time would discourage them from adopting this method.

3.4.3. Perceptions of drop-down and paper users regarding barcode scanning

Paper users were more likely to agree on the benefits of barcode scanning than drop-down users (86% vs. 59%, respectively,

Table 2
Efficiency of inventory recording methods: results of a time and motion study.[a]

Vaccine inventory method	Number of vials	Mean time per vial (s)	95% confidence intervals
Barcode scanning (scanning only)[b]	1139	4.3	3.5–5.2
Barcode scanning (entire process)	1139	10.4	6.7–14.0
Drop-down menu	1641	0.5	0.3–0.7
Paper form	2583	1.7	1.5–2.3

[a] F test = 29.13, p value < 0.0000001 (comparisons between paper form, drop-down menu and barcode scanning [scanning only]).
[b] Based on 132 batches of vials.

Table 4
Percentage of respondents who agreed/strongly agreed to statements regarding their vaccine inventory method.

	Barcode scanning (n = 31)	Drop-down menu (n = 25)	Paper form (n = 8)	FDR adjusted p values
Statements				
All inventory staff[a]				
It was easy to use this inventory recording method.	80.6	92.0	100	0.28
I was able to complete my tasks quickly using this method.	71.0	92.0	87.5	0.10
I did not receive sufficient training for this inventory method.	6.5	0	0	0.28
Whenever I make a mistake using this method, I can recover easily.	56.7	87.5	87.5	0.03[b]
I feel that this method leads to the recording of accurate vaccine information.	96.8	96.0	75.0	0.88
Overall, I am satisfied with this method.	74.2	100.0	71.4	0.03[b]
I feel that this method leads to the recording of more accurate vaccine information than other approaches that I have used.	85.2	87.5	33.3	
Barcode scanning users only				
I found that the barcode scanner did not scan consistently so I often had to scan vials more than once.	56.7			
I found it easy to scan vials successfully using the barcode scanner.	71.0			
Recording inventory using barcode scanning took longer than recording inventory using other approaches.	37.9			
The barcode scanning equipment took up too much room at my station.	18.5			
Based on time only, I would prefer to record vaccine inventory using a different method.	25.8			
Based on ability to accurately record inventory data, I would prefer to record vaccine inventory using a different method.	12.9			
I feel that recording inventory through barcode scanning will improve nurse documentation.	77.4			
I do not feel that the benefits of using barcode scanning at the point of inventory are worth the change in process.	32.3			
I feel that recording inventory through barcode scanning will improve the accuracy of clinic inventory records.	77.4			
I feel that using barcode scanning at the point of vaccination (to record vaccine data per client) will be beneficial in terms of reducing the number of errors on immunization records.	58.1			
Overall, I prefer recording inventory using barcode scanning over any approaches I have used in the past.	66.7			
Drop-down and paper users only				
I feel that scanning barcodes on vials would decrease the rates of errors associated with recording vaccine information, compared to my current approach.		59.1	85.7	
I feel that scanning barcodes on vials would take longer than my current approach of recording vaccine inventory.		36.4	42.9	
I feel that scanning barcodes on vials would be a major change to my current approach of recording vaccine inventory.		43.5	71.4	
I feel that using barcode scanning at the point of vaccination (to record vaccine data per client) will be beneficial in terms of reducing the number of errors on immunization records.		60.9	100	
I feel that barcode scanning of vials should be used to record inventory at my clinic.		39.1	57.1	

[a] Significance testing was conducted between responses from barcode scanning users and each of drop-down and paper method users for questions related to the six key dimensions outlined by the IBM Computer System Usability Questionnaire (CSUQ).
[b] Statistically significant difference between barcode scanning and drop-down users at p value <0.05.

for improved accuracy of inventory information; and 100% vs. 61%, respectively for improved client record accuracy). A smaller percentage of drop-down users felt that barcode scanning would be a major change to their inventory approach, compared to paper users (44% vs. 71%, respectively); however, a higher percentage of paper users felt that barcode scanning should be used to record vaccine inventory, compared to drop-down users (57% vs. 39%, respectively).

3.5. Post-hoc analyses

Staff who had used barcode scanning to record inventory for at least one previous clinic had more positive responses overall than those using it for the first time. Additionally, those staff who were employed in the health unit where barcode scanning was initially tested, had more favorable responses towards barcode scanning than other users. However, no statements were statistically significant after adjustment for multiple comparisons.

4. Discussion

To our knowledge, this study is the first to test the use of vaccine manufacturer-produced 2D barcode labels with GTIN, lot number and expiry date on vaccines in an immunization setting. Our results demonstrated readability of these barcodes and fairly positive user perceptions of this technology, but also suggested that in a setting where a single vaccine with limited lot numbers is administered, as is common in mass influenza vaccination clinics, scanning every vial into clinic inventory is more time-consuming than drop-down menu and paper-based methods. As with other early adoption projects involving new healthcare technology [14,15], incorporating barcode scanning technology into the inventory recording process for immunization clinics is logistically feasible but process modifications and increased user experience will likely be required before full benefits can be realized.

The barcode scanning process studied involved individual vial processing and was therefore more labour-intensive than drop-down or paper-based methods which required only a visual inspection of the vials followed by an overall count per lot number. Scanning each vial was necessary to assess the quality of the 2D barcodes with variable data, and we were able to demonstrate good readability. However, opening each box and processing every vial was a major change to conventional inventory workflow and barcode scanner users had lower satisfaction rates than drop-down menu users; the increased time for inventory entry could therefore hinder acceptance of this technology. Barcode scanning during inventory recording may be more efficient and more readily adopted in high-volume clinics if a less time-consuming workflow is used (e.g. only one box per manufacturer-sealed batch of ten vials is opened and scanned ten times, or a secondary packaging barcode is scanned instead). While adopting this new process would not identify packaging errors, to our knowledge such occurrences are extremely rare given manufacturers' production protocols and standards.

Even when tasks related to box-opening were omitted from the total time, barcode scanning time per vial was still longer compared to drop-down menu and paper methods. A handheld scanner was selected for the study as we pre-determined that its mobility may be helpful in this setting. The barcodes were only two squared centimeters in size and the scanner read the barcodes using a five-dot matrix, which necessitated that the central dot be aimed at the barcode for a successful scan; therefore, this process required good vision and dexterity, a possible challenge for some users. Use of different scanner technology may address this issue. A fixed scanner that is adhered to a stand on the staff member's workspace, or scanners with other aiming support such as a single-dot, may ultimately prove more user-friendly; these will be tested in subsequent studies to determine whether there is an alternative scanning system that results in improved user perceptions as well as increased efficiency. Increased experience is also likely to lead to quicker times as well as better perceptions of this method, as supported by our post-hoc comparison which indicated trends towards more favorable impressions of ease, speed and overall satisfaction among those who had used barcode scanning technology in at least one previous clinic, compared to staff who were using scanners for the first time.

Interestingly, paper-based users had more favorable perceptions of barcode scanning than drop-down menu users; this may be due to the latter group being more familiar with the individual vial scanning process given that they were trained alongside the barcode scanning users. Furthermore, as paper users had the lowest levels of satisfaction and poorest impressions of their method's accuracy in recording data, perhaps they were more open to a new approach than users of an electronic method such as drop-down menus which is likely perceived to be less vulnerable to human error.

Our survey results indicate that immunization clinic staff perceive barcode scanning technology to have good value in a vaccination setting, leading to improved client safety, more accurate and complete nurse documentation, and more accurate clinic inventory records. However, few errors were observed overall during the study period, making it difficult to compare accuracy of barcode scanning to the other methods. Additionally, given that this is the first time barcode scanning of vaccine variable data has been examined in a vaccination setting, we are unable to comment definitively on whether the barcode system errors are a function of the technology or simply associated with the early adoption phase and thus would be eliminated or reduced over time. However, given that past studies have demonstrated decreased rates of errors associated with barcode scanning as user experience increased and minor system changes were made to facilitate optimal use, we anticipate similar results [16].

Based on this study, we have numerous recommendations to facilitate adoption of this technology which may also reduce the risk of errors. Some health units designated one person to do all the scanning at every clinic; as the general consensus was that the scanning itself became much easier over time, efficiency could improve by designating certain staff members as inventory staff and training them very thoroughly. A multi-faceted approach to training (including a demonstration video, and laminated one-page scanning instructions and template) would be beneficial for these users. Training materials should clearly demonstrate the most efficient method of using the technology, and should comprehensively describe all steps, from attaching the scanner to the laptop at the start of the process to submitting inventory. Scanning technique should also be included in training to optimize efficiency and reduce repetitive motion injuries; holding down the scanner's button while positioning the scanner was found to be more successful than clicking the scanner several times. We observed that scanning vials in batches of 10 or more, rather than 1 by 1 (or in randomly sized batches), is more efficient. We have developed a users' toolkit to provide immunization staff with guidance on how to initiate the process of barcode scanning in their vaccination settings, and have included our recommendations for optimal scanning technique [17].

This study had several limitations. Only one vaccine lot number was used for all barcode scanning sites, and therefore we can only speculate that error rates would not likely change if multiple lot numbers were used within the same site since each vial is processed in the same way regardless of the number of lots. However, it is possible that correcting errors may be even more time-consuming with multiple lots than with single lots since correcting vial number counts would require more back-tracking. Additionally, it is possible that the true benefit of barcode scanning in comparison to other methods for recording inventory would be best evaluated in a setting with multiple vaccines and lots. For this study, the majority of clinics using drop-down menus had a limited number of lot numbers (<3), both per site and within the system, reducing the complexity and time required when selecting lot numbers for drop-down users; therefore, the possibility of making an error by selecting the wrong option on the menu was quite low, and may be the true reason for the lack of errors with this method and the favorable perceptions from its users. Also, we did not evaluate another source of drop-down error, that being inaccurate data entry at the time that the lot number/expiry date drop-down menu was populated. This step is not required for organizations using barcode scanning, and could serve as a source of error for sites using the drop-down menu. Finally, our observations of clinics using paper-based methods were based on a convenience sample and may not be representative of all organizations using this methodology.

Responses to survey questions about the barcode scanning process may have been more informative if they were separated from questions about opening the boxes, as discussions with staff often indicated that they felt fairly comfortable with scanning despite minimal experience but the box opening was a deterrent. Finally, given that each health unit using paper forms had only one or two trained inventory staff, the sample size for this group was very small ($n = 8$). The unbalanced sample size comparison with barcode scanning users likely prevented us from finding significant differences in responses between these groups. Our survey's small sample size also restricted the identification of significant findings in post-hoc analyses.

5. Conclusions

This study was the first to examine the feasibility of scanning 2D barcodes on vaccine primary packaging for immunization clinic inventory. As with the adoption of other healthcare technologies, including computerized physician order entry and barcode scanning of medications in hospital settings, there will be challenges to overcome during the transition to barcode scanning in vaccination settings [18,19]. Our results indicate that while barcode scanning is perceived to be beneficial in reducing recording errors, individual vial scanning for high-volume clinics is time-consuming and may hinder adoption of this technology. Our results and recommendations will help inform the development of efficient vaccination processes as barcodes with variable data are placed on vaccines in the coming years, not only in Canada but in other countries including the United States, where adoption of this technology for childhood vaccines is currently being considered [20]. Benefits of barcode scanning may be more evident in settings where multiple vaccines and lot numbers are used; to understand the logistics of integrating this technology into these settings, future studies should take place in sites such as physicians' offices and general public health immunization clinics.

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