Sample collection and sample handling errors submitted to the transfusion error surveillance system, 2006 to 2015

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BACKGROUND: In Canada, transfusion-related errors are voluntarily reported to a tracking system with the goal to systematically improve transfusion safety. This report provides an analysis of sample collection (SC) and sample handling (SH) errors from this national error-tracking system.

STUDY DESIGN AND METHODS: Errors from 2006 to 2015 from 23 participating sites were extracted. A survey was conducted to obtain information regarding institutional policies. Samples received in the blood bank were used to calculate rates. "Wrong blood in tube" (WBIT) errors are blood taken from wrong patient and labeled with intended patient's information, or blood taken from intended patient but labeled with another patient's information.

RESULTS: A total of 42,363 SC and 14,666 SH errors were reported. Predefined low-severity (low potential for harm) and high-severity errors (potential for fatal outcomes) increased from 2006 to 2015 (low SC, SH: 13-27, 3-12 per 1000; high SC, SH: 1.9-3.7, 0.5-2.0 per 1000). The WBIT rate decreased from 12 to 5.8 per 10,000 between 2006 and 2015 ($p < 0.0001$). The overall WBIT rate was 6.2 per 10,000, with variability by site (median, 0.3 per 10,000; range, 0-17 per 10,000). Sites with error detection mechanisms, such as regrouping second sample requirements, had lower error rates than sites that did not (SC, SH: 12, 1 per 1000 samples vs. 17, 3 per 1000 samples; $p < 0.0001$).

CONCLUSION: WBIT rates decreased significantly. Low-severity error rates are climbing likely due to increased ascertainment and reporting. Prevention studies are necessary to inform changes to blood transfusion standards to eliminate these errors.

Avoidance of ABO-incompatible transfusions is an important aspect of safe health care, as it is listed as one of five "never" events by the Canadian Patient Safety Institute.[1] Errors in the transfusion process can lead to adverse transfusion events, including acute hemolytic transfusion reactions and death.[2,3] To reduce errors, various national hemovigilance programs were implemented to monitor transfusion-related errors.[4-6] Factors that have influenced the reduction of such errors include machine-readable technologies interfacing between patients and their therapies, although

ABBREVIATIONS: ED(s) = emergency department(s); ePPID = electronic positive patient identification; OR(s) = operating room(s); SC = sample collection; SH = sample handling; TESS = Transfusion Error Surveillance System; WBIT = wrong blood in tube.

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costs and logistical challenges have been barriers to wide implementation.[7,8]

The Transfusion Error Surveillance System (TESS) was launched in 2005 to systematically track transfusion-related errors in Canada and is funded by the Public Health Agency of Canada. It seeks to improve transfusion practice by tracking transfusion-related errors and near-misses, providing information to users on system failures, enabling peer benchmarking, and providing a tool to track improvement in care with system changes. Errors reported to TESS are classified as low, medium, or high severity, based on their potential harm to a patient. TESS is an anonymous error-tracking system in which the patient, clinical team members, and hospital are not identifiable to ensure high levels of voluntary reporting.

A previous TESS report attributed the highest frequency of errors to sample collection (SC) and sample handling (SH) between 2005 and 2010.[9] The Public Health Agency of Canada reported similar results in 2013 of SC and SH errors to account for 36.2% and 14.4% of all errors, respectively.[10] SC errors relate to the sample tube, whereas SH errors take into account paperwork and transport of a sample. Sample mislabeling is common and poses a risk of several types of high-severity SC events. According to one study, samples that do not meet labeling standards are 40 times more likely to have a blood grouping discrepancy.[11] Similarly, one center in Canada has routinely tested rejected samples to increase detection of wrong blood in tube (WBIT) events, finding 91 of 5941 (one in 65) "extra WBITs" among rejected samples between 2012 and 2017, a 55-fold higher rate (66 of 239,810) than in acceptable samples (personal communication, Ann Wilson, McGill University Health Centre, Quebec, December 28, 2017). Therefore, these errors have the potential to compromise patient safety, highlighting the need to develop reliable preventative systems. In 2003, Dzik and colleagues[12] reported 6.1 per 1000 mislabeled samples in an international, multi-institutional study. In 2010, the Q-probes group reported 11.2 per 1000 mislabeled samples and in 2017 reported 7.4 per 1000, showing little change over the 7 years.[13,14] Despite numerous publications highlighting the prevalence of these errors, there has been no decrease in rates of these errors over time, suggesting that system-wide changes will be required to eliminate these hazards.

A worrisome error is WBIT events with a potential for an ABO-incompatible transfusion if not detected with a discrepancy with a historical blood group. WBIT occurs when a sample is labeled for patient A, who is in need of a transfusion, but the blood in the tube was collected from patient B, or when the blood in the tube was collected for the intended patient, but the tube is labeled with the wrong patient identification. These two kinds of errors are arguably the most difficult to detect, as they can be identified only if the patient has a historical blood type. Because of this, reported rates of WBIT are greatly underestimated. The Biomedical Excellence for Safer Transfusion group reported a WBIT rate of five in 10,000 samples,[12] and the Q-Probes group reported a WBIT rate of 4.3 in 10,000 samples.[14] Although SC and SH errors have the potential to produce serious harm, the study of their rates over time may also be of interest to scrutinizing improvements in the transfusion process, quantifying variability between hospitals, and modeling impacts on health care costs (delays in care and need for recollection of samples).

The focus of this study was to analyze SC and SH errors over a 10-year period in all 23 Canadian participating hospital sites. The primary objective of the study was to determine the rate of SC and SH errors. The secondary objectives were to detail the types of sample errors, variability of rates across participating sites, changes in rates over the time period, and hospital characteristics associated with error rates.

MATERIALS AND METHODS

From 2006 to 2015, SC and SH errors were reported voluntarily to TESS by 23 Canadian hospitals. TESS is a web-based system that provides a method to track transfusion-related errors and generate analytic reports. Participating sentinel sites (87%) meet quarterly to propose improvements to the manual and tracking system. Errors were reported by clinical and blood transfusion staff. Trained technologists at each site entered errors into the TESS database. Errors were defined as any deviation from established policies and standard operating procedures. The SC and SH errors are categorized into 23 unique codes (Table 1). SC errors relate to labeling and sample tube errors, whereas SH errors relate to paper/computer work and factors of sample transport. WBIT was defined as either blood taken from the wrong patient and labeled with the intended patient's information, or blood taken from the intended patient but labeled with another patient's information.

TESS categorizes errors based on whether the error reached the patient or was a near-miss. Errors are also classified as to whether patient harm resulted or if a system barrier (such as electronic barcoding technology) was able to prevent the error from resulting in harm. Each error is classified by its potential to cause harm if the error was not detected. Errors are categorized as high- (potential for fatal outcomes), medium- (potential for minor/transient injury), or low-severity (no potential to cause patient harm). The system also allocates codes designated to consequences of events (e.g., transfusion delayed, incorrect dose administered).

The following service areas are considered locations by TESS: medical-surgical wards, intensive care units, outpatient clinics and procedure units, emergency departments (EDs), obstetrics, operating rooms (ORs), and transfusion services. Site sizes were defined as the following: small, less

TABLE 1. TESS SC and SH event codes*

SC		SH	
Event code	Definition	Event code	Definition
SC01	**Sample labeled with wrong patient identification**	SH01	Sample arrives without requisition
SC02	**Not labeled**	**SH02**	**Paperwork and sample ID do not match**
SC03	**Wrong patient collected (not from intended patient)**	SH03	Patient ID incomplete/illegible on requisition
SC04	Collected in wrong tube type	SH04	No patient ID on requisition
SC05	Sample NSQ (nonsufficient quantity)	SH05	No phlebotomist/witness identification
SC06	Sample hemolyzed	SH06	Sample arrives with incorrect type of requisition
SC07	**Label incomplete/illegible for key patient identifiers**	SH07	Patient information (other than ID) missing/ incorrect on requisition
SC08	Sample collected unnecessarily	SH10	Sample transport issues
SC09	Requisition arrives without sample	SH11	Incorrect test ordered/requested
SC10	**Armband incorrect/not available**	SH12	Test not ordered/requested
SC12	Label incomplete/illegible for nonkey patient identifiers	SH99	Other
SC99	Other		

* Bolded errors are hard-coded as high potential severity.

than 2000 units of red blood cells (RBCs) transfused per year; medium, 2000 to 10,000 units of RBCs per year; and large, more than 10,000 units of RBCs per year. Denominator data were extracted using blood bank information systems from each institution. The total number of samples received by the blood bank was used as the denominator to calculate rates of SC and SH errors by site and hospital location.

Demographic data for sites were collected using an anonymous survey (Table 2). Sites were anonymized by unique identifiers and queried regarding available technology and process barriers for transfusion-associated errors. Accreditation by formal organizations, personnel responsible for SC, and the education of staff on transfusion were also assessed.

Descriptive statistics were calculated for all variables. Continuous measures were summarized using means, whereas categorical measures were summarized using counts and proportions. Rates were reported per 1000 or per 10,000. Rates of errors over time as well as comparison of frequencies of errors based on site-specific safety measures were compared using Poisson Regression test. All analyses were carried out using computer software (SAS version 9.4, SAS Institute).

RESULTS

Between the years 2006 and 2015, 42,363 SC and 14,666 SH errors were reported with 1,736,512 samples received by the 23 blood banks. Approximately 99% of all errors were near-miss events; 1% reached the patient, of which 1.5% resulted in harm. The top five most frequent SC and SH errors are listed in Table 3. The most common SC error was sample collected unnecessarily (37% of all SC errors; in date sample already processed), and the most common SH error was no phlebotomist/witness identification on the requisition/computer form (61% of all SH errors). Potentially high-severity errors are described in Table 4; 17.1% of SC errors and 7.4% of SH errors were classified as high severity. Over the study period, 1082 WBITs occurred (2.5% of SC errors). The rate of WBITs decreased from 12 to 5.8 per 10,000 between 2006 and 2015 ($p < 0.0001$).

Annual rates of errors by potential severity are presented in Fig. 1. Low-severity SC errors increased twofold from 13 to 27 per 1000 samples from 2006 to 2015 ($p < 0.0001$). Low-severity SH errors increased fourfold from 2.7 to 12 per 1000 samples from 2006 to 2015 ($p < 0.0001$). High-severity SC errors were stable over time: 1.9 to 3.7 per 1000 samples from 2006 to 2015 ($p = 0.31$). High-severity SH errors increased from 0.5 to 2.0 per 1000 from 2006 to 2015 ($p < 0.0001$). The median rate of high-severity SC errors was 1.1 per 1000 and 0.7 in 1000 for high-severity SH errors (Table 5). High-severity error rates by site ranged from 0 to 133 per 10,000 for SC and 0 to 35 per 10,000 for SH errors. Two outlier sites (18 and 15) had high-severity SC rates of 75 and 133 in 10,000 and high-severity SH rates of 33 and 35 in 10,000 samples, respectively.

The two locations with the highest rates of SC errors were the OR and the ED, 59 and 58 per 1000, respectively (Table 6). High-severity SC errors most commonly occurred in the intensive care unit (9.5 per 1000), OR (8.3 per 1000), and ED (7.4 per 1000). The highest rates of SH errors occurred in the OR, medical-surgical wards, and ED with 20, 13, and 12 per 1000, respectively. In both the OR and the ED, hemolyzed samples and unnecessarily collected samples were the two most frequent error types (OR: 12 and 23 per 1000 samples; ED: 28 and 13 per 1000, respectively).

Eight sites had rates of SC errors above 100 per 10,000 samples, whereas only three had rates of SH errors above this level (Table 5). Sites with the highest rates of SC errors were attributable to high rates of unnecessarily collected samples. The site with the highest rate of SC errors (823 per

TABLE 2. Demographic data of participating sites, rates of total SC and high-severity SC errors (n = 17)*

Question	Institutions, number	Institutions, %	SC errors	p value	High-severity SC errors	p value
Which organization is your Transfusion Service Laboratory accredited by?						
a. AABB	4	24	17	a. vs. c., d. vs. a., d. vs. c.	1.1	c. vs. a., d. vs. a., d. vs. c.
b. CAP	0	0	0	<0.0001	0.0	<0.0001
c. Provincial accrediting organization	5	29	5		1.7	
d. None	8	47	20		3.4	
Type of hospital						
a. Academic facility	11	64	21	a. vs. c., a. vs. b.	3.1	a. vs. c., a. vs. b. <0.0001
b. Community teaching facility	4	24	4.1	<0.0001	1.0	
c. Community nonteaching facility	2	12	5.3		1.1	
Does your hospital have a transfusion committee in place that has met at least quarterly for the last year?						
Yes	17	100	N/A	N/A	N/A	N/A
No	0	0				
Does your hospital have a dedicated position for the investigation of transfusion-related adverse events?						
Yes	12	71	19	<0.0001	2.7	<0.0001
No	5	29	5		1.7	
Does your hospital have a dedicated position for investigation of transfusion-related errors?						
Yes	15	88	17	<0.0001	2.4	<0.0001
No	2	12	4		2.0	
Does your hospital have a dedicated phlebotomy team?						
Yes	14	82	18	<0.0001	2.8	<0.0001
No	3	18	3.2		0.5	
Approximately what percentage of samples are drawn by the phlebotomy team?						
None	3	18	3.2	<0.0001†	0.5	<0.0001†
1%-25%	0	0	0		0.0	
26%-50%	6	35	32		4.1	
51%-75%	1	6	22		3.8	
76%-100%	7	41	4.4		1.5	
Are there annual or biannual certification requirements for collection of samples for nurses/phlebotomists?						
Yes	5	29	3.5	<0.0001	1.1	<0.0001
No	12	71	20		2.9	
Is the transfusion service at your hospital computerized for the collection of samples?						
Yes	9	53	23	<0.0001	2.9	<0.0001
No	8	47	6.5		1.8	
Is a signature required on the sample tube to signify that patient identity was checked?						
Yes	14	82	16	<0.0001	2.5	<0.0001
No	3	18	9.1		1.9	
Are samples transported with paperwork or is the system completely computerized?						
a. Computerized, samples received without paper requisition	3	18	16	a. vs. b., b. vs. c., a. vs. c.	0.2	a. vs. b., b. vs. c., a. vs. c.
b. Computerized, samples received with paper requisition	6	35	26		4.2	<0.0001
c. Not computerized, samples received with paper requisition	6	35	7.4	<0.0001	1.7	
d. Missing/no responses	2	12	N/A		N/A	

Table 2: *Continued*

Question	Institutions, number	Institutions, %	SC errors	p value	High-severity SC errors	p value
If samples are transported with paperwork, is a signature required on the accompanying form?						
Yes	14	82	17	<0.0001	2.6	<0.0001
No	3	18	5.8		1.5	
Does your hospital use barcoding for sample receipt in the laboratory?						
a. Specimen number entry	14	82	16	a. vs. b., b. vs. c., a. vs. c.	2.5	a. vs. b., b. vs. c., a. vs. c.
b. Patient hospital number entry	4	24	42		6.9	<0.0001
c. Neither	2	12	2.8	<0.0001	1.0	
What information is mandatory for a sample to be received for processing (i.e., sample rejected if not present)?						
a. Patient first and last name	17	100	All	N/A	All	N/A
b. Patient date of birth	11	65	17		3.0	
c. Patient hospital number or unique identifier	17	100	All		All	
d. Paper requisition with same patient identification	14	82	15		2.8	
e. Signature of sample collector on paper requisition	12	71	17		3.1	
f. More than one signature on paper requisition (i.e., witness or witness attestation)	8	47	21		3.7	
g. Signature or initials of sample collector on sample tube	14	82	16		2.5	
h. More than one signature on sample tube (i.e., ID witness)	3	18	3.2		0.5	
i. Date of SC on paper requisition	9	53	21		3.5	
j. Time of SC on paper requisition	9	53	21		3.5	
k. Date of SC on sample tube	6	35	9.4		0.4	
l. Time of SC on sample tube	3	18	26		4.2	
m. Other (initials on tube match blood taker's signature on witness attestation)	3	18	26		4.2	
Was regrouping required on two separate collections prior to releasing group specific red blood cells during the study years?						
Yes	6	35	12	<0.0001	1.1	<0.0001
No	11	65	17		3.1	

* Errors presented as rates per 1000 samples.
† If treated as a continuous variable, as the percent of samples collected increases, there is a significant decrease in errors.
N/A = not applicable.

TABLE 3. Top five SC and SH events

Event	Number (%)	Rate per 1000 (95% CI)
SC event		
Sample collected unnecessarily	15,454 (37)	8.9 (8.8-9.0)
Sample hemolyzed	10,580 (25)	6.1 (6.0-6.2)
Label incomplete/illegible for nonkey patient identifiers	5,668 (13)	3.3 (3.2-3.3)
Label incomplete/illegible for key patient identifiers	5,090 (12)	2.9 (2.8-3.0)
Collected in wrong tube type	1,531 (3.6)	0.9 (0.8-0.9)
SH event		
No phlebotomist/witness identification	8,996 (61)	5.2 (5.1-5.3)
Patient info (not ID) missing/incorrect on requisition	1,421 (9.7)	0.8 (0.8-0.9)
Paperwork and sample ID do not match	1,080 (7.4)	0.6 (0.6-0.7)
Sample arrives without requisition	694 (4.7)	0.4 (0.4-0.4)
Patient ID incomplete/illegible on requisition	689 (4.7)	0.4 (0.4-0.4)

CI = confidence interval.

10,000) was largely attributable to hemolyzed samples. Sites with the highest rates of SH errors were chiefly attributable to high levels of no phlebotomist/witness identification.

Seventeen of 23 (74%) site surveys on demographics were received (Table 2). All sites were computerized and historical records reviewed for concordance for every sample tested. Overall, 65% of sites were academic institutions, and 53% had undergone laboratory-specific accreditation by an external organization, other than mandatory provincial accreditation. Most (70%) sites utilized paper requisitions with samples, and 35% required regrouping on two collections prior to releasing non–group O RBCs. Sites that required regrouping during the study period had lower SC and high-severity SC error rates (12 and 1.1 per 1000), compared to those that did not (17 and 3.1 per 1000) ($p < 0.0001$). These sites also had significantly lower WBIT rates than sites without regrouping (0.4 and 1 per 10,000) ($p < 0.0001$). Sites with higher percentages of samples collected by a phlebotomy team had lower WBIT rates (26%-50% = 1.6 per 10,000, 51%-75% = 1 per 10,000, 76%-100% = 0.4 per 10,000; $p < 0.0001$). Sites with a dedicated position for the investigation of transfusion-related errors had higher WBIT rates (0.9 and 0.4 per 10,000; $p = 0.0003$). Only one site used electronic positive patient identification (ePPID) for collection of 1% to 25% of samples in ORs, on the phlebotomy service, among medical-surgical wards, and in outpatient clinics (Site 22). Sites whose collection systems were computerized and which required a paper requisition and/or witness attestation had the lowest rate of SH errors (4.2 per 1000). Those with computerized laboratory systems that did not require paper requisitions had the highest rate of SH errors (15 per 1000). No phlebotomist/witness identification errors (i.e., no phlebotomist identification on the tube) accounted for 94% of these SH errors.

DISCUSSION

From 2006 to 2015 using a national error-tracking system, we report 42,363 SC and 14,666 SH transfusion errors from 23 participating sites. Throughout the decade, the number of errors reported doubled from 2006 to 2015, almost certainly due to improved reporting, the addition of new error codes, and promotion of a culture of safety. Both low- and high-severity error rates rose, likely due to increased feedback activity rather than a deterioration in patient safety. This may also be due to the implementation of important safety barriers that increase detection of errors, such as the group check sample. To address WBITs and other high-severity error types that provide potential for ABO incompatibility, many hospitals have implemented a "group check" sample to improve WBIT detection.[9] This measure requires a second sample to confirm blood grouping, thereby preventing an ABO-incompatible transfusion due to an undetected SC error. This procedure detects errors that previously went unrecognized. Seventy-four percent of sites provided information regarding SC processing and implemented safety barriers, with only 35% indicating the implementation of the group check and 4% implementing limited ePPID, a generic system that facilitates electronic labeling through either radio-frequency identification or barcodes.

Since the initial years of TESS (2005-2007), error characterization has improved. Previously, errors were likely not reported until categorizations were broadened and better standardized. For example, unnecessarily collected samples were not originally classified as errors and therefore were not systematically captured at all sites. Meanwhile, the measure is likely still a significant underestimate in an environment where up to 42% of laboratory tests are still considered wasteful.[15] Therefore, in general, an increase in particular error type likely represents more complete reporting of errors rather than an increase in frequency of errors. Hospitals that had a dedicated position, such as a transfusion safety officer, for transfusion-related errors had higher rates of reported SC errors ($p < 0.0001$; Table 2), suggesting that this role may be important to complete capture of errors. Over time, the rate of high-severity SC errors remained stable, while low-severity errors increased dramatically from 13 to 27 per 1000 samples between 2006

TABLE 4. High potential severity SC and SH events

Event	Number (%)	Rate per 10,000 (95% CI)
SC event		
Sample labeled with wrong patient identification	832 (2)	5 (4.47-5.12)
Not labeled	1010 (2)	6 (5.46-6.17)
Wrong patient collected	250 (0.6)	1.4 (1.26-1.62)
Label incomplete/illegible for key patient identifiers	5090 (12)	29 (28.51-30.12)
Armband incorrect/not available	66 (0.2)	0.4 (0.29-0.47)
SH event		
Paperwork and sample ID do not match	1080 (7)	6 (5.85-6.59)

CI = confidence interval.

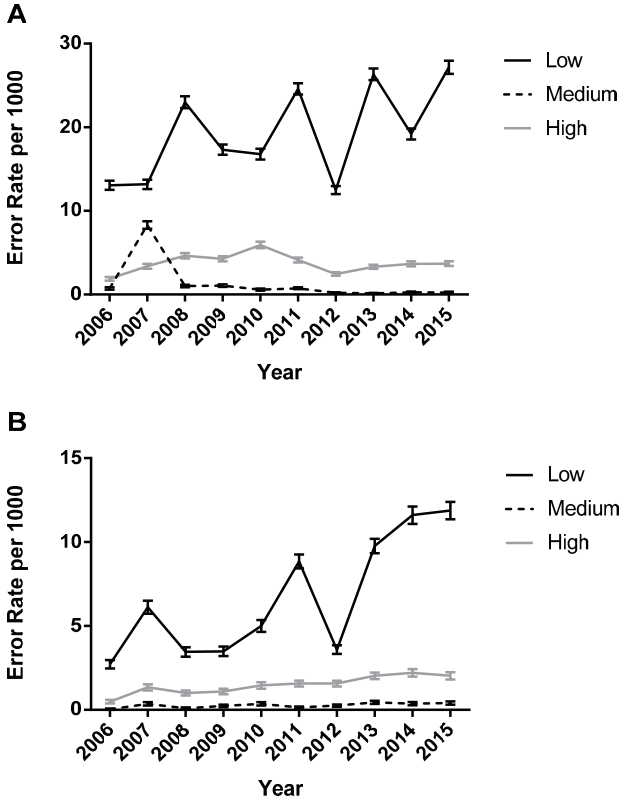

Fig. 1. (A) Yearly SC error rates per 1000 samples by potential severity. (B) Yearly SH error rates per 1000 samples by potential severity.

and 2015 ($p < 0.0001$), supporting the theory that increased error rates are due to better reporting.

During the study period, there were 1082 reported WBITs; this equates to one WBIT every 3.4 days at these 23 hospitals alone. The overall rate of WBITs was 6.2 per 10,000. This rate is similar to that of Dzik's in 2003.[12] In our work, the median WBIT rate per site was 0.3, ranging from 0 to 16.9 per 10,000. A site's WBIT rate may not necessarily indicate quality of practice, as it is strongly affected by their ability to detect such errors. Due to the potential severity of WBIT errors, transfusion error publications have focused on curtailing this type of SC error.[16,17] A key finding of this report was the decreased WBIT rate over the study period (12 to 5.8 per 10,000). Sites that had an implemented group check system has a significantly lower WBIT rate than sites that did not (0.4 vs. 1 per 10,000). Because systems such as the group check sample should increase WBITs by detection, decreases in WBIT rate are likely as a result of other preventative measures such as education at these sites that have taken initiative in implementing systems to improve patient safety. Hospitals that had a dedicated position for the investigation of transfusion-related errors had significantly higher WBIT rates than those that did not (0.9 and 0.4 per 10,000), suggesting that this role is important for and focuses on detecting these error types. Other than the group check sample as a safety mechanism, some centers have implemented the Blood-Loc system, requiring a check of patient identification prior to transfusion.[18] Brown and colleagues[19] reported the implementation of ePPID reduced error rates per 1,000 from 2.02 preimplementation to 0.13 postimplementation, demonstrating error prevention rather than just improved detection. In 2000, HemaQuebec implemented a system whereby all regional hospitals have shared access to historical blood bank testing results. As a result, the incidence of ABO mistransfusions decreased 4.6-fold, as well as twofold and 2.5-fold decreases in acute hemolytic and delayed hemolytic transfusion reactions, respectively.[20]

Areas with the highest rates of SC and SH errors were the ED and the OR. A 32% reduction in SC errors would be seen if ED errors alone were eliminated. Spain and colleagues[21] evaluated the effects of implementing education and electronic barcoding technology on SC key behaviors in the ED. This before-and-after study compared errors preintervention, postintervention with education only, and postintervention with education and implementation of electronic armband scanners. Behaviors of health care professionals, such as sample labeling and asking patients to state their name and date of birth, were identified. Education alone improved sample labeling at the bedside from 41.6% to 72.6% postintervention and to 70.6% with education and armband scanner. However, education alone does not generally last in the long term, and technology may be helpful in sustaining adherence to bedside

TABLE 5. SC and SH errors by site*

Site	Samples received (number)	SC Errors (number)	SC Rate per 10,000	SC HS rate per 10,000	SH Errors (number)	SH Rate per 10,000	SH HS rate per 10,000
8	154,617	80	5	1.7	78	0.5	0.6
5	18,668	24	13	2.1	38	20	5
1	1,264	3	24	0	2	16	0
6	9,679	24	25	5.2	24	25	0
12	85,796	327	38	24	180	21	8
10	65,170	257	39	16	249	38	13
13	87,157	367	42	18	565	65	15
3	1,057	5	47	9.5	1	9.5	0
2	805	4	49	0	5	62	25
7	5,084	29	57	22	40	79	16
4	3,671	23	63	8.2	4	11	0
11	40,946	274	67	24	69	17	2
16	**115,329**	**771**	**67**	**1.2**	**860**	**75**	**0.7**
14	58,215	516	89	7.2	186	32	8
21	250,450	4,520	180	13	1,428	57	6
20	**160,565**	**3,019**	**188**	**3**	**2,868**	**179**	**0.8**
19	**71,271**	**1516**	**213**	**2.5**	**1,287**	**181**	**1**
17	37,407	810	217	18	334	89	17
22	298,553	6,471	217	39	3,607	121	11
9	51,807	1,180	228	33	347	67	29
18	252,628	10,665	422	75	1,403	56	33
15	138,467	11,394	823	133	1,086	78	35

HS = high severity.
* Bolded sites = voluntary sites; nonbolded = sentinel sites.

TABLE 6. SC and SH errors by location

Location	SC Errors (number)	SC Samples received (number)	SC Rate per 1000	SH Errors (number)	SH Samples received (number)	SH Rate per 1000
Transfusion service	22	484,070	0.05	19	484,070	0.04
Outpatient clinic	150	401,393	0.37	81	401,393	0.2
Obstetrics	1,785	101,166	18	687	101,166	6.8
Outpatient procedure	2,991	157,975	19	1,050	157,975	6.6
Laboratory service	130	4,767	27	75	4,767	16
Intensive care unit	4,341	107,248	41	2,225	107,248	21
Medical-surgical ward	13,960	336,171	41	4,220	336,171	13
Emergency	14,225	244,851	58	3,012	244,851	12
Operating room	1,862	31,703	59	628	31,703	20

labeling. Uptake is optimized when education is implemented with a change in work practice. Baumlin and colleagues[22] described the improvement in patient safety and quality of care as a result of the implementation of an ED information system, by factors such as computerized charting and order entry.

The OR has been reported as a common location for transfusion errors that potentially result in death.[23-25] A review of ABO-incompatible RBC transfusions described eight cases, six of which occurred in the OR, and three of which were attributed to sample labeling or missing paperwork errors.[26] Dzik[27] suggests that since high frequencies of medical errors occur in chaotic settings, there is potential benefit for targeting new technology to improve patient safety. The ED and the OR both concentrate on a limited number of beds and are therefore ideal for piloting and validating such technology.

Others have also considered the use of barcoded wristbands with handheld devices to scan patient identification.[8,28] These scanners are coupled with small printers to create patient labels to diminish the opportunity for mislabeling. Electronic barcoding for patient identification reduces the rates of mislabeled samples by 84% from a mean percentage of 320 to 50 per 10,000.[29] Only one of the participating TESS sites currently uses ePPID technology for a fraction of collected samples (1%-25%). Although implementing new technology has the potential to reduce errors related to patient misidentification and labeling,

cost of new technology and implementation challenges must be considered. A study by Chan and colleagues[30] reported the cost of implementing an electronic barcode system to be HK$1,250,000 (approx. $212,273 CAD or $160,241 USD), not including additional annual fees. The improvement of transfusion-related errors requires a balance among technology, process interventions, and education.[23,31] The highest rates of errors of the ED and the OR were hemolyzed samples and unnecessarily collected samples. These common low-severity errors present the issue of cost, rather than patient safety. Throughout the study period, the estimated cost of a recollected sample was calculated to be $31.85, totaling approximately $1,193,133 for all recollected and unnecessary blood bank samples among these 23 hospital sites. A systematic review of practices in the ED describes the use of straight needle venipuncture as opposed to drawing blood using intravenous starts and the use of antecubital rather than distal sites to reduce hemolysis.[32] Technology could prevent duplicate SC by notifying the health care provider that a (recent, still-representative) sample has already been collected, and therefore block recollection. Computerization may also prevent errors such as wrong tube type by use of a system that dictates the necessary tube type. Potential strategies to improve error prevention such as electronic systems must be tested in properly designed clinical trials.

It was found that 82% of SC and 78% of SH errors involved nursing staff. This is not surprising, as nurses account for the majority of SCs while facing frequent interruptions. As such, they are more vulnerable to inadvertent mislabeling, the use of the wrong sample tube for collection, or failing to fulfill documentation requirements. Not surprisingly, fewer errors occurred at sites with higher percentages of samples collected by the phlebotomy team. Sites with 76% to 100% of samples collected by phlebotomists had an SC error rate of 4.4 per 1000 versus an SC error rate of 32 per 1000 at sites with 26% to 50% of samples collected ($p < 0.0001$). Similar results are described at other institutions.[33] To address these types of errors, strategic education for nursing staff and other sample collectors such as phlebotomists is likely an adjuvant tool to ePPID. In Canada, blood transfusion became an advanced nursing competency in 2006, and now the completion of a web-based module or live session with a testing component is encouraged. However, it is unknown if the implementation of simulations for nursing staff or phlebotomists would attenuate the high rates of SC and SH errors.

The drive to improve transfusion-related errors is lacking worldwide. One potential barrier to adopting improvement is the multifaceted cost of technology. Dzik[27] describes possible reasons for resistance to implementing technology such as underestimation of errors, and viewing technology as new and confusing. Mistaken assumptions abound on errors simply being a "bad nurse" issue, unrelated to the system. The United Kingdom is a leader in hemovigilance with the well-established Serious Hazards of Transfusion program and annually releases recommendations for improvement in transfusion-related errors. In 2002, Serious Hazards of Transfusion created a national auditing program to analyze the transfusion process, looking at specific junctures that impact patient safety. With repeated auditing, improvement in compliance with transfusion safety guidelines was seen. For example, the percentage of patients wearing wristbands increased from 86% to 99.5% between 2003 and 2011.[4] Numerous North American centers are accredited by AABB and the College of American Pathologists, bodies that promote the transfusion safety agenda. AABB has a center for patient safety to analyze transfusion-associated incidents. AABB has created guidelines pertaining to patient safety, such as the guidelines that samples must be labeled at the bedside with a mechanism in place to identify the sample collector.[28]

Our study is limited by the fact that it is not mandatory for hospitals in Canada to participate in TESS. Participating sites are classified as sentinel or voluntary. Sentinel sites meet monthly to ensure coding standardization and quarterly to discuss issues and strategies in error reporting. Voluntary sites potentially coded events differently than sentinel sites. Five sentinel sites had higher SC error rates than did the voluntary site, with the highest SC error rate suggesting sentinel sites are similar, in terms of error rates, to nonsentinel sites across Canada. Between 2006 and 2015, some sites have merged and others left the program, providing inconsistent reporting of errors across sites for all years. This report does not consider the changes in policy related to SC and SH over the time period, as well as differences over time between various locations such as the OR and ED. Another limitation is whether a phlebotomist or a nurse is involved with an error, as both are coded as nursing staff in TESS. Therefore, we cannot differentiate between errors involving the phlebotomy team or errors involving nursing staff. Beginning in 2016, TESS will allow the selection of a nurse or phlebotomist for a given event so as to improve the clarity of data in the system for future analyses. There is no doubt that all error-tracking and hemovigilance systems are plagued by underreporting by frontline staff due to lack of understanding of the importance of error reporting, failure to understand what defines an error, failure to report due to workload stress, and failure to report due to concerns about adverse consequences for health care personnel.

This study provides a comprehensive analysis of a national hemovigilance program. The rate of WBITs decreased significantly over the time period, suggesting increasing awareness and commitment to patient safety by sites. Common low-severity errors are rising and

present potential burden of cost. Electronic systems have the potential to address the high-severity and common low-severity errors. Education of nursing and phlebotomy staff in these areas should be enhanced to address common errors (e.g., hemolyzed samples). Transfusion-related errors should be a priority for future research to improve patient safety and potentially mitigate cost. Further investigation of national error-tracking systems is required to understand trends in transfusion-related errors and the impacts of error prevention strategies. Data are needed to better inform standard-setting organizations so that transfusion standards for SC evolve based on high-quality evidence to reduce the risk of harm from transfusion-related errors.

CONFLICT OF INTEREST

The authors have disclosed no conflicts of interest.

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