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Absence of acute adverse in-vitro effects on AS-1 Red Blood Cells and Whole Blood Derived Platelets following prolonged exposure to 13.56 MHz Radio Energy

Rodeina Davis, Jerome Gottschall, Alfonso Gutierrez, Clive Hohberger, and Dharmaraj Veeramani

BloodCenter of Wisconsin, Milwaukee, Wisconsin; UW RFID Lab, University of Wisconsin-Madison, Madison, Wisconsin; and Zebra Technologies, Vernon Hills, Illinois

Abstract

Background—There is growing interest in radio frequency identification (RFID) technology application for tracking blood products to achieve higher productivity and safety in the transfusion medicine supply chain. We have conducted a limited study to assess the temperature and biological effects of 13.56 MHz RF radiation on red blood cells (RBC) and whole blood-derived platelets (WBDP) under extreme exposure conditions.

Study Design and Methods—Using an FDA-approved protocol, test units of both RBC and WBDP were subjected to approximately 100 watts of RF energy for an extended duration (23-25 hours) to assess worst-case effects. Three replications of the test were performed.

Results—Hemolysis after 23-25 hours of RF energy exposure was 0.09% and 0.05% respectively for TEST and CONTROL RBC units and well within the $\leq 1\%$ limit in the FDA-approved acceptance criteria. For WBDP units, the mean pH of TEST and CONTROL units were 7.27 and 7.19 respectively following 23-25 hours of RF energy exposure, and well above the ≥ 6.2 acceptance limit. Further, there was no detectable acceleration in cellular degradation of RBC and WBDP products. While there was minimal temperature rise, the relative temperature increase between TEST and CONTROL units never exceeded the 1.5 °C acceptance criterion.

Conclusion—13.56 MHz-based RFID technology is unlikely to have any significant temperature or biological effects on RBC and WBDP units under the normal operating conditions (a maximum of 4 watts RF power exposure for about 20 non-consecutive minutes for RFID tracking during the life of the blood product).

Keywords

RFID; radio frequency identification; transfusion safety; blood product supply chain

Introduction

There is growing interest in radio frequency identification (RFID) technology as a complement to bar code technology in transfusion medicine. This is because even with

Correspondence to: Jerry Holcombe; BloodCenter of Wisconsin; 638 North 18th Street, Milwaukee, WI 53233; telephone: (414) 937-6084; fax: (414) 937-6332; jerry.holcombe@bcw.edu.

Address reprint requests to: Rodeina Davis, BloodCenter of Wisconsin, 638 North 18th Street, Milwaukee, WI 53233; Telephone: (414) 937-6345; Rodeina.Davis@bcw.edu.

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existing safeguards in place, incidence of mistransfusion persists where the wrong blood is given to the wrong patient. In recent years, a few hospitals and blood centers have been exploring and testing the use of RFID for specific transfusion medicine delivery processes and have found it to be a promising technology.¹⁻⁸ A consortium including blood centers (BloodCenter of Wisconsin, Milwaukee, WI, Carter Blood Care, Dallas, TX, and Mississippi Blood Services, Jackson, MS), hospitals (Baptist Health Systems, Jackson, MS, and University of Iowa Hospital and Clinics, Iowa City, IA), the University of Wisconsin-Madison RFID Lab, and several technology partners (including SysLogic, Inc., TAGSYS, Zebra Technologies, Psion Teklogix, Mediarware Information Systems) is actively engaged in the first-ever comprehensive investigation of RFID for automatic identification, tracking and condition-monitoring of blood and blood products across the entire transfusion medicine supply chain.

RFID offers several advantages over bar coding. It does not require line-of-sight and is capable of reading multiple tags simultaneously. In addition, RFID tags (transponders) allow multi-write capabilities and more data storage than bar code labels, and can be integrated with sensors to facilitate time and temperature tracking.

RFID can be based on a variety of different standard frequency bands ranging from Low Frequency (125 KHz), to High Frequency (13.56 MHz), to Ultra High Frequency (850 – 950 MHz), and beyond (2.45 GHz and 5.8GHz). Among these, the 13.56 MHz band has several relative advantages over the other frequency bands that makes High Frequency (HF) based RFID attractive for transfusion medicine applications. Specifically, the performance of RFID tags operating at 13.56 MHz is minimally affected by liquids. Further, 13.56 MHz is the only true global RFID standard; in contrast, the standards for UHF RFID can vary from country to country. Hence, the International Society for Blood Transfusion (ISBT) working party on RFID has recommended HF (13.56 MHz) as the international standard for transfusion medicine.

A question that has remained unanswered until now, the answer to which was insisted upon by the FDA, is the potential impact of RF energy exposure on blood products in terms of heating (temperature elevation) and adverse biological effects. To answer this question, the RFID consortium designed and conducted a rigorous set of experiments (limit tests) with an FDA agreed-upon protocol using a specially designed RF apparatus. This paper describes our findings and evaluation of the worst-case effects of 13.56 MHz RF radiation on red blood cells and platelets under extreme exposure conditions.

Materials and Methods

The study team elected to involve the FDA early on to determine its interest and any concerns with the using RFID in transfusion medicine. Members of the team met with the FDA on March 15, 2007. The FDA stressed a need to first determine what impact RF energy might have on blood products, if any, with the possibility of more specific and exhaustive testing based on findings from a limited test protocol. Negotiations resulted in the parameters to be studied, length of time of product exposure to RF, acceptance criteria, and number of products to be studied. Most importantly, the FDA would not permit transfusable products to be used in an RFID-enabled pilot until they had reviewed the results of the in-vitro tests.

Blood products evaluated in this study included red blood cell and platelet components separated from whole blood units (WBs). All WBs were collected from eligible blood donors using the standard collection procedures of BloodCenter of Wisconsin. The WBs were collected in a 450 mL Baxter Healthcare PL146 bag containing 63 mL of Citrate

Phosphate Dextrose (CPD) anticoagulant/preservative solution and were separated into components using standard centrifugation methods. The packed red blood cell (RBC) products had AS-1 added as a preservative and stored at 1-6°C until time of testing. The WB-derived platelets (WBDP) were stored in a Baxter PL1240 bag on a Helmer PF48i flatbed platelet agitator at $22 \pm 2^\circ\text{C}$ until time of testing.

The RBC and WBDP products used for this study came from separate WB units of the same blood group and age (i.e., collected on the same day). Three pairs of RBC units and three pairs of WBDP were tested, i.e., one TEST unit and a CONTROL unit per pair. Each pair of WBDP was combined using a sterile connecting device, draining one unit into the second unit to make a “pool.” The pool was mixed several times before being split back into two platelet bags with weights within 1 gram of one another. The pairs of RBC units chosen for testing had comparable, but not equal, weights.

The RF apparatus for this test was custom-designed and built for the execution of this project. It comprised an 86 cm Helmholtz coil whose geometric and electrical design inherently produces a uniform magnetic field within a limited cylindrical volume at its geometric center. This apparatus allows the entire test unit of blood product to be exposed to a uniform, in-phase 13.56 MHz magnetic strength of 5 Amperes/meter with a magnetic flux density of $6.28 \mu\text{T}$ and with less than 1% variation in magnetic field strength over the test unit.⁹ The RF apparatus' coil chamber was built using Plexiglas laminates, and the chamber had a non-metal test platform with a perforated base to hold the test units of blood products (and allow ventilation). A Faraday shield was constructed to eliminate stray RF field propagation.

Measurement of the temperature was accomplished using three Luxtron fiber optic temperature probes, two T-type thermocouples (Omega), one NIST calibrated temperature probe, and associated measurement devices. Data collection of the temperature was done at one-minute intervals using LabVIEW software.

The testing was designed to focus on two primary areas of interest:

- Rise in temperature of blood products (RBCs and WBDPs) due to heating generated by extended exposure to an intense RF field, and
- Cellular degradation from extended exposure to an intense RF field.

The anticipated maximum exposure to RF energy under normal operating conditions for RFID tracking would be less than 4 watts (the maximum allowed under FCC regulations) for about 20 minutes (non-consecutive) during the life of the blood product. In contrast, the limit test was designed to expose the RBC and WBDP units to extreme conditions of 100 watts of RF energy for 23 – 25 continuous hours inside the Helmholtz coil apparatus.

This study was reviewed by BloodCenter of Wisconsin's Institutional Review Board.

Per the protocol, acceptance criteria were defined as follows:

- For RBCs, the mean hemolysis of both the TEST and CONTROL groups will be $\leq 1\%$ following 23-25 hours of RF exposure.
- For WBDPs, the mean pH of both the TEST and CONTROL groups will be ≥ 6.2 following 23-25 hours of RF exposure.
- The maximum temperature increase of the TEST unit relative to the CONTROL will not exceed 1.5°C at any period within 23-25 hours of continuous RF exposure.

The RBC and WBDP were separately tested under different ambient conditions. The RBC products were tested in pairs (TEST and CONTROL) in a walk-in refrigerator where the ambient temperature is routinely controlled, monitored and Rees alarmed to maintain an appropriate storage temperature range for red cell products, 1°C - 6°C. The testing of the WBDP products (TEST and CONTROL) was done in another room which was thermostatically controlled to maintain the ambient temperature between 20°C - 24°C.

The RBC units were kept in a Styrofoam container during the test. Due to concerns about inadequate gas exchange in a Styrofoam container, the WBDP units (TEST and CONTROL) were placed directly on an agitating device (long, flat piece of non-conductive pegboard sliding on rollers and connected to a Helmer platelet agitator). Figure 1 illustrates the configuration for testing RBC units and Figure 2 illustrates the setup for testing WBDP units.

Temperature probe placement was important. In order to insert the optical probe into each product, a needle was used to poke a hole through the barrier of one of the bag's ports. Two Luxtron fiber optic temperature probes were inserted into the TEST unit – one probe was threaded until reached the bottom of the bag while the other was left in the center of the bag. One Luxtron probe was inserted into the center of the CONTROL unit. The CONTROL unit had a thermocouple attached to the outside of the bag in an area devoid of an air pocket. A second thermocouple was hanging freely a few inches away from the CONTROL unit to measure and log the ambient temperature. In addition, the NIST calibrated thermocouple was located in another part of the room to log the ambient temperature.

One unit (TEST) was placed in the center of the RF apparatus, and one unit (CONTROL) was placed a minimum of 2 meters from the RF apparatus and outside the RF field generated by the coil. The three pairs of RBC products and three pairs of WBDP were tested for various in-vitro parameters over a 23-25 hour period of exposure to RF.

To perform the biological effect evaluation, all RBC and WBDP products, both TEST and CONTROL, were tested at three sampling points relative to RF exposure duration: 0 hours, 7 hours and 23-25 hours. The pretreatment (0 hours) sample was taken immediately before the RF field was powered on. For the 7 hour and 23-25 hour samples, the RF field was turned off and the probes removed. The probes were cleaned with 70% isopropyl alcohol solution and allowed to air dry while the products were being sampled. Hemostats were used to clamp the ports to the blood bag, and the products were taken to a Sartorius scale located just outside the RF testing area. The products were weighed, mixed and sampled. Product pairs were returned to the testing room within 15 minutes, and the optical probes were re-inserted for additional testing until the TEST units had realized 23-25 hours of RF exposure.

For the RBC units, we evaluated percent Hemolysis, complete blood count, RBC morphology score, free hemoglobin, and potassium. For the WBDP products, the complete blood count, blood gases, lactate, and P-selectin were evaluated. P-selectin was tested as a marker of platelet activation.¹⁰

Complete blood counts were performed using an automated cell counter (Cell-Dyn 3700, Abbott Diagnostics Division, Abbott Park, IL). Samples for blood gas measurements were collected into specialized capped 1-mL syringes, packed on ice, and delivered immediately to a local outsource laboratory (Dynacare) for analysis using a Radiometer 725 (Copenhagen) gas analyzer to determine pH, pO₂, pCO₂ and bicarbonate at 37°C. Supernatant samples were spun twice in a Beckman centrifuge (Arlington Heights, IL) at 3,000 × g for 10 minutes in preparation for free hemoglobin, lactate, and potassium. All samples were kept frozen at -80°C until batch analysis could be performed. Plasma hemoglobin measurements were performed by Diagnostic Laboratories, BloodCenter of

Wisconsin using the Harboe method and a VERSAmax spectrophotometer (Molecular Devices Corporation, CA). Red blood cell supernatant samples were measured for absorbance at three wavelengths (415, 380, and 450). Formulas were used to determine the levels of hemoglobin and hemolysis present in the plasma. Lactate and potassium samples were sent to a local outsource laboratory (Dynacare) for measurement with AU 5431 Analyzer (Olympus), using the indirect ISE method.

Results

Cellular analysis of RBC units

A total of three pairs of RBC products were tested with each pair consisting of one TEST and one CONTROL. Pair 1 was six days old, Pair 2 was eight days old and Pair 3 was nine days old at the start of the RF treatment. Pairs 1 and 3 had almost identical weights while Pair 2 had a difference of 13 g between TEST and CONTROL.

The mean hemolysis percentages of both the TEST and CONTROL groups, following 23-25 hours of RF exposure, were well within the $\leq 1\%$ acceptance criterion (Table 1):

RBC morphology was scored on a scale of 100-500, where the lower score indicates that the RBC was better maintained. There were no significant differences in morphology score in TEST and CONTROL units. There was a slight increase in free hemoglobin and Hemolysis over the 24-hour period for all individual RBC products. This may be due to the extra mixing of the products prior to each sampling. The TEST RBC for Pair 1 started with a higher free hemoglobin measurement than all the other units which probably relates to a donor variance issue. This TEST RBC still was well within the acceptance criteria of $< 1.0\%$ hemolysis at the end of 23-25 hours of RF exposure. For Pairs 2 and 3, there was no difference in hemolysis between TEST and CONTROL.

Differences in the complete blood count (CBC) results between TEST and CONTROL RBC were expected as each of the six RBC products came from a different donor. There were no significant differences in CBC results for individual RBC products considering pre- versus post-RF exposure. There was no significant difference in potassium between TEST and CONTROL RBC units. Table 2 below shows the data for Pair 2 of RBC TEST and CONTROL units.

Cellular analysis of WBDP units

Two of the pairs of WBDP were three days old and the other pair was two days old at the time of testing.

All three WBDP pairs were tested for pH and blood gases. All pH values were well above the acceptance criteria of 6.2 at the end of 23-25 hours of RF exposure (Table 3).

With the exception of slightly higher average platelet concentration in one CONTROL unit over its corresponding TEST unit (Table 4), there were no differences in the WBC count, platelet count or mean platelet volume between TEST and CONTROL units in all the WBDP pairs.

There were no changes seen in pCO₂ or bicarbonate levels between TEST and CONTROL WBDP units. There were some inconsistencies in the pO₂ content, including elevated levels at 7 hours in all WBDP and a drop at 23-25 hour for one of the pairs. This discrepancy can be attributed to a limitation of the study design that allowed air to enter into the platelet bag through the sample port where the optical probes were inserted.

There were no differences in lactate or P-selectin between TEST and CONTROL WBDP units.

Analysis of temperature effects

Temperature measurements were obtained from two thermocouple probes, three fiber optic probes, and one NIST calibrated temperature probe. For RBC and platelet TEST and CONTROL bags the temperatures at bag center and surface were collected and analyzed. The difference in the absolute temperatures of the TEST and CONTROL bags does not necessarily reflect the actual temperature variation of the TEST bag. This is due to the initial conditions of the individual bags (pre-test handling) and slight differences in temperature conditions within the testing environment where the TEST and CONTROL bags were located. For RBCs, the CONTROL bag was subject to full refrigerator convection while the TEST bag was not because it was shielded by the Helmholtz coil case (Plexiglas panels) and was closer to the heat-generating coil resistors. This caused ambient temperature surrounding the TEST bag to be slightly higher (throughout the testing) than the ambient temperature near the CONTROL bag.

To determine the actual temperature trend of the TEST bag, the following data normalization procedure was performed:

D_n = Temperature Differential at time n between test bag and control bag

D_0 = Initial temperature differential at time 0 between test bag and control bag

The normalized temperature differential at time n was then calculated as $ND_n = D_n - D_0$

The observed temperature readings were compared against the test threshold (maximum acceptable temperature increase of 1.5°C).

Temperature effect on RBC units

Due to the pre-test handling differences, the starting temperatures of TEST and CONTROL units were not the same. During the first 4 hours, the CONTROL RBC unit cooled faster than the TEST RBC unit until they both reached a steady state temperature. This difference in cooling rates can be attributed to two factors. First, the CONTROL unit was located in an area of free air circulation, and was therefore subject to full refrigerator convection cooling; in contrast, the TEST unit was shielded to some extent from the convection cooling by the Plexiglas panels comprising the Helmholtz coil apparatus within which the TEST unit was located. Second, the ambient temperature within the RF apparatus was also influenced by the coil resistors which dissipated heat. In spite of these differences in the local ambient environment for the TEST and CONTROL units, both bags reached a stable temperature after about 4 hours. The data and trends following the bag temperature stabilization are, therefore, more relevant for our analysis.

The data plot of the room temperature measured by the thermocouple showed that it oscillates between 3°C and 5°C, with an average of ~4°C. These oscillations correspond to the thermostatic control of the refrigerator and may be attributed to the relative location of the thermocouple near the inflow ventilation outlet in the room. An NIST thermometer, placed on a shelf at a different location in the refrigerator, was relatively unaffected by the temperature changes due to the thermostatic control and tracked the ambient temperature at ~4°C.

We observed a short spike in the ambient temperature twice during the test duration. These changes in ambient temperature are likely attributable to a cyclic reset in the central automatic freezer temperature control. This spike in the ambient temperature had a greater

effect on the temperature of the CONTROL unit than the TEST unit (This can be attributed to the two factors alluded to previously that influenced the heating/cooling of the TEST unit). Overall, these ambient temperature spikes caused an insignificant and transient temperature elevation of the RBC units.

To extract samples after 7 hours of RF exposure, the bags were handled outside the walk-in refrigerator, and this resulted in raised temperatures of the TEST and CONTROL units. However, once the TEST resumed, the bags cooled down to the same temperature as before the sampling period. Once the cooling curve stabilized, the temperature difference between the center of the TEST and CONTROL bags remained constant throughout the remainder of the each trial run.

Temperature effect on WBDP units

The testing of the WBDP units was done in a larger room than the walk-in refrigerator used for RBC units testing. The temperature of the room was controlled by HVAC equipment and maintained in the 20°C - 24°C range.

The analysis of the temperature difference data shows that the center temperatures of the TEST and CONTROL bags stayed very close to one another. A minor upward trend was noted for a very short time after commencement of each test run. This was partially due to the fact that the CONTROL bag was subject to room convection while the TEST bag was protected from room convection by the Helmholtz coil case. The CONTROL bag was located in an area with better air circulation while the TEST bag was in a shielded environment near coil resistors that were dissipating heat and thereby influencing the neighboring ambient temperature.

The temperature at the surface of the TEST and CONTROL WBDP units showed similar variation. At no time during the 24 hour RF exposure duration did the relative difference in temperature between the TEST and CONTROL WBDP units exceed the acceptance criterion limit of 1.5°C.

Table 5 and Table 6 summarize the temperature variation of RBC and WBDP paired products respectively.

T-C @ Center:	Relative temperature variation at the bag centers (TEST – CONTROL)
T-C @ Surface:	Relative temperature variation at the bag surface (TEST – CONTROL)
Full Period:	Data collected for all three days of testing
Stable Period:	Data collected after 4 hours after the start and after the 7-hour sample collection. This ignores warming during product sampling outside the testing environment, and the subsequent temperature stabilization that occurs when the product is returned to the testing environment.

In addition, the temperature at the center of the TEST bag was compared with that at the edge (surface) of the same bag. It was observed that the center temperature tended to converge with or did not diverge from the surface temperature, a sign that dielectric heating is not present.

Discussion

Based on the limit testing that we conducted to discern the temperature and biological effects of 13.56 MHz RF radiation on RBC and WBDP products under extreme exposure situations, we can conclude that changes in cellular degradation and temperature rise were minimal. The limit test results following 23-25 hours of exposure to very high RF energy demonstrate minimal change in temperature, free hemoglobin (RBC) and pH (WBDP).

With regard to in-vitro biological effects, data were consistent between TEST and CONTROL products with the exception of a few non-trending individual test results. There was insignificant cellular change between pre-RF and post-RF exposure. We observed a slight increase in RBC hemolysis over time which may be attributable to the nature of handling the units prior to sample extraction. Inconsistent pO₂ levels in WBDP, we concluded, were due to air entering the product through the same holes where the optical probes were inserted.

With regard to temperature effects, the RF field emitted by the Helmholtz coil had no significant effect on the temperature of RBC and WBDP blood products. The temperature difference between the TEST and CONTROL bags became relatively constant as stable conditions were achieved throughout the 6 days of testing. Any temperature increase observed during the first 2-3 hours of the test for the TEST bag is due to differences in the rates of cooling of the TEST and CONTROL bags, and is considered not significant after reviewing the normalized data trend. The relative temperature increase of the TEST units did not exceed at any time the acceptance maximum limit of 1.5°C beyond the temperature of the CONTROL units.

This study had a number of limitations. Experiments were not done at various stages of product aging thus it is unknown whether different findings might result, for example, if performed near outdate. No in-vivo survival studies were performed; therefore no comment can be made on whether prolonged exposure affects RBC recovery or platelet survival. The effects of RF energy on platelets were not studied.

This study's principal finding that 13.56 MHz RF radiation does not cause adverse thermal changes and cellular degradation in RBC and WBDP products, even after extended exposure and at high power levels resulted in approval to use transfusable red cells and platelets in an RFID-enabled pilot study.

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Figure 1.

Figure 2.

TABLE 1
Comparison of % hemolysis of the three pairs of TEST and CONTROL RBC units

% Hemolysis at 23-25 hours		
	Test Group	Control Group
1	0.16	0.03
2	0.04	0.06
3	0.06	0.06
Mean	0.09	0.05

Table 2
Comparison of RBC TEST and CONTROL units (Pair 2)

Time after RFID exp.	RBC Morphology		Pl. Hgb (mg/dL)		Hemolysis (%)	
	Test	Control	Test	Control	Test	Control
0 Hr	179	198	11.92	9.33	0.03	0.02
7 Hr	210	189	10.93	14.22	0.03	0.03
23-25 Hr	184	191	17.81	27.28	0.04	0.06
Mean	191	193	13.55	16.94	0.03	0.04
SD	17	5	3.72	9.28	0.01	0.02

Time after RFID exp.	Pre-Sample Weight (g)		RBC (10 ⁶ /ul)		Hgb (g/dL)		Hct (%)		MCV (fL)	
	Test	Control	Test	Control	Test	Control	Test	Control	Test	Control
0 Hr	310	323	6.21	6.87	17.7	18.1	56.4	57.0	90.8	83.0
7 Hr	294	306	6.22	6.89	17.9	18.1	55.9	56.9	90.0	82.6
23-25 Hr	273	291	6.21	6.79	18.6	18.9	56.7	56.9	91.3	83.8
Mean	292	307	6.21	6.85	18.1	18.4	56.3	56.9	90.7	83.1
SD	19	16	0.01	0.05	0.5	0.5	0.4	0.1	0.7	0.6

Time after RFID exp.	Potassium (mEq/L)	
	Test	Control
0 Hr	20	18
7 Hr	20	18
23-25 Hr	21	19
Mean	20	18
SD	1	1

Table 3
Comparison of mean pH of the three pairs of TEST and CONTROL WBDP units

	pH at 23-25 Hours	
	Test Group	Control Group
1	7.19	7.12
2	7.30	7.24
3	7.32	7.20
Mean	7.27	7.19

Table 4
Comparison of a pair of WBDP TEST and CONTROL units

Time after RFID exp.	pH		pO ₂ (mmHg)		pCO ₂ (mmHg)		Bicarbonate (mmol/L)	
	Test	Control	Test	Control	Test	Control	Test	Control
0 Hr	7.17	7.18	71	83	45	44	16	16
7 Hr	7.27	7.19	109	121	33	40	14	15
23-25 Hr	7.32	7.20	118	86	24	36	12	14
Mean	7.25	7.19	99	97	34	40	14	15
SD	0.08	0.01	25	21	11	4	2	1

Time after RFID exp.	Pre-Sample Weight (g)		WBC (10 ³ /ul)		PLT (10 ³ /ul)		MPV (fL)	
	Test	Control	Test	Control	Test	Control	Test	Control
0 Hr	64	63	0.369	0.352	1486	1525	8.16	8.12
7 Hr	57	56	0.332	0.355	1489	1534	7.41	7.36
23-25 Hr	50	49	0.249	0.302	1485	1509	8.12	7.93
Mean	57	56	0.317	0.336	1487	1523	7.90	7.80
SD	7	7	0.061	0.030	2	13	0.42	0.40

Time after RFID exp.	Lactate		P-Selectin (%)	
	Test	Control	Test	Control
0 Hr	6.7	6.7	31	32
7 Hr	7.4	7.2	29	32
23-25 Hr	8.7	8.2	28	36
Mean	7.6	7.4	29	33
SD	1.0	0.8	2	2

Table 5
Summary of temperature variation data from RBC units testing

	T-C @ Center		T-C @ Surface	
	Full Period	Stable Period	Full Period	Stable Period
Average Change (°C)	0.144	0.041	-0.212	-0.397
Std. Deviation	0.353	0.330	0.399	0.333
Data points (n)	4,100	2,663	4,100	2,663
99% Conf. interval	0.0142	0.0165	0.0161	0.0166
Upper limit (°C)	0.158	0.058	-0.196	-0.380
Lower limit (°C)	0.129	0.025	-0.228	-0.413

Table 6
Summary of temperature variation data from WBDP units testing

	T-C @ Center		T-C @ Surface	
	Full Period	Stable Period	Full Period	Stable Period
Average Change (°C)	0.300	0.287	-0.069	-0.133
Std. Deviation	0.274	0.273	0.590	0.559
Data points (n)	3,944	2,642	3,944	2,642
99% Conf. interval	0.0112	0.0137	0.0242	0.0280
Upper limit (°C)	0.311	0.300	-0.045	-0.105
Lower limit (°C)	0.289	0.273	-0.093	-0.161