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The integration of barcode scanning technology into Canadian public health immunization settings

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ABSTRACT

Background: As part of a series of feasibility studies following the development of Canadian vaccine barcode standards, we compared barcode scanning with manual methods for entering vaccine data into electronic client immunization records in public health settings.

Methods: Two software vendors incorporated barcode scanning functionality into their systems so that Algoma Public Health (APH) in Ontario and four First Nations (FN) communities in Alberta could participate in our study. We compared the recording of client immunization data (vaccine name, lot number, expiry date) using barcode scanning of vaccine vials vs. pre-existing methods of entering vaccine information into the systems. We employed time and motion methodology to evaluate time required for data recording, record audits to assess data quality, and qualitative analysis of immunization staff interviews to gauge user perceptions.

Results: We conducted both studies between July and November 2012, with 628 (282 barcoded) vials processed for the APH study, and 749 (408 barcoded) vials for the study in FN communities. Barcode scanning led to significantly fewer immunization record errors than using drop-down menus (APH study: 0% vs. 1.7%; $p = 0.04$) or typing in vaccine data (FN study: 0% vs. 5.6%; $p < 0.001$). There was no significant difference in time to enter vaccine data between scanning and using drop-down menus (27.6 s vs. 26.3 s; $p = 0.39$), but scanning was significantly faster than typing data into the record (30.3 s vs. 41.3 s; $p < 0.001$). Seventeen immunization nurses were interviewed; all noted improved record accuracy with scanning, but the majority felt that a more sensitive scanner was needed to reduce the occasional failures to read the 2D barcodes on some vaccines.

Conclusion: Entering vaccine data into immunization records through barcode scanning led to improved data quality, and was generally well received. Further work is needed to improve barcode readability, particularly for unit-dose vials.

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1. Introduction

Barcode scanning technology enhances patient safety, reduces errors involving drug administration, and increases the timeliness and accuracy of medication-related documentation [1–5]. Since 10–60% of immunization records are missing important information or contain errors [6–9], possibly due to the small print used for lot number and expiry date on vaccine vials, the value of barcode scanning may extend to vaccines. In 1999, Canada's National Advisory Committee on Immunization (NACI) recommended placing barcodes on vaccine products to automate the recording of vaccine-related data in electronic systems [10].

The Public Health Agency of Canada (PHAC) leads the Automated Identification of Vaccines Project Advisory Task Group (AIVP ATG), which includes representation from the vaccine industry, healthcare professional organizations, and barcode standard-setting organizations. With a mandate of providing leadership and support for developing and implementing vaccine barcodes in Canada [11], AIVP ATG reached a consensus on vaccine barcode standards in 2009. These include placing two-dimensional (2D) barcodes, with unique Global Trade Item Number (GTIN) and lot number, and optional expiry date, on primary packaging (Fig. 1) [11]. Based on the GS1 System of Standards, the GTIN is a global standard for product identification. It is the foundation for electronic processes such as data synchronization and barcode scanning, with resultant improvement in operational efficiencies, cost reduction, and patient safety [12]. Canadian vaccine manufacturers have committed to adhering to the barcode standards by 2016 [13].

To support barcode scanning feasibility studies, a collaborative was formed among AIVP ATG, the PHAC/Canadian Institutes of Health Research Influenza Research Network (PCIRN), PHAC, and Sanofi Pasteur Ltd. We previously studied barcode scanning of influenza vaccine vials for recording inventory in mass immunization clinics and found high barcode readability and favorable user perceptions [14]. However, we observed no improvement in record accuracy, likely because most clinics used a single influenza vaccine lot; the benefits of barcode scanning may be more apparent in settings where multiple vaccines are being used, resulting in a greater potential for errors. The objective of this study was to compare barcode scanning with manual electronic approaches for recording individual-level immunization data for a variety of vaccines administered in public health settings.

2. Methods

2.1. Study design

We conducted intervention-control feasibility studies in two public health settings. The intervention involved scanning the following vaccines labeled with 2D barcodes containing GTIN, lot number, and expiry date: Pediacel® (Diphtheria, Acellular Pertussis, Tetanus, Polio, *Haemophilus influenzae* type b), Quadracel® (Diphtheria, Tetanus, Acellular Pertussis, Polio), Adacel® (Tetanus, Diphtheria, Acellular Pertussis), Td Adsorbed (Diphtheria, Tetanus), Adacel®-Polio (Tetanus, Diphtheria, Acellular Pertussis, Polio), and Vaxigrip® (Influenza). All vaccines used are listed in Table 1.

We compared the collection of vaccine data (vaccine name, lot number, and expiry date) by: (1) barcode scanning of vaccine vials with 2D barcodes (listed above); and (2) existing methods of entering vaccine information into the electronic systems for non-barcoded vials. We used post-immunization chart audits, time-and-motion studies, observation recording, and telephone interviews to compare the data collection approaches.

We received ethics approval from the Health Sciences Research Ethics Board at the University of Toronto, Canada.

Table 1
Vaccines used at study sites.

Vaccine name	Manufacturer	Packaging
Barcoded vaccines		
Adacel®	Sanofi Pasteur	Single-dose vial
Adacel-Polio®	Sanofi Pasteur	Single-dose vial
Pediacel®	Sanofi Pasteur	Single-dose vial
Quadracel®	Sanofi Pasteur	Single-dose vial
Td Adsorbed®	Sanofi Pasteur	Single-dose vial
Vaxigrip®*	Sanofi Pasteur	Multi-dose vial
Non-barcoded vaccines		
Boostrix ®	GlaxoSmithKline	Pre-filled syringe
Engerix B®	GlaxoSmithKline	Single-dose vial
Gardasil®	Merck	Single-dose vial
Havrix®	GlaxoSmithKline	Pre-filled syringe
Imovax Polio ®	Sanofi Pasteur	Pre-filled syringe
Ixiaro®	Novartis	Pre-filled syringe
Menactra®	Sanofi Pasteur	Single-dose vial
Pneumovax®	Merck	Single-dose vial
Prevnar®	Pfizer	Pre-filled syringe
Recombivax	Merck	Single-dose vial
Rotarix®	GlaxoSmithKline	Pre-filled syringe
Twinrix ®	GlaxoSmithKline	Pre-filled syringe
Typherix®	GlaxoSmithKline	Pre-filled syringe
Typhim Vi®	Sanofi Pasteur	Pre-filled syringe
Vivaxim®	Sanofi Pasteur	Pre-filled syringe

* Used at Study Site 2 only.

2.1.1. Study Site 1: Algoma Public Health, Ontario

The study was performed in Algoma Public Health (APH), one of the 36 local public health units in Ontario, Canada. APH serves a population of 115,870 (2011) [15], delivering the majority of vaccines in Sault Ste. Marie, Ontario and the surrounding area through two general weekly immunization clinics (~100 to 160 vaccines administered per week) (personal communication, Susan Berger, APH). Routine childhood and adult vaccines are given as well as travel-related vaccines. We recruited Intrahealth Canada Ltd., a British Columbia-based electronic medical record (EMR) vendor who added barcode scanning functionality to their *Profile* software system so that their client APH could participate (*Profile* immunization screen shown in Fig. 2) [16].

For barcoded vaccines, the immunizers scanned the vial to populate the client's record with the vaccine information (name, lot number, expiry date). For non-barcoded vaccines, the immunizers used *Profile*'s conventional method of recording vaccine information using drop-down menus that included all vaccines in inventory.

Immunization staff were provided with scanners (DS4208-HC Scanner, Motorola Ltd., United States, $260 CAD) with stands (Intellistand for DS42xx series, Motorola Ltd., United States, $39), and each nurse was trained on a one-on-one basis using dummy vials by an APH staff member who was experienced with barcode scanning.

2.1.2. Study Site 2: First Nations communities, Alberta

Our second study site was First Nations (FN) communities in Alberta. Those belonging to First Nations are Aboriginal people in Canada who are neither Inuit nor Metis (having Aboriginal and European heritage) [17]. Research agreements were developed with four First Nations communities to conduct full or partial data collection: Siksika Nation (on-reserve population [2011], 2858), Stoney First Nations (on-reserve population, 407), Kehewin First Nation (on-reserve population, 900), and Cold Lake First Nations (on-reserve population, 1235) [18]. OKAKI Health Intelligence is an Alberta-based immunization data collection software vendor that provides the *Community Health and Information Program* (*CHIP*) software to >30 First Nations communities. They upgraded their system in spring 2012 to include barcode scanning functionality

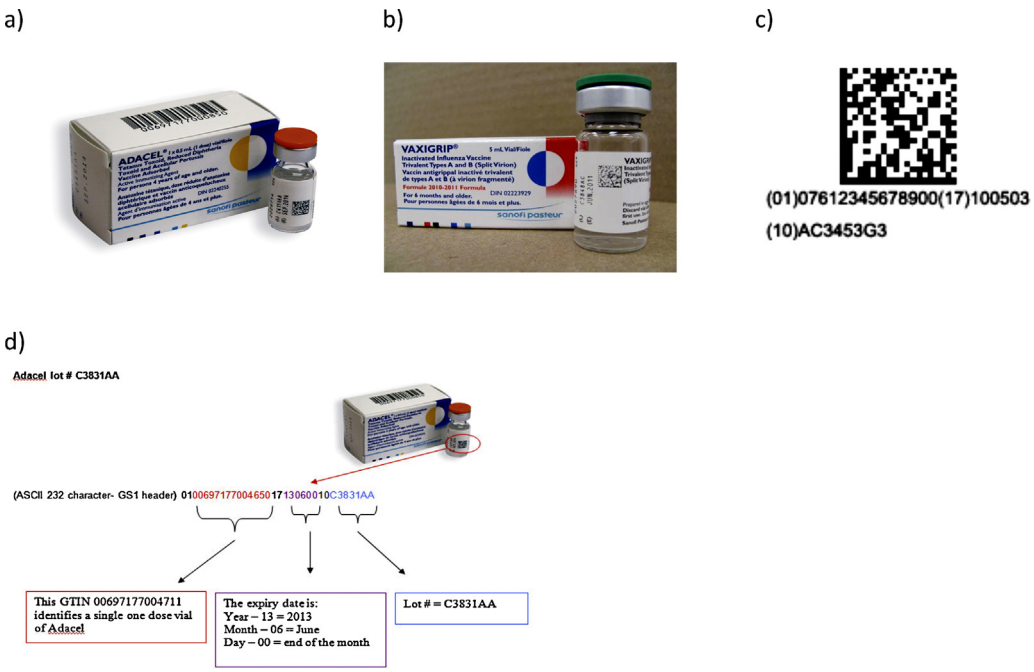

Fig. 1. (a) Vial of Adacel®: Adacel®'s packaging is a single-dose vial containing 0.5 mL of vaccine; (b) Vial of Vaxigrip®: Vaxigrip®'s packaging is a multi-dose vial containing 5.0 mL of vaccine; (c) Example of a GS1 DataMatrix: A two dimensional (2D) barcode (GS1 DataMatrix symbology) consists of printed squares or dots, spiraling outwards from the center of the symbol. The above 2D barcode includes a 14-digit Global Trade Item Number, (GTIN), expiry date and lot number. 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. By embedding a GS1 GTIN into a barcode to identify a vaccine product, healthcare providers have the ability to electronically scan a vaccine product and automatically populate patient health records or immunization registries with up-to-date, accurate product information pulled from the Vaccine Identification Database System (VIDS). Manufacturers are responsible for (i) providing standardized product information for each vaccine GTIN in ECCnet Registry, a national product registry used by industry to provide accurate product information based on global standards; and (ii) publishing this information to data recipients such as VIDS; (d) Description of 2D barcode components: The barcode consists of product specific GTIN, the expiry date and lot number information.

[19]. *CHIP* requires staff to enter data through a combination of typing data and drop-down menus (Fig. 3).

For barcoded vaccines, immunizers scanned the vial to populate the client's record with the vaccine name and lot number; expiry date was not recorded. For non-barcoded vaccines, immunizers used *CHIP*'s conventional methods (i.e., typing in lot number and using drop-down menus for vaccine name and other data).

Immunization staff were provided with scanners (DS6700, Motorola Ltd., United States, $522) and stands (Intellistand for DS67xx series, Motorola Ltd., Unites, States, $55), as well as a group training session by OKAKI staff to demonstrate the scanning process.

2.2. Data collection

After obtaining informed consent from the immunization nurses, we collected the following:

(i) *Immunization record quality* – After the immunizer recorded vaccine data, we audited the record, examining the completeness and accuracy of the relevant data fields (vaccine name, lot number, and expiry date [the latter for APH only]) compared to the information on the vial.

(ii) *Time* – We measured total time required to record vaccine data into immunization records, comprising time required for immunizers to either scan the barcode data into immunization records or enter it using the manual method. "Start time" of an observation was when the nurse accessed the immunization data entry screen while "end time" was submission of data for that vial. For barcoded vials, a scan time was also recorded, starting from the time the vial was placed under the scanner to the time the vial was scanned successfully, indicated by the population of data into the client's record. These data were captured by an Excel macro to time the process, with a stopwatch used as backup.

(iii) *Barcode readability* – For barcoded vaccines, we recorded the number of vials for which the manual method of inputting vaccine data was required due to an unreadable barcode. Nurses were instructed that if they felt that a particular barcode could not be scanned, they could revert to the manual method at their own discretion.

(iv) *User perceptions* – We conducted semi-structured telephone interviews with immunizers following the data collection period to understand perceptions of the software systems with respect to integration into staff workflow, ease of use, and accuracy. As nurses were not assigned to a single treatment arm, each had experience with both methods (i.e., barcoding and manual). All immunizers were invited to be interviewed.

2.3. Sample size

Based on earlier work and information from immunization managers, we assumed a 1% data entry error rate with barcode scanning and 5% data entry error rate with the manual method. Collecting data for 666 vaccinations per case study (333 barcoded vials and 333 non-barcoded vials) allowed us to detect this difference in data quality with 80% power and 5% alpha-level.

2.4. Statistical analysis

We compared data quality of the immunization records using *z*-tests, where the proportions of immunization records with one

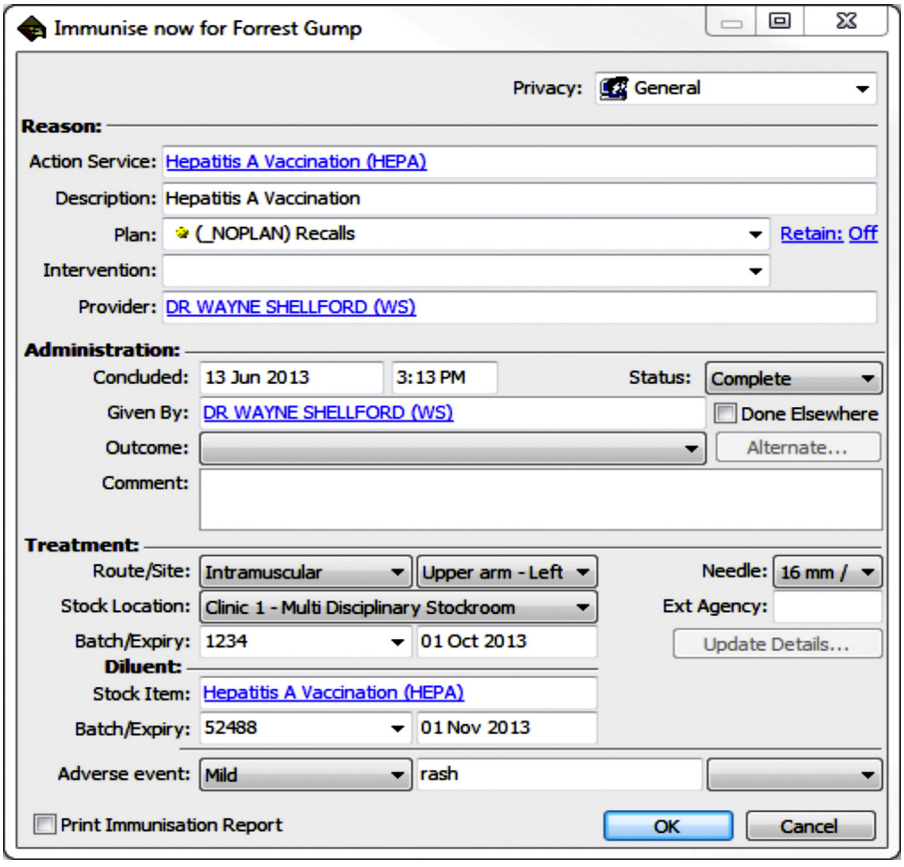

Fig. 2. Immunization data entry screen of Profile. This figure depicts the screen that is used by immunization staff to enter vaccine data into the client's immunization record in Profile.

or more errors in the vaccine name, lot number, or expiry date fields for barcoded vials and non-barcoded vials were compared. We used the *t*-test to compare the average time required by immunization staff to record vaccine data using barcode scanning and the manual method. We assessed readability of barcode scanning by recording the number of barcoded vials that could not be scanned successfully. Analyses were performed using STATA 10 (StataCorp LP, College Station, United States).

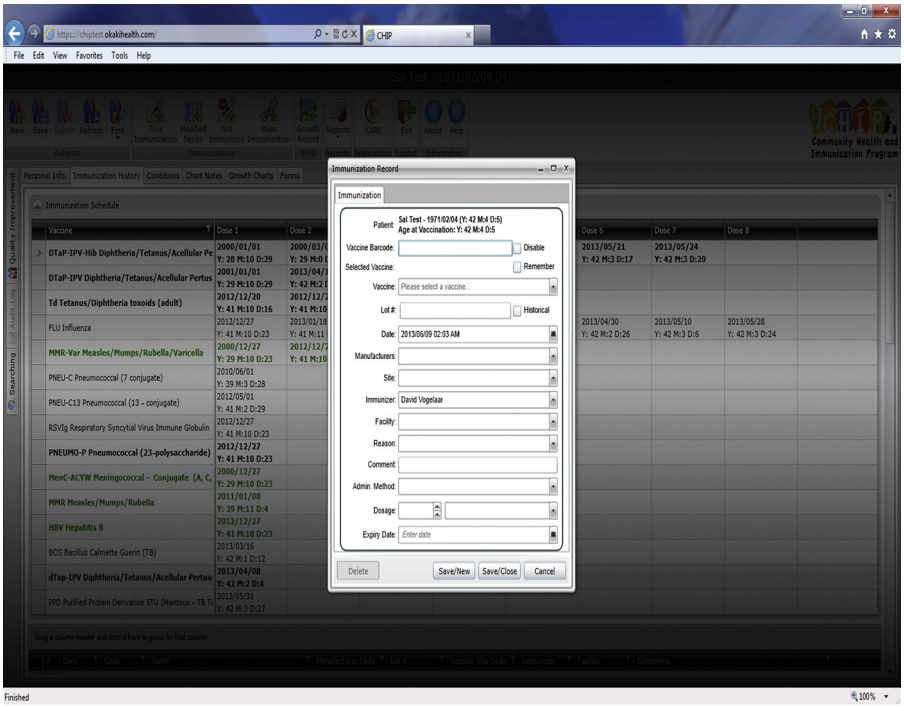

Fig. 3. This figure depicts the screen that is used by immunization staff to enter vaccine data into the client's immunization record in CHIP.

The interviews were imported into qualitative analysis software (N-Vivo Version 9.0, QSR International, Burlington, United States) to facilitate data organization, review, coding, analysis, and exploration of themes that emerged from the data. Two team members (JAP and SQ) read each transcript once to get an overall sense of the data, and then again to code. Consensus decision-making was used to arrive at mutually agreed-upon coding.

3. Results

For Study Site 1, we collected data from 282 barcoded vials and 346 non-barcoded vials over 21 immunization clinic days between July 23 and October 4 2012 (Table 2). For Study Site 2, full data collection was completed in Siksika Nation and Stoney Nations for 408 barcoded vaccine vials and 341 non-barcoded vaccine vials over 25 clinic days from October 15 to November 23 2012 (Table 2). User perception data were also collected in Kehewin First Nation and Cold Lake First Nations.

3.1. Data quality

Study Site 1: We observed zero errors with barcode scanning, compared to seven errors in six immunization records (1.7%) in the manual arm ($p = 0.04$) (Table 3). The latter included one instance of the nurse recording the wrong vaccine name, and three instances each of incorrectly recorded lot numbers and expiry dates.

Study Site 2: We observed zero errors for the barcode arm and 26 errors in 19 immunization records (5.6%) for the non-barcode arm ($p < 0.001$) (Table 3). Eight errors were from choosing the wrong vaccine name from the drop-down menu, and 18 were from typing lot numbers incorrectly.

3.2. Time

Study Site 1: Mean time per vial to enter vaccine data did not differ between scanning and manual methods (27.6 s vs. 26.3 s; $p = 0.39$) (Table 4). The mean scan time was 8.8 s/vial (range = 0.1–94.5 s).

Study Site 2: Barcode scanning was significantly faster than entering data using the manual method (30.3 s vs. 41.3 s; $p < 0.001$) (Table 4). For scanning alone, the mean time was 4.4 s/vial (range = 0.29–58 s).

3.3. Readability

Study Site 1: Immunizers reverted to the manual method for data entry for 15 vials (5.3%). The mean scanning time before the nurse switched to manual entry was 32.9 s (range = 1.6–87.2 s).

Study Site 2: Immunizers switched to the manual method for four (0.98%) barcoded vials. The mean scanning time before switching to manual entry was 5.1 s/vial (range = 1.2–15.3 s).

3.4. User perceptions

Study Site 1: We conducted interviews with eight immunization nurses (the remaining two were trainees who only administered non-barcoded vaccines during the study). All reported that the training was adequate and appreciated the opportunity to practice with dummy vials. They also noted that the designated resident "barcode scanning expert" (nurse who learned the process early on) was valuable in supporting the adoption of the technology, helping to resolve issues that arose. All noted the benefits of scanning for recording accurate and complete information.

Nearly all interviewees mentioned early difficulties with scanning, leading to the discovery that the pattern on the countertop surface was creating interference. A blank white sheet placed under the scanner improved the scanning success rate. Many nurses felt that the barcode readability was not consistent; using a particular technique to scan one vial successfully did not always translate into success with subsequent vials, and multiple attempts were often needed.

> "I would like it [barcode scanner] to be more sensitive because [. . .] our site was doing it yesterday and there were some [scanners] that you have to, turn and turn and up and down, and it takes. . . I could've typed it in ten times by the time it actually scanned it."
> - *Immunization Nurse #2*

Four participants expressed a strong willingness to continue with scanning as is, and were happy with the scanner and technique they used during this study.

> "Although there were some times with certain vaccines it [scanner] doesn't scan as well, that can become frustrating but overall I liked it [scanning]. I thought, you know, we thought it was more accurate, we were reducing human error. I thought it was great!
> - *Immunization Nurse #6*

The remaining four felt that a more sensitive scanner was needed to improve acceptance. Resistance to change was acknowledged as a potential barrier to adopting this technology, beyond the logistics of the new method:

> "[. . .] it's a matter of changing, if you're ever in a change mode, it takes a while for people to adjust to something and if you don't come from the same mindset as someone who has to do reports, then you don't have the same appreciation. It's one more thing to do, why don't we just stick with drop-down kind of thing."
> - *Immunization Nurse #5*

Study Site 2: Of the seven immunization nurses interviewed, all were satisfied with the training, and found the technique easy and fast to learn; one mentioned that a one-on-one scanning session would be helpful in the future. These nurses indicated that they enjoyed the benefits of barcode scanning and were willing to continue using it for recording vaccine data.

> "It's more accurate, you don't have to try to decipher people's writing and people didn't write all the information so there's all that human error so this way it's all pre-programmed so it's [scanning's] a lot more efficient in my mind."
> - *Immunization Nurse #13*

All of the nurses commented that the barcodes could not always be read by the scanners, either not working immediately or at all despite the same technique being successful with previous vials. This was a source of frustration for the majority of the nurses interviewed. Three nurses mentioned scanning ease for influenza vials, but challenges with single-dose childhood vaccines, specifically Pediacel.

> "I can say though that because flu are multi-dose vials, it's a lot easier than the smaller Pediacel. It's easier to scan the other one sometimes if you're not holding it exactly right, it [scanner] doesn't read it [vial]. But on flu, either it's a different kind of barcode or it's just bigger, but it's a lot easier. When you're going in, once you found your spot, especially with the Pediacel, it worked more consistently, like right away. And then sometimes, one of them [vials] would be frustrating and there were a couple that I gave up on. I think after five times, you get frustrated."
> - *Immunization Nurse #12*

Several nurses felt that the technology could be useful in other immunization settings if the barcode readability issue was resolved, proposing that current barcodes may be too small or too light in color. Another mentioned that barcode scanning may

Table 2
Case study characteristics.

Characteristic	Algoma Public Health	First Nations communities
Number of clinic days observed	21	25
Number of immunization nurses	10	9
Mean number of vials/day/clinic (min, max)	29 (8, 51)	26 (2, 72)
Total number of barcoded vaccine vials	282	408
Total number of non-barcoded vaccine vials	346	341
Number of unique sites	1	2

Table 3
Error rates for barcoded and non-barcoded methods, per study site.

	Algoma Public Health				First Nations Communities			
	Non-barcode errors		Barcode errors		Non-barcode errors		Barcode errors	
	n	%	*n*	%	*n*	%	*n*	%
Vaccine name	1	0.3	0	0	8	2.4	0	0
Lot number	3	0.9	0	0	18	5.3	0	0
Expiry date	3	0.9	0	0	N/A	N/A	N/A	N/A
Total errors by record fields	7	0.7	0	0	26	3.8	0	0
Total errors by immunization record	6	1.7[a]	0	0[a]	19	5.6[b]	0	0[b]

[a] Fisher's exact test p-value = 0.035.
[b] Fisher's exact test p-value < 0.001.

eliminate even more errors if introduced earlier in the immunization data recording process (i.e., prior to vaccine administration), so that it could alert immunization staff to expired vaccines.

4. Discussion

We demonstrated the feasibility and benefits of barcode scanning compared to manual electronic approaches of recording individual-level immunization data for routine childhood and influenza vaccines in public health settings. Barcode scanning was more accurate than drop-down menus, and is faster for recording vaccine data compared to typing vaccine lot numbers. By thoroughly testing barcode scanning in live settings, we gained a better understanding of the complexities of its integration into existing workflows.

Adopting new technologies in healthcare settings has often introduced risks such as increased user workload, communication breakdowns, and fragmentation of information [20,21]. In both case studies, our readability data indicate that users may expect immediate success with scanning. Some nurses switched from barcode scanning to the manual method when vial barcodes were not read promptly (i.e., within 2 s). Therefore, more work is needed to ensure optimal barcode readability. It is important to choose a scanner that is both affordable for public health agencies and sufficiently sensitive to read the small barcodes. GS1 Canada has developed a scanning guide to aid new adopters in this decision [22]. Adequate training must be provided to ensure comfort with scanning and the optimal technique, and users must have sufficient technical support. Our interviews indicated that users were very satisfied with the training sessions, and that the combination of one-on-one instruction, practice time with dummy vials, and an on-site barcode scanning expert is an ideal training model. Finally, vaccine manufacturers must ensure that their production lines are printing barcodes at an adequate darkness for scanning. Study participants reported that the smaller unit dose vials were most problematic; although the barcodes are the same size as those on multi-dose influenza vials, the smaller size of the actual vial leads to greater curvature of the barcode, which may explain the scanning difficulties. These types of challenges have been previously identified in studies evaluating the use of barcode scanning technology for medication administration in hospitals and healthcare institutions in North America. While scanning has been found to effectively reduce the rate of human errors associated with dispensing, transcribing and administering medications [1,4,5], it has also been problematic to users for reasons including troublesome scanners, barcode not being readable (smudged, torn, etc.), and inadequate training [21].

Our interviews with immunization staff also demonstrated that users anticipate that this technology will improve record quality and efficiency. The workflow used in this evaluation (scanning after vaccine administration) was chosen because of the nursing practice of recording vaccine information into immunization records following vaccination rather than before, in case the vaccine does not end up being administered. However, it may be worthwhile to consider alternative processes that include scanning prior to

Table 4
Comparison of time (s) between barcoded and non-barcoded methods, per study site.

Vaccine type	*n*	Mean	95% CI	Median	Minimum, Maximum
Algoma Public Health					
Complete immunization process (per vial)					
Non-barcode	346	26.3	24.6–27.9	21.7	6.4, 121.6
Barcode	282	27.6	25.5–29.7	22.9	1.3, 140.1
Barcode scanning only (per vial)					
Barcode	282	8.8	7.1–10.4	3.8	0.1, 94.5
First Nations Communities					
Complete immunization process (per vial)					
Non-barcode	341	41.3	38.9–43.8	37.0	10.2, 203.0
Barcode	408	30.3	28.8–31.9	28.0	2.0, 116.0
Barcode scanning only (per vial)					
Barcode	408	4.4	3.8–5.0	2.0	0.3, 58.0

vaccine administration so that issues such as wrong vaccine, recalled lot number, or expired product can be identified before the client is immunized.

These results can facilitate the adoption of this approach in Canada as well as elsewhere. The U.S. has recently adopted the Canadian vaccine barcode standards to promote harmonization, and consequently vaccine manufacturers are beginning to alter their U.S. product labeling to include 2D barcodes [23]. Investigators at the Centers for Disease Control and Prevention have initiated a pilot project designed to determine best practices for labeling and tracking vaccines using 2D barcodes [24].

Our study had several limitations. First, we did not examine the effect of vaccine packaging type on outcomes. Packaging types can vary, with single-dose vials, multi-dose vials, and prefilled syringes. Non-barcoded vaccines for both study sites were single-dose vials or pre-filled syringes. For Study Site 1, all of the barcoded vaccines used were single-dose, while for Study Site 2, influenza vaccines in multi-dose vials were used, in addition to single-dose vials and pre-filled syringes. Given that single-dose vials are smaller than multi-dose vials, and therefore have greater curvature, it is possible that the observed difference between the two arms in Study Site 2 may have been larger than it would have been if only vaccines with single-dose vials were used. Second, APH had adopted *Profile* only three months prior to the study, therefore the time required to record vaccine data may have been greater due to unfamiliarity with a new system. Third, the number of vaccinations at APH during the pre-determined data collection period was lower than anticipated, and therefore we were unable to meet our sample size requirements for barcoded vaccines. This may have resulted in our inability to detect a significant difference in data quality between barcode scanning and manual methods. Fourth, we included nurse trainees in our observation period at APH, and it is possible that their times to record vaccine data may be higher than for nurses, due to their limited experience; however, given that only five of the 346 observations for non-barcode vials were based on data recording by trainees, the impact on our study results was minimal. Fifth, in the FN study, one of the scanners was an older unit, which may have caused delays. Sixth, several nurses in the FN study did not respond to our interview requests. Although there were nine nurses observed in the FN study, there were additional nurses in the two participating communities in which we conducted interviews only without doing on-site observations. Therefore, there were several nurses that did not respond to our request for an interview. These individuals may have different opinions than those who responded. Finally, the comparisons for both case studies involved completely electronic methods; since many public health settings employ paper-based immunization data collection, comparing with paper methods may have increased generalizability.

5. Conclusions

Our study has demonstrated the benefits of barcode scanning of routine vaccines in two diverse public health settings. Barcode scanning has good acceptability, and improvements in data quality are evident, particularly when compared to the combination of typing in lot number and the use of drop-down menus for other data fields. However, further work is needed to understand and improve barcode readability. Future studies should focus on additional vaccination settings such as physician offices, schools, and pharmacies.

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