

End-to-end electronic control of the hospital transfusion process to increase the safety of blood transfusion: strengths and weaknesses

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BACKGROUND: Incorrect blood component transfused is a frequent serious incident associated with transfusion and often involves misidentification of the patient and/or the unit of blood.

STUDY DESIGN AND METHODS: This study extended the evaluation of an electronic system involving bar code technology and handheld computers. Electronic control of collection of blood from blood refrigerators was incorporated into a previously described process for blood sample collection and blood administration. Practice was evaluated before and after its introduction in cardiac surgery.

RESULTS: The baseline audits revealed poor practice. Significant improvements were found following the introduction of the electronic system, including from 8 percent to 100 percent in checking that the blood group and unit number on the blood pack matched the compatibility label and the pack was in date ($p \leq 0.0001$). Similar significant improvements were found in blood sample collection, the collection of blood from blood refrigerators, and the documentation of transfusion. Staff found the system easy to operate and preferred it to standard procedures.

CONCLUSIONS: A bar code patient identification system improved transfusion practice, although areas for improvement were identified. These results provide support for further work on the development of such systems for both transfusion and other procedures requiring patient identification.

Incorrect blood component transfused (IBCT) is the most frequent serious incident associated with blood transfusion. Between 1996 and 2003, the Serious Hazards of Transfusion (SHOT) scheme reported 221 ABO-mismatched transfusions and 13 deaths and 75 cases of major morbidity due to IBCT.¹ During the 2003 reporting year, the scheme received reports from 351 hospitals.¹ A total of 358 of 480 (75%) of all reports were IBCT incidents. Errors involved all stages of the transfusion process and many different types of staff. Multiple errors were found in 52 percent of cases. A total of 588 errors were identified: 27 percent were due to errors during requesting, prescription, or sample collection; 31 percent occurred in the blood bank; and 40 percent were due to errors when collecting and/or administering blood.

The single most important factor in IBCT incidents is misidentification of the patient during the transfusion process.²⁻⁶ One of the main reasons underlying these errors is that the clinical transfusion process, in common with other routine hospital procedures requiring patient identification, is complex and laborious. The SHOT scheme has recommended the evaluation of computerized transfusion aids and bar code technology for confirmation that the correct unit of blood is administered.¹ We previously reported our experience with a bar code patient identification system that was found to simplify

ABBREVIATIONS: BCSH = British Committee for Standards in Haematology; CRU(s) = cardiac recovery unit(s); CTU = cardiothoracic ward; IBCT = incorrect blood component transfused.

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the clinical transfusion process and improve practice in the setting of a hematology unit.⁷

The objective of this study was to establish whether bar code technology with allied training could be extended into an acute clinical area, cardiac surgery, and linked to an electronic system for blood collection and tracking to provide end-to-end electronic control and documentation of the complete hospital transfusion process (hereafter called the “electronic process”). Cardiac surgery, where urgent and rapid transfusions of single or multiple blood components are frequently required, was chosen to extend the capability of the electronic process after its initial implementation in the relatively nonacute clinical environment of hematology.

MATERIALS AND METHODS

The transfusion process in clinical areas for cardiac surgery patients was evaluated at three different stages of the transfusion process before and after the implementation of bar code technology and education in cardiac surgery; blood sample collection (carried out either in an outpatient phlebotomy area or on the cardiac ward); blood collection from blood refrigerators (from the main blood bank, in cardiac theaters, or the cardiac recovery unit [CRU]); and blood administration (carried out in cardiac theaters, the CRU, or the cardiothoracic ward [CTU]). The baseline audits were carried out before any intervention.

Standard transfusion procedure

The standard transfusion procedure was as described in the Oxford Radcliffe Hospitals transfusion policies and procedures documents, which are based on the recommendations in the British Committee for Standards in Haematology (BCSH) guidelines for the administration of blood.⁸ The Oxford Radcliffe Hospitals use an additional system of patient identification in which a unique number is allocated to each patient at the time of collection of the blood sample for compatibility testing (the red label system); this has been described previously.⁷

The “end-to-end” electronic process for transfusion

The process involves the use of handheld computers that scan information from bar codes. The manufacturers of the hardware were Symbol (Holtsville, NY; handheld computers/laser scanners) and Zebra (Buckinghamshire, UK; portable label printers and wristband printers). The software (SafeTx and BloodTrack Courier) was produced by Olympus (UK) Ltd (Middlesex, UK). The transfusion procedures in this study were adapted and extended from those previously described.⁷ They are summarized below with some changes and additions, particularly in relation to the use of automated blood collection from blood

refrigerators under the control of BloodTrack Courier software on computers alongside each blood refrigerator linked to a central computer in blood bank:

Patient identification

Patients were allocated a bar coded identification wristband. The bar code symbology used was PDF417; each patient’s bar-coded wristband included his or her surname, first name, date of birth, gender, and hospital number.

Sample collection

During the process of collecting the blood sample for compatibility testing, the patient was identified verbally by asking the patient, if conscious, to state his or her surname, first name, and date of birth and checking these against written documentation including the eye-readable details on the wristband. The sample of blood was collected. The phlebotomist using the handheld computer then scanned his or her user identification bar code (linear format). Next, the bar code on the patient’s wristband was scanned and a label containing the patient’s details in eye readable and bar code format was generated with the portable printer; lastly, the label was attached to the patient’s cross-match sample. For outpatients, the patient’s bar code wristband was not attached to the patient but held by the patient with other hospital paperwork.

Blood bank

- When a sample was delivered to the blood bank, the receptionist scanned the bar code on the sample tube to enter the patient’s identification details into the blood bank computer.
- When blood was allocated to a patient, a compatibility label incorporating the patient’s unique identification bar code was generated and applied to the blood bag. The bar code at this stage also included the unit number of the allocated blood.
- A bidirectional interface between the blood bank computer and the BloodTrack Courier in blood bank allowed the patient identification details for each allocated blood unit to be transferred to BloodTrack Courier.
- The unit of blood was taken by laboratory staff to the BloodTrack Courier kiosk next to the main blood issue refrigerator in blood bank. The staff scanned their identity badge bar code, and were then prompted to select “putting in,” which unlocked the refrigerator door. The staff were prompted to scan the unit number of each unit and to place the unit in the blood refrigerator.

Blood collection

- The staff tasked with blood collection brought a handwritten blood collection slip containing the patient identification details (surname, first name,



Fig. 1. Blood collection with BloodTrack Courier. The bar code of the unit is scanned, bringing up the patient details on the screen. A verbal prompt asks the member of staff to ensure that the blood was for the correct patient by checking the patient identification details on the blood collection slip match those on the screen.

date of birth, gender, and hospital number) to the blood refrigerator.

- The staff scanned their staff identity badge bar code into BloodTrack Courier; for staff known to be trained, the lock opened.
- Staff who were not trained in the use of the system were denied access and were prompted to contact blood bank. (An override button was provided to allow the “comfort” of emergency access to non-trained staff. If this was ever used, however, an alarm would sound in blood bank to alert laboratory staff.)
- The staff selected “taking out” for collection of blood.
- A unit of blood for the patient was then selected.
- The bar code of the unit was then scanned, bringing up the patient details on the screen (Fig. 1).
- A prompt asked the staff to ensure the blood was for the correct patient. The staff checked the patient identification details on the blood collection slip matched those on the screen and then confirmed that this was the patient for whom blood was required.
- Additional units could be collected by repeating the cycle.
- The units could be taken directly to the clinical area or transferred to a satellite blood refrigerator in cardiac theaters or the CRU, where the procedure for “putting in” blood was repeated, as described above.
- Alarms sounded at the blood refrigerator and in the blood bank if an attempt was made to remove the wrong blood, the procedure was carried out incorrectly, for example, scanning the unit twice, or the blood exceeded 30 minutes out of the refrigerator.

Blood administration

- Before administering blood, the staff with the handheld computer made five scans according to prompts by the device:
 1. The staff’s user identification bar code.
 2. The identification bar code on the patient’s wristband.
 3. The compatibility label on the blood bag.
 4. The unit number on the blood bag.
 5. The product code on the blood bag.
- The handheld computer confirmed if the bag was the correct one for the patient; if not, it would indicate “Do Not Transfuse” and sound an audible alert.
- Users were prompted by the handheld computer to seek verbal clarification of a patient’s identification details, that is, first name, surname, and date of birth, and to visually check all details displayed on the handheld computer screen.
- The handheld computer also prompted the user to carry out other essential pretransfusion checks, including the expiry date of the unit.
- For cardiac surgery, the software was adapted to allow checking of multiple units of red cells (RBCs), platelets, and fresh-frozen plasma.
- Staff were prompted to enter pretransfusion patient observations into the handheld computer.
- Only once all these checks were carried out were the staff prompted that it was safe to commence the transfusion.
- A final report, including observations carried out during and after the transfusion, was printed and kept as a record in the patient’s notes.
- Information from the handheld computers about each unit of blood was downloaded by docking the handheld computers into a computer in each clinical area. This information was transferred via the hospital network to a computer in the blood bank (Fig. 2). The information included the ISBT128 unit number; patient identification details (both the intended recipient and the actual recipient, who should obviously be the same); the date and time the unit arrived in the patient area; the date and time the transfusion started and ended; the volume of the transfusion; patient observations (temperature, blood pressure, and pulse) before, during, and after the transfusion; the identification of staff carrying out each step; and the occurrence and type of any reactions.
- The use of the red label system was discontinued after bar code technology was introduced.

Measures to assess the performance of the various stages of the transfusion process

It was unrealistic to expect to document a reduced number of IBCT incidents because of the small scale of the

Query Blood Unit - Neoteric BloodTrack SafeTx Manager

Search for in From

Query

Status

Report

Blood Unit Information

Blood Unit Number	Product	Arrival Time (Device)
G052 505 251 321 U	Red Cells	13-Dec-2005 21:48:06

Transfusion Information

Start Time Volume (mL)

End Time Special Requirements

Event	Time (Device)	Caregiver	Device	Vitals	Reactions
End Transfusion	13-Dec-2005 21:53	5025	AICU1	T:36 BP:130/65 P:65 R:14	
Begin Transfusion	13-Dec-2005 21:52	5025	AICU1	T:36 BP:120/65 P:65 R:14	
Emergency Transfusion	13-Dec-2005 11:05	5025	AICU2		
Emergency Transfusion	13-Dec-2005 11:03	5025	AICU2		
End Transfusion	13-Dec-2005 11:00	5025	AICU2	T:36 BP:130/65 P:65 R:14	
Begin Transfusion	13-Dec-2005 10:57	5025	AICU2	T:36 BP:120/65 P:65 R:12	
Begin Transfusion	13-Dec-2005 10:00	5025	AICU2	T:36 BP:120/65 P:65 R:12	

Patient Information

	Patient Wristband	Compatibility Label
Patient ID	4130938	4130938
Last Name	STAVES	STAVES
First Name	Julie	JULIE
DOB	28-Dec-1966	
Sex	F	
Blood Unit Number	G052 505 251 321 U	G052 505 251 321 U

F10 Set Up

Fig. 2. Information from the handheld computers about each unit of blood is downloaded by docking the handheld computers into a computer in each clinical area. This information was transferred via the hospital network to a computer in the blood bank. The information included the ISBT128 unit number; patient identification details (both the intended recipient and the actual recipient, who should obviously be the same); the date and time the unit arrived in the patient area; the date and time the transfusion started and ended; the volume of the transfusion; patient observations (temperature, blood pressure, and pulse) before, during, and after the transfusion; the identification of staff carrying out each step; and the occurrence and type of any reactions.

project, carried out within one clinical department. Surrogate measures were used to determine better performance of aspects of the transfusion sequence. Tools to assess performance of the various stages of the transfusion process were based on the Oxford Radcliffe Hospitals transfusion policies and procedures and the BCSH guidelines.⁸ Detailed auditing of specific stages of the transfusion process was carried out to serve as a baseline and was then repeated after introduction of the electronic process. The presence of the auditor was apparent to the staff carrying out transfusion procedures. Staff and patient satisfaction questionnaires and the time spent on some procedures were also studied.

Education and training

Once the baseline observations of practice were completed, staff involved in transfusion were provided with training. This included the aims and objectives of the project and the use of the electronic process, some discussion about safe transfusion practice, and why and how IBCT incidents occur. After a 1-month familiarization period with the new electronic process, repeat observations were carried out. The objective was to assess what impact the introduction of the electronic process and allied training had had on the correct performance of the procedures.

Statistical analysis

To determine if the introduction of the electronic process and allied training improved compliance with transfusion procedures, the proportion of transfusions for which each part of the process was carried out correctly was summarized before and after the introduction of the bar code patient identification technology. The results were expressed as percent improvement in each case.

Rather than perform statistical tests for every step, the most critical elements of the process were selected and/or combined and compared before and after the implementation of the electronic process. For blood sample collection, these critical elements were verbal verification by the patient of his or her name and date of birth and the immediate labeling of the sample tube with the patient's name, hospital number, date of birth, gender, and sample date. For blood collection, these elements were the taking of written documents to the refrigerator; checking that the documentation matched the patient's name, hospital number, date of birth, and gender; and checking that these parameters matched the information on the blood bag. For blood administration the elements were checking the wristband for name, hospital number, and date of birth against the blood bag and checking the blood group and unit number on the blood pack against those on the compatibility number and that the expiry date had not passed. Statistical analysis was carried out on the consolidated components with Fisher's exact tests of independent proportions.

RESULTS

Blood sample collection

Fifty sample collection procedures were audited before and after the introduction of the electronic process. The baseline audit demonstrated that only 4 of 24 (17%) inpatients and 13 of 26 (50%) outpatients were asked to verbally identify themselves by stating their full name and date of birth before the collection of their blood sample for compatibility testing. Following the introduction of the electronic process, all 24 inpatients and 26 outpatients (100%) were asked to verbally identify themselves by stating their full name and date of birth (Tables 1 and 2).

In the baseline audit for blood sample collection, 21 of 24 (88%) inpatients and 3 of 26 (12%) outpatients were wearing identification wristbands at the time their identification checks were carried out. With the electronic process, all 24 (100%) inpatients were wearing identification wristbands but none of the 26 (0%) outpatients (Table 1). As previously described, bar code wristbands were not attached to outpatients before sample collection but are held by the patient with other hospital paperwork, which is a potential weakness in the process.

In the baseline audit, only 17 of 21 (81%) inpatients and 2 of 3 (67%) of outpatients had the details on their

wristband checked before blood sample collection. Following the introduction of the electronic process, all patients, even outpatients, had the wristband details checked.

Labeling of the blood sample tube was only carried out immediately after the collection of the sample in 10 of 24 (42%) inpatients and 18 of 26 (69%) outpatients with the standard procedure; the sample was pre-labeled in 1 of 24 (4%) of the inpatients and there was a delay of several minutes in labeling in 13 of 24 (54%) inpatients and 8 of 26 (31%) outpatients, usually while the phlebotomist went out of the room to direct the patient to the site of the next investigation. Labeling was carried out immediately in all cases after the implementation of the electronic process.

In the baseline audit, sample labeling was carried out correctly in 21 of 24 (88%) inpatients and 23 of 26 (88%) outpatients; in the other cases, date of birth or gender were omitted. Full labeling details were provided in all cases after the implementation of the electronic process.

Statistical analysis (Table 2) was carried out on two consolidated sets of steps in the process. In the baseline audit, 4 to 24 (17%) of inpatients and 13 to 26 (50%) outpatients were correctly asked to identify themselves, compared to 100 percent in both patient groups after the new technology and training were implemented ($p < 0.0001$). Similar significant results were found with immediate and accurate labeling of the sample tube.

Collection of blood from blood refrigerators

Blood collections were audited before and after the introduction of the electronic blood collection system (50 from the main blood bank refrigerator, 20 from the theater refrigerator, and 10 from the CRU refrigerator). The baseline audit showed that written documentation about the patient was brought to the refrigerator in 42 of 50 (84%), 8 of 20 (40%), and 1 of 10 (10%) of the collections from the main blood bank, theater, and CRU refrigerators, respectively. After the introduction of the electronic process, written documentation about the patient was brought to the refrigerator in 19 of 20 (95%; $p = 0.43$), 18 of 20 (90%; $p = 0.002$), and 5 of 5 (100%; $p = 0.002$) of the collections from the main blood bank, theater, and CRU refrigerators.

There was variation in the completeness of the patient identification brought to the blood refrigerator; the patient details on the document were all correct in 11 of 42 (26%) at the main blood bank, 0 of 8 in theater, and 0 of 1 in the CRU. This improved to 20 of 20 at the main blood bank ($p < 0.0001$), 18 of 18 in theater ($p < 0.0001$), and 5 of 5 in the CRU ($p = 0.17$) after the implementation of the electronic process (Table 3).

The performance of checking the patient documentation with the same details on the blood bag, when collecting blood from blood refrigerators, was already good and it did not improve significantly (Table 3). A few staff

TABLE 1. Measures for assessing the performance of blood sample collection in patients*

Variable	Standard system	Bar code patient identification system	Percent improvement
Patient asked to state first name			
Inpatients	4/24 (17)	24/24 (100)	83
Outpatients	14/26 (54)	26/26 (100)	46
Patient asked to state surname			
Inpatients	4/24 (17)	24/24 (100)	83
Outpatients	14/26 (54)	26/26 (100)	46
Patient asked to state date of birth			
Inpatients	6/24 (25)	24/24 (100)	75
Outpatients	13/26 (50)	26/26 (100)	50
Patient wearing an identification wristband			
Inpatients	21/24 (88)	24/24 (100)	12
Outpatients	3/26 (12)	0/26 (0)	-12
Patient identification on wristband checked			
Inpatients	17/21 (81)	24/24 (100)	29
Outpatients	2/3 (67)	26/26 (100)	33
Sample tube prelabeled			
Inpatients	1/24 (4)	0/24 (0)	4
Outpatients	0/26 (0)	0/26 (0)	0
Sample tube labeled after a delay			
Inpatients	13/24 (54)	0/24	54
Outpatients	8/26 (31)	0/26	31
Sample tube labeled immediately			
Inpatients	10/24 (42)	24/24 (100)	58
Outpatients	18/26 (69)	26/26 (100)	31
Patient's hospital number entered correctly on the sample tube			
Inpatients	24/24 (100)	24/24 (100)	0
Outpatients	26/26 (100)	26/26 (100)	0
Patient's surname entered correctly on the sample tube			
Inpatients	24/24 (100)	24/24 (100)	0
Outpatients	26/26 (100)	26/26 (100)	0
Patient's first name entered correctly on the sample tube			
Inpatients	24/24 (100)	24/24 (100)	0
Outpatients	26/26 (100)	26/26 (100)	0
Patient's date of birth entered correctly on the sample tube			
Inpatients	23/24 (96)	24/24 (100)	4
Outpatients	25/26 (96)	26/26 (100)	4
Patient's gender entered correctly on the sample tube			
Inpatients	21/24 (88)	24/24 (100)	12
Outpatients	23/26 (88)	26/26 (100)	12
Phlebotomist signed the sample tube			
Inpatients	24/24 (100)	NA	NA
Outpatients	26/26 (100)	NA	NA
Date the sample taken entered correctly on the sample tube			
Inpatients	24/24 (100)	24/24 (100)	NA
Outpatients	26/26 (100)	26/26 (100)	NA

* Data are reported as number (%).

TABLE 2. Consolidated sets of steps in blood sample collection

Variable	Number	Standard system	Bar code patient identification system	Fisher's exact p value
Patient asked to state surname, first name, and date of birth				
Inpatients	24	4 (17)	24 (100)	<0.0001
Outpatients	26	13 (50)	26 (100)	<0.0001
Sample tube labeled immediately with hospital number, first name, date of birth, gender, and sample date				
Inpatients	24	9 (37.5)	24 (100)	<0.0001
Outpatients	26	15 (58)	26 (100)	0.0003

* Data are reported as number (%).

TABLE 3. Measures for assessing the performance of blood collection from blood refrigerators

Variable	Standard collection	After the implementation of electronic blood collection	Percent improvement
Written documentation taken to refrigerator			
Main blood bank	42/50 (84)	19/20 (95)	11 (p = 0.43)
Theater	8/20 (40)	18/20 (90)	50 (p = 0.002)
CRU	1/10 (10)	5/5 (100)	90 (p = 0.002)
Documentation correct for surname			
Main blood bank	39/42 (93)	20/20 (100)	7
Theater	8/8 (100)	18/18 (100)	0
CRU	1/1 (100)	5/5 (100)	0
Documentation correct for first name			
Main blood bank	35/42 (83)	20/20 (100)	17
Theater	8/8 (100)	18/18 (100)	0
CRU	1/1 (100)	5/5 (100)	0
Documentation correct for hospital number			
Main blood bank	40/42 (95)	20/20 (100)	5
Theater	7/8 (87.5)	18/18 (100)	12.5
CRU	1/1 (0)	5/5 (100)	100
Documentation was checked against the blood bag			
Main blood bank	25/42 (60)	17/20 (80)	25
Theater	8/8 (100)	17/18 (94)	-6
CRU	1/1 (100)	5/5 (100)	0

* Data are reported as number (%).

TABLE 4. Consolidated set of steps in blood collection

Variable	Standard system	After the implementation of electronic blood collection	Fisher's exact p value
Documentation correct for all parameters			
Main blood bank	11/42 (26)	20/20 (100)	<0.0001
Theater	0/8 (0)	18/18 (100)	<0.0001
CRU	0/1 (0)	5/5 (100)	0.167

* Data are reported as number (%).

members tended to do these visual checks in addition to the bar code scans only for the first unit and not further units.

It was estimated there were 23 steps in the collection of blood before the implementation of the electronic process and 9 after implementation. The use of BloodTrack Courier reduced the time taken to carry out the checking procedures for collecting a blood unit from an average of 3 minutes per unit to 1 minute per unit.

Administration of blood

A total of 50 first-unit RBC transfusions were audited before and after the introduction of the electronic process in the CRU and 10 first-unit RBC transfusions were audited before and after its introduction in both the cardiac theaters and the CTU (Table 5). Six of the 50 patients were conscious in the CRU at the time of transfusion in the baseline audit; none of these 6 (0%) patients were asked to verbally identify themselves by stating their surname, first name, and date of birth before the administration of blood, and in none of these patients was the

information on the wristband checked at any stage. After the implementation of the electronic process, only 1 of 4 (25%) conscious patients was asked to provide his or her name and date of birth for identification, and this information checked against the same details on the wristband.

All patients in the CRU (100%) wore an identification wristband before and after the implementation of the electronic process, whereas 9 of 10 (90%) patients in theaters wore an identification wristband before its implementation and all 10 (100%) patients wore an identification wristband after its implementation. The cross-checking of the patients' identification details on the wristband and blood packs was carried out correctly in all cases in the CTU ward and in 60 to 100 percent of cases in the CRU and theaters in the baseline audit. After the introduction of the electronic process, it was carried out correctly in all cases in all three clinical areas.

The administration of blood involves bedside checking that the blood group and unit number are the same on the blood service label on the blood bag and the compatibility label attached to the blood bag by the blood bank.

TABLE 5. Measures for assessing the performance of blood administration

Variable	Standard system	Bar code patient identification system	Percent improvement
Patient asked to state first name			
CRU	0/6†	1/4† (25)	25
Theater			NA
CTU	1/10 (10)	4/10 (40)	30
Patient asked to state surname			
CRU	0/6†	1/4† (25)	25
Theater			NA
CTU	1/10 (10)	4/10 (40)	30
Patient asked to state date of birth			
CRU	0/6†	1/4† (25)	25
Theater			NA
CTU	3/10 (30)	6/10 (60)	30
Patient wearing an identification wristband			
CRU	50/50 (100)	50/50 (100)	0
Theater	9/10 (90)	10/10 (100)	10
CTU	10/10 (100)	10/10 (100)	0
Patient's first name on identification wristband checked and correct			
CRU	48/50 (96)	50/50 (100)	4
Theater	6/10 (60)	10/10 (100)	40
CTU	10/10 (100)	10/10 (100)	0
Patient's first name on blood pack checked and correct			
CRU	50/50 (100)	50/50 (100)	0
Theater	10/10 (100)	10/10 (100)	0
CTU	10/10 (100)	10/10 (100)	0
Patient's surname on identification wristband checked and correct			
CRU	48/50 (96)	50/50 (100)	4
Theater	6/10 (60)	10/10 (100)	40
CTU	10/10 (100)	10/10 (100)	0
Patient's surname on the blood pack checked and correct			
CRU	50 (100)	50 (100)	0
Theater	10 (100)	10 (100)	0
CTU	10 (100)	10 (100)	0
Patient's date of birth on their identification wristband checked and correct			
CRU	48/50 (96)	50/50 (100)	4
Theater	6/10 (60)	10/50 (100)	40
CTU	10/10 (100)	10/10 (100)	0
Patient's date of birth on the blood pack checked and correct			
CRU	50/50 (100)	50/50 (100)	0
Theater	10/10 (100)	10/10 (100)	0
CTU	10/10 (100)	10/10 (100)	0
Patient's hospital number on their identification wristband checked and correct			
CRU	49/50 (98)	50/50 (100)	2
Theater	6/10 (60)	10/10 (100)	40
CTU	10/10 (100)	10/10 (100)	0
Patient's hospital number on the blood pack checked and correct			
CRU	50/50 (100)	50/50 (100)	0
Theater	10/10 (100)	10/10 (100)	0
CTU	10/10 (100)	10/10 (100)	0
Blood group on the blood pack cross-referenced with blood group on compatibility label			
CRU	10/50 (20)	50/50 (100)	80
Theater	2/10 (20)	10/10 (100)	80
CTU	10/10 (100)	10/10 (100)	0
Unit number on the blood pack cross-referenced with unit number on the compatibility label			
CRU	5/50 (10)	50/50 (100)	90
Theater	1/10 (10)	10/10 (100)	90
CTU	3/10 (30)	10/10 (100)	70
Expiry date of the blood checked			
CRU	48/50 (96)	50/50 (100)	4
Theater	10/10 (100)	10/10 (100)	0
CTU	2/10(20)	10/10 (100)	80
All checks carried out at the bedside			
CRU	50/50(100)	50/50 (100)	0
Theater	8/10 (80)	10/10 (100)	20
CTU	10/10 (100)	10/10 (100)	0
Was the blood prescribed			
CRU	29/50 (58)	48/50 (96)	38
Theater	0/10 (0)	0/10 (0)	0
CTU	6/10 (60)	10/10 (100)	40

TABLE 5. *Continued*

Variable	Standard system	Bar code patient identification system	Percent improvement
Were the following observations taken and recorded before transfusion:			
Temperature			
CRU	12/50 (24)	50/50 (100)	76
Theater	10/10 (100)	10/10 (100)	0
CTU	10/10 (100)	10/10 (100)	0
Pulse			
CRU	18/50 (36)	50/50 (100)	64
Theater	10/10 (100)	10/10 (100)	0
CTU	3/10 (30)	10/10 (100)	70
Blood pressure			
CRU	18/50 (36)	50/50 (100)	64
Theater	10/10 (100)	10/10 (100)	0
CTU	3/10 (30)	10/10 (100)	70
Has the unit number been recorded in the medical record or prescription chart			
CRU	0/50 (0)	50/50 (100)	100
Theater	0/0 (0)	10/10 (100)	100
CTU	3/10 (30)	10/10 (100)	70
Was the date and time of the unit transfusion documented			
CRU	11/50 (22)	50/50 (100)	78
Theater	0/10 (0)	10/10 (100)	100
CTU	4/10 (40)	10/10 (100)	60
Is there clear documentation of the number of units transfused			
CRU	0/50 (0)	50/50 (100)	100
Theater	0/10 (0)	10/10 (100)	100
CTU	1/10 (10)	10/10 (100)	90
Is there a clear statement given for the reason for transfusion			
CRU	1/10 (2)	16/50 (32)	30
Theater	0/10 (0)	0/10 (0)	0
CTU	1/10 (10)	0/10 (0)	-10
Were the following observations taken and recorded 10-20 min after start of transfusion:			
Temperature			
CRU	9 (18)	30 (60)	42
Theater	10/10 (100)	10/10 (100)	0
CTU	5/10 (50)	4/10 (40)	-10
Pulse			
CRU	14/50 (28)	10/50 (20)	-8
Theater	10/10 (100)	10/10 (100)	0
CTU	6/10 (60)	4/10 (40)	-20

* Data are reported as number (%).

† Patients in the CRU who were conscious at the time of bedside checking before blood administration.

The baseline audit demonstrated that in only 5 of 50 (10%) patients in the CRU, 1 of 10 (10%) patients in theaters, and 3 of 10 (30%) of patients in the CTU was the unit number on the blood bag checked with the unit number on the compatibility label attached to the blood bag by the blood bank. Similarly, the baseline audit demonstrated that in only 10 of 50 (20%) patients in the CRU and 2 of 10 (20%) patients in theaters was the blood group on the blood bag checked with the blood group on the compatibility label; this procedure was carried out correctly in the CTU ward. After the introduction of the electronic process, all patients in all three clinical areas had the unit number and blood group on their blood bag matched correctly with the unit number on the compatibility label on the blood bag.

In the baseline audit, 12 of 50 (24%) of patients in the CRU, 10 of 10 (100%) patients in theaters, and 3 of 10 (30%) of patients in the CTU had complete pretransfusion observations (pulse, blood pressure, and temperature)

taken. After the introduction of the electronic process, all patients had the appropriate pretransfusion observations taken in both the CRU and theaters.

The baseline audit demonstrated that there was very poor documentation of the date and time of the transfusion, and the number of units transfused in all three clinical areas in cardiac surgery. After the introduction of the electronic process, documentation was complete, with a report label printed and included in the patient's medical records.

Statistical analysis was carried out on a smaller set of key parts of the transfusion process involving consolidation of a number of the steps in Table 5. The results are shown in Table 6. The patient's wristband was checked against the blood pack in 48 of 50 (96%) procedures in the CRU, 6 of 10 (60%) in theater, and 10 of 10 in CTU. After the electronic process was implemented, this improved to 50 of 50 in CRU ($p = 0.49$) and 10 of 10 in theater ($p = 0.087$)

TABLE 6. Consolidated sets of steps in blood administration

Variable	Number	Standard system	Bar code patient identification system	Fisher's exact p value
Patient's first name, surname, date of birth, and hospital number on the wristband checked with those details on the blood pack				
CRU	50	48 (96)	50 (100)	0.49
Theater	10	6 (60)	10 (100)	0.087
CTU	10	10 (100)	10 (100)	>0.99
Blood group and unit number on blood pack checked with those on the compatibility label and expiry date checked				
CRU	50	4 (8)	50 (100)	<0.0001
Theater	10	1 (10)	10 (100)	0.0001
CTU	10	0 (0)	10 (100)	<0.0001

* Data are reported as number (%).

but did not alter the rate in CTU of 10 of 10 (100%). The blood group and the unit number on the blood bag were checked against the compatibility label, and the expiry date was checked, during 4 of 50 (8%) procedures in CRU, 1 of 10 in theater, and 0 of 10 in CTU. After the electronic process was introduced, this improved to 50 of 50 in CRU ($p < 0.0001$), 10 of 10 in theater ($p = 0.0001$), and 10 of 10 in CTU ($p < 0.0001$).

During the study, it was documented that one IBCT was prevented by the electronic process in the CRU. The wrong blood was delivered to the bedside of a patient with a similar name before the electronic blood collection system was in operation. Visual checking failed to identify that the blood was not intended for the patient, but checking with the handheld computer indicated that it was the wrong blood.

Staff satisfaction

Staff satisfaction questionnaires were distributed to staff in all three clinical areas in cardiac surgery, and 28 of 30 gave very positive feedback about their experience with the electronic process and said they would recommend its use in other areas. The majority felt that it was straightforward, quick, and easy to use and had a far more structured and systematic approach than the standard checking process. Many found that it gave them more confidence in checking the correct information due to the screen reminder prompts. One member of staff even commented how she could remember how to use it after 7 months' leave.

It was also felt to be time-saving in an acute clinical setting because it allowed single-person checking avoiding the need to wait for another nurse to be available and allowing more than 1 unit to be checked at a time when rapid transfusion or multiple types of blood component were required.

Staff commented on how they felt more accountable, because they were checking transfusions on their own, which they felt put more responsibility on the individual resulting in a more thorough checking process. They also felt that the checks were more extensive, which was inter-

esting because the number of steps to complete the transfusion checklist was fewer in comparison to the standard system. The small number of negative comments related to those who used the system infrequently and who considered they needed more practice.

DISCUSSION

A variety of approaches have been used to reduce the risk of transfusion errors, including use of specially trained nurses to carry out all procedures in relation to transfusion, additional identification systems for blood transfusion, increasing monitoring of blood administration practice,⁹ the repeat determination of the patient's ABO group at the bedside before transfusion,¹⁰ and physical barriers to transfusion, such as placing the unit of blood in a locked plastic bag that can only be opened with a code marked on the patient's wristband and the cross-match sample.¹¹⁻¹³ None of these methods is ideal in that they are impractical for routine practice and/or costly, and they have not been shown to be totally effective in preventing transfusion errors.

The objective of this study was to develop electronic end-to-end control of the hospital transfusion process with the specific aim of minimizing errors occurring outside the blood bank to improve patient safety. This work extended that previously reported by our group on the use of handheld computers and bar code patient identification for blood sample collection and blood administration in hematology.⁷ Although this study in the more challenging clinical setting of cardiac surgery found significant improvements in the performance of blood sample collection, the collection of blood from blood refrigerators, and the administration and documentation of blood transfusion after the introduction of an end-to-end electronic transfusion process, further improvements are required to achieve in full the aims of this work.

Observations of practice before the implementation of the new procedures revealed that almost all the key steps in the transfusion process were not carried out correctly; these included patient identification before blood sample collection, labeling of sample tubes, the collection

of blood from blood refrigerators, bedside checking before blood administration, monitoring of transfused patients, and the documentation of transfusion. One of the main issues raised by the results of this study, as with our previous study,⁷ is “why is compliance with procedures for the clinical transfusion process so poor?” One major factor is the complexity of blood transfusion procedures; there are many steps in the apparently simple process of requesting, matching, delivering, and transfusing blood involving a number of different departments and staff. This complexity is shared with many other routine hospital procedures. A second factor is the lack of any formal regular education and training with regard to blood transfusion, certainly within the hospital in the study. This is probably typical of other hospitals; recent national surveys in the United Kingdom demonstrate that many hospitals do not provide regular training in the procedures for the administration of blood to relevant staff¹⁴ (and unpublished observations).

The design of the electronic process used in this study is such that the user is compelled to adhere to certain actions, for example, the checking of patient identification wristbands. During the baseline audit, it was observed that individuals were frequently distracted and interrupted while checking blood, for example, interrupting a procedure to answer the phone or respond to questions from patients and colleagues. The use of the electronic process appeared to dissuade individuals from becoming distracted and interrupted. Its simplicity seemed to encourage staff to complete the process once they had started it.

Although the results after implementation of the new system were significantly better, there remain some areas for further improvement. As already indicated above, these include training to avoid overreliance on the technology particularly for the key step of patient identification. The whole process is dependent on patients having bar-coded wristbands at every step of the process. There are a number of weaknesses in identifying patients with wristbands in both the standard and the electronic processes. Initial patient identification is a key step and depends on the correct verbal identification of conscious patients (and other means for identifying unconscious patients) and then attaching the correct wristband to the patient. There is considerable potential for patient misidentification at this stage, resulting in the attachment of a wristband with the wrong patient's details. One weakness of patient identification for blood sample collection both for the standard and for the electronic process is that cardiac surgery patients who are outpatients in advance of surgery hold rather than wear their wristband. Furthermore, wristbands are an inconvenient method for identifying patients in theaters because they are not always readily accessible for checking, and they are frequently removed in the setting of cardiac surgery to facilitate vas-

cular access. In some cases, it was observed that checking was carried out in the anesthetic room with an additional wristband rather than using the wristband attached to the patient; this is clearly unsafe practice. Possible enhancements to the use of bar codes for patient identification are the use of biometrics such as fingerprint technology or iris scanning for initial patient identification and the use of radiofrequency identification in theaters. These technologies could be combined with bar code technology that may remain a convenient method for patient identification and checking for the interim steps.

The electronic process also needs to be redesigned to promote greater consistency in practice in what documentation is brought to blood refrigerators to ensure the right blood is collected. The use of an “on demand” blood collection slip printed at the bedside from the patient's wristband with the SafeTx system would allow this to be accomplished, and this is now included in an enhanced version of this system since this study was carried out.

Another weakness of the electronic process was the lack of a requirement forcing the clinical staff to enter observations during and after transfusions. Observations of a patient's temperature, blood pressure, and pulse are considered to be important in the early detection of transfusion reactions, but baseline auditing demonstrated that 24 percent of patients in the CRU did not have any pretransfusion observations recorded. The electronic process compels staff to input pretransfusion observations before allowing them to continue with the pretransfusion checking procedure. Following the introduction of the electronic process, all patients had a set of pretransfusion observations taken and recorded.

Severe transfusion reactions often occur during the first half-hour of a transfusion. For this reason, hospital policy and BCSH guidelines⁸ recommend that patients have their temperature and pulse taken 15 minutes after starting a transfusion. Baseline auditing demonstrated that compliance with this requirement of the policy was poor. The bar code patient identification system had little impact on this. While the design of the system is such that it provides an option to record “15-minute observations,” it would appear that because checkers are not compelled to carry out this stage, they often choose not to, particularly when the clinical environment allows them to observe the patient easily.

Similarly, staff are not compelled to carry out all of the steps with the electronic process, but rather they are provided with prompts. The staff member must indicate that they have carried out the check by ticking the appropriate box before proceeding to the next step. For example, the verbal identification of the patient was carried out poorly before blood administration for conscious patients in the CRU and the CTU ward. This is in contrast to the experience in hematology where the introduction of the electronic transfusion process resulted in full compliance with

this action.⁷ This emphasizes the need for continued staff training and further amendments to the design of the electronic process.

The baseline audit identified that documentation of the transfusion was often poor. In addition, the audit identified a number of steps associated with documenting the transfusions that merely add to the complexity of the procedure rather than increasing safety, including transcribing unit numbers from transfusion report forms to prescription charts. The electronic process addressed these issues with the printing of a self-adhesive transfusion record for the patient's notes and downloading the information from the handheld computers to a computer in blood bank. This improved documentation provided a thorough audit trail for each unit of blood, which is a mandatory requirement of the clinical transfusion process as part of national guidelines in the UK⁸ and recent EU legislation.¹⁵

IBCT remains the most frequent adverse event associated with blood transfusion, and the single most important factor in IBCT incidents is misidentification of the patient during the transfusion process.¹⁻⁶ It was unrealistic to expect to document a reduced number of IBCT incidents because of the small scale of this project, which was carried out within one clinical department. Surrogate output measures were used to determine better performance of aspects of the transfusion sequence. One IBCT, however, was prevented by the electronic process in the CRU during the period of the study.

The main reason for introducing electronic checking is the recognition that clinical staff do not always carry out checking procedures correctly. Total reliance on electronic checking, however, is undesirable because electronic systems are likely to fail from time to time. Training in the use of the new process should continually emphasize this point. In our view, technology should be used to help individuals rather than take over their thinking. The technology should encourage users to think about what they are doing and why. When the technology fails, which it may do from time to time, individuals must still have the knowledge and understanding to check blood safely. Computerized transfusion aids cannot eliminate human error, but the less complicated and more "user-friendly" the "system" is, the less scope there is for error. It is vital not to underestimate the role of comprehensive education, training, and continued support, which are essential for the successful implementation of a reengineered transfusion process supported by technology.

The system used in this study was designed to simplify and guide the user through the various stages of the transfusion process. The introduction of the technology had a positive impact on compliance with the correct performance of these procedures. Our hospital is planning to introduce the electronic transfusion process throughout its services (1500 beds, four acute sites); the estimated

costs are \$500,000 per year for leasing the equipment and ongoing training and technical support. The high costs of implementing such a system in a hospital mean that to become accepted, the technology may have to be multi-functional for other procedures requiring patient identification and known to be prone to error, such as drug administration.¹⁶ An obvious place to start is the electronic prescribing of blood according to algorithms incorporating agreed guidelines for the use of blood.

There is considerable potential for reducing blood use. The use of RBCs has decreased by 12 percent in the past year in our hospital through a number of actions including providing training in appropriate blood use to clinical teams in high-blood-use specialties, insisting that clinical staff provide an indication for transfusion with every request for blood, providing a link between the hematology and blood bank computer systems so that recent blood count data are highlighted when requests for blood are entered into the blood bank computer, and empowering blood bank staff to challenge medical staff about any requests for blood that appear to be inappropriate. In our previous study in hematology, it was found that intensive training produced compliance with the performance of correct bedside checking procedures in 40 percent of cases, but it was not until the introduction of the electronic transfusion process compelled individuals to carry out bedside checking correctly that compliance with the procedure improved to 100 percent of cases.⁷ While compliance with guidelines for appropriate blood use might not be expected to improve to 100 percent, a system for electronic prescribing of blood according to algorithms incorporating agreed guidelines should reduce the inappropriate use of blood. Significant savings in blood use might realize sufficient cost savings to allow the implementation of electronically controlled blood transfusion procedures in hospitals with the prime aim of improving patient safety.

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