Whole Blood Storage Temperature Investigation in Austere Environments

Cesar Avila, MD[1]; Samuel Sayson, MD[2]; Bruce Bennett, MD[3]*

ABSTRACT

Introduction: Military medical research has affirmed that early administration of blood products and timely treatment save lives. The US Navy's Expeditionary Resuscitative Surgical System (ERSS) is a Role 2 Light Maneuver team that functions close to the point of injury, administering blood products and providing damage-control resuscitation and surgery. However, information is lacking on the logistical constraints regarding provisions for and the stability of blood products in austere environments. **Methods:** ERSS conducted a study on the United States Central Command (USCENTCOM) area of responsibility. Expired but properly stored units of stored whole blood (SWB) were subjected to five different storage conditions, including combinations of passive and active refrigeration. The SWB was monitored continuously, including for external ambient temperatures. The time for the SWB to rise above the threshold temperature was recorded. **Results:** The main outcome of the study was the time for the SWB to rise above the recommended storage temperature. Average ambient temperature during the experiment involving conditions 1 through 4 was 25.6°C (78.08°F). Average ambient temperature during the experiment involving condition 5 was 34.8°C (94.64°F). Blood temperature reached the 6°C (42.8°F) threshold within 90 minutes in conditions 1 and 2, which included control and chemically activated ice packs in the thermal insulated chamber (TIC). Condition 2 included prechilling the TIC in a standard refrigerator to 4°C (39.2°F), which kept the units of SWB below the threshold temperature for 490 minutes (approximately 8 hours). Condition 4 entailed prechilling the TIC in a standard freezer to 0.4°C (32.72°F), thus keeping the units of SWB below threshold for 2,160 minutes (i.e., 36 hours). Condition 5 consisted of prechilling the TIC to 3.9°C (39.02°F) in the combat blood refrigerator, which kept the SWB units below the threshold for 780 minutes (i.e., 13 hours), despite a higher average ambient temperature of almost +10°C (50°F). **Conclusion:** Combining active and passive refrigeration methods will increase the time before SWB rises above the threshold temperature. We demonstrate an adaptable approach of preserving blood product temperature despite refrigeration power failure in austere settings, thereby maintaining mission readiness to increase the survival of potential casualties.

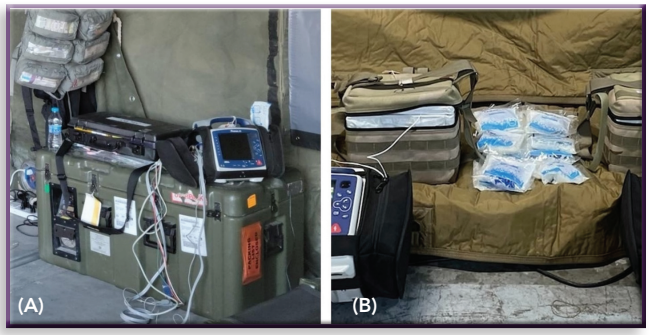
KEYWORDS: *stored whole blood; forward deployed surgical team; austere environments; walking blood bank; fresh whole blood; Role 2 care; blood transfusion; Golden Hour Offset Surgical Team*

Introduction

The US Navy's ERSS is a nine-member Special Operations Role 2 Light Maneuver team that functions close to the point of injury, administering blood products and providing damage-control resuscitation and surgery before medical evacuation. Hemorrhage is the leading cause of preventable death on the battlefield; between 2001 and 2011, mortality analysis from the Iraq and Afghanistan wars identified 976 potentially survivable injuries, of which 91% were related to hemorrhage.[1] Over the past 20 years, military medical research has affirmed that early administration of blood products and timely treatment save lives.[1-3]

To counter the logistical difficulties of maintaining a readily available supply of all physiologic ratios of blood components in far-forward deployed settings, fresh whole blood (FWB) and SWB serve as the cornerstone in the treatment of hemorrhage. FWB can be kept at room temperature for 24 hours; SWB is kept at 1°C to 6°C for up to 35 days in the anticoagulant citrate-phosphate-dextrose-adenine-1.[4] The ERSS maintains up to 20 units of SWB in theater, using active or passive cooling measures (i.e., portable combat refrigerators or coolers) (Figure 1). Although active refrigeration provides prolonged storage, power outages are not uncommon, leading to the loss of refrigeration and waste of SWB, hindering resuscitative medical capabilities. For instance, while transporting blood on a Landing Craft Air Cushion, a combat refrigerator failed when the batteries became wet. Another mishap occurred in an extremely hot environment when a generator overheated, leading to loss of power to the medical tent, thus causing the blood temperature to rise above the recommended storage temperature. Because of the time required to activate our FWB

FIGURE 1 **(A)** *Combat HemaCool Refrigerator and* **(B)** *Combat Golden Hour Cooler.*



*Correspondence to cesar.avila@navy.mil
[1]**LCDR Cesar Avila,** [2]**CAPT Samuel Sayson,** and [3]**CAPT Bruce Bennett** are affiliated with The Bureau of Medicine and Surgery (BUMED), the United States Department of the Navy, Falls Church, VA.

protocol (i.e., the walking blood bank), knowing how long before SWB is rendered unusable would be valuable. Unfortunately, information is lacking on the logistical constraints regarding provisions for and the stability of blood products in austere environments. Our objective was to investigate the definite time before SWB temperature rises above storage recommendations and study a combination method of active and passive refrigeration to increase blood product preservation in the event of power failure.

Methods

Expired but properly stored units of SWB were subjected to five different storage conditions. For each condition, two 500mL units of SWB were removed from the combat refrigerator unit system (Acutemp AX56L mobile refrigerator/freezer) and placed in the combat cooler TIC (Original Golden Hour Container; Minnesota Thermal Science) with two activated Instant Cold Packs (Cardinal Health). A thermometer probe was placed through the TIC and positioned between two units of SWB. There was no dead space in the TIC. The Propaq MD monitor/defibrillator (Zoll Medical) was used to measure continually at 10-minute intervals and recorded the SWB temperature.

Baseline temperatures of each TIC were obtained prior to initiating the study. The experiment was conducted in the USCENTCOM area of responsibility that experiences extreme heat environments. External environmental ambient temperatures were also monitored and recorded throughout the study. The storage conditions of 1 through 4 were performed simultaneously inside a climate-mitigated warehouse with an average ambient temperature of 25.6°C (78.08°F) and a high temperature of 27°C (80.6°F). Storage condition 5 was monitored simultaneously in a far-forward deployed, shaded outdoor desert environment about 1,000 meters from the firing line during a mission with an average ambient temperature of 34.8°C (94.64°F) and a high temperature of 45°C (113°F). Temperature monitoring continued until all the SWB units went above the recommended storage temperature of 6°C (42.8°F).

Condition Settings

Condition 1 (control): SWB units were placed in the TIC stored at ambient room temperature. Temperature of the TIC at baseline was 24.5°C (76.1°F).

Condition 2: SWB units were placed in the TIC stored at ambient room temperature; SWB units were wrapped with two chemically activated Instant Cold Packs. Temperature of the TIC at baseline was 24.5°C (76.1°F).

Condition 3: The TIC was prechilled in a standard refrigerator; then SWB units were placed in the TIC and wrapped with two chemically activated Instant Cold Packs. Temperature of the TIC at baseline was 4°C (39.2°F).

Condition 4: The TIC was prechilled in a standard freezer; then SWB units were placed in the TIC and wrapped with two chemically activated Instant Cold Packs. Temperature of the TIC at baseline was 0.4°C (39.2°F).

Condition 5: The TIC was prechilled in the combat blood refrigerator; then SWB units were placed in the TIC and wrapped with two chemically activated Instant Cold Packs. Temperature of the TIC at baseline was 3.9°C (39.02°F).

Data were collected and analyzed using Microsoft Excel.

Results

The temperature curves of each condition and ambient temperatures were graphed (Figure 2). Average ambient temperature during the experiment involving conditions 1 through 4 was 25.6°C (78.08°), with a standard deviation of 0.77°C (33.39°F). Average ambient temperature during the experiment involving condition 5 was 34.8°C (94.64°F), with a standard deviation of 6.1°C (42.98°F). The set conditions, starting TIC temperature, and time to reach threshold temperature limit are shown in Table 1. There was no significant difference in the control versus use of Instant Cold Packs to prolong the time to threshold temperature of the SWB units. In each case, the blood temperature reached the 6°C (42.8°F) threshold within 90 minutes. Prechilling the TIC in a refrigerator to 4°C (39.2°F) kept the units of SWB below the threshold temperature of 6°C (42.8°F) for 490 minutes (approximately 8 hours). Prechilling the TIC in a freezer to 0.4°C (32.72°) kept the units of SWB below threshold for 2,160 minutes (i.e., 36 hours). In the austere environment, prechilling the TIC to 3.9°C (39.02°F) in the combat blood refrigerator kept the SWB units below threshold for 780 minutes (i.e., 13 hours), despite a higher average ambient temperature of almost +10°C (50°F).

FIGURE 2 *Stored whole blood temperature.*

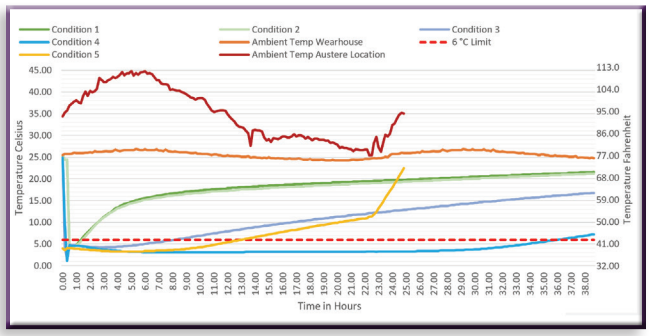


TABLE 1 *Set Conditions, Starting TIC Temperature, and Time to Reach Threshold Temperature Limit*

Condition	Starting TIC Temperature	Time to Reach 6°C (42.8°F)
1. Control – TIC stored at room temperature	24.5°C/76.1°F	80 min/1.33 h
2. Ice packs – TIC stored at room temperature	24.5°C/76.1°F	90 min/1.50 h
3. Ice packs – TIC prechilled in refrigerator	4.2°C/39.6°F	490 min/8.17 h
4. Ice packs – TIC prechilled in freezer	0.39°C/32.7°F	2,160 min/36.0 h
5. Ice packs – TIC prechilled in refrigerator	3.9°C/39.0°F	780 min/13.0 h

TIC, thermal insulated chamber.

Discussion

Providing blood products in far-forward deployed environments is a logistical challenge. While FWB (i.e., the walking blood bank) serves as an alternative strategy, maintaining available SWB for immediate use is of paramount importance because delay to transfusion is associated with increased mortality.[3,5,6] The ERSS regularly trains and was involved in the activation of the largest walking blood bank transfusion since World War II,[7] but achieving FWB transfusion requires time for donor screening, blood typing, and abstraction of FWB,

when every minute counts for survival. This study provides the time until SWB, when stored in TICs under different methods, will go out of temperature tolerance.

Our study demonstrates that SWB will go out of threshold temperature in approximately 90 minutes, despite adding instant chemically activated cold packs, when the combat cooler is stored at room temperature. This time increases to more than 8 hours when the combat cooler is prechilled to a standard refrigerator temperature of 4.0°C (39.2°F). Furthermore, the time increases to more than 36 hours when the combat cooler is prechilled to the standard freezer temperature of 0.0°C (32.0°). Hence, adding a prechilled combat cooler to the standard method of refrigeration will extend the time of storage at proper temperature by at least 8 hours.

The additional time provided by using the prechilled combat cooler will maintain mission readiness, allowing for activation of a walking blood bank, procurance of an alternative power source, or a request of resupply of SWB. This would ensure that there is no delay in blood to aid the survival of potential casualties. The ERSS now places combat coolers inside the combat refrigerator in preparation for possible loss of active refrigeration.

This study has limitations intrinsic to the nature of its being an expeditionary medical unit, its area of operation, and the size of sample for analysis. This study performed only a temperature investigation of SWB in expeditionary medical settings; it did not assess the full viability of SWB, because hemolysis from hemolytic motion trauma can occur. Additionally, the initial TIC temperature for condition 4 was 0.39°C (32.7°F), which is below the 1°C (33.8°F) storage recommendation. Although the SWB did not go below 1°C (33.8°F), some components of the SWB could have reached that temperature, and the effects on viability or function are not clear. Our blood products and medical gear consist of SWB and a combat-issued refrigeration system, which are not readily accessible to general medical facilities. Furthermore, the Middle East has environmental factors that are difficult to reproduce. Finally, expired units of SWB were used, although we minimized the impact of this by conducting the study within 2 days after expiration. Despite these limitations, this study attempts to fill the gap of information regarding the logistical concerns of using SWB in austere environments.

Conclusion

Combining active and passive refrigeration methods will increase the time before the loss of blood product resources in case of power failure. To our knowledge, this is the first study looking at the logistical methods of refrigerated preservation of SWB products in expeditionary medical units in theater. Although the viability of blood products may not be guaranteed by temperature alone, this study demonstrates an adaptable approach to preserve the temperature of blood products using our prespecified conditions despite refrigeration power failure in austere settings, thereby maintaining mission readiness to increase the survival of potential casualties.

Disclosure

The authors have nothing to disclose.

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