

SUPPLEMENT ARTICLE

Effect of parachute delivery on red blood cell (RBC) and plasma quality measures of blood for transfusion

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Abstract

Background: Parachute airdrop offers a rapid transfusion supply option for humanitarian aid and military support. However, its impact on longer-term RBC survival is undocumented. This study aimed to determine post-drop quality of RBCs in concentrates (RCC), and both RBCs and plasma in whole blood (WB) during subsequent storage.

Study design and methods: Twenty-two units of leucodepleted RCC in saline, adenine, glucose, mannitol (SAGM) and 22 units of nonclinical issue WB were randomly allocated for air transportation, parachute drop, and subsequent storage (parachute), or simply storage under identical conventional conditions ($4 \pm 2^\circ\text{C}$) (control). All blood products were 6–8 days post-donation. Parachute units were packed into Credo Cubes, (Series 4, 16 L) inside a PeliCase (Peli 0350) and rigged as parachute delivery packs. Packs underwent a 4-h tactical flight (C130 aircraft), then parachuted from 250 to 400 ft before ground recovery. The units were sampled aseptically before and after airdrop at weekly intervals. A range of assays quantified the RBC storage lesion and coagulation parameters.

Results: Blood units were maintained at $2\text{--}6^\circ\text{C}$ and recovered intact after recorded ground impacts of $341\text{--}1038\text{ m s}^{-2}$. All units showed a classical RBC storage lesion and increased RBC microparticles during 42 days of storage. Fibrinogen and clotting factors decreased in WB during storage. Nevertheless, no significant difference was observed between Control and Parachute groups. Air transportation and parachute delivery onto land did not adversely affect, or shorten, the shelf life of fresh RBCs or WB.

Discussion: Appropriately packaged aerial delivery by parachute can be successfully used for blood supply.

KEYWORDS

austere environment, blood, parachute, RBC concentrate, red blood cell, transfusion, whole blood

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1 | INTRODUCTION

Hemorrhage and hemorrhagic shock are the principal causes of morbidity and preventable mortality in battle-field casualties¹ and civilian trauma victims.² Clinical guidelines advocate hemorrhage control and early blood-based resuscitation of severely injured casualties.^{3,4} Some authors now advocate early use of whole blood (WB).^{5,6} The change in clinical practice challenges logistics of blood supply, especially for remote healthcare. Delivery options, including parachute air drops, may be required for combat and other austere environments. However, physical insults such as continual vibration⁷ and impact vibration⁸ can damage RBCs and cause hemolysis.

The most comprehensive study assessing the effects of parachute delivery on RBCs showed that a simulated parachute-drop into seawater did not cause damage to RBCs.⁹ Although this study simulated the worst-case scenario for parachute drop onto water (descent rates with partial canopy failure), the forces involved were likely to be much less than those associated with parachute drop onto land.

Two other studies are also notable. The first investigated the effects of simulated high-altitude low-opening (HALO) parachute drop in a hypobaric chamber, followed by carriage during a 12-h simulated soldier foot patrol,¹⁰ but there is no mention of physical insults associated with the “parachute” element other than changes in ambient pressure. Simulated parachute drop did not cause any clinically significant changes.¹⁰ The second study investigated the effects of actual parachute drop on a limited range of RBC quality measures (hemoglobin, hematocrit, and hemolysis), and again no effects of parachute drop were found.¹¹ However, the study is limited because the units of RBC concentrate (RCC) in SAG-M were already expired (53 days after collection), and the assessment was confined to before and immediately after the parachute drop. Therefore, there are no published studies that address the effect of parachute delivery onto land on the quality and shelf life of in-date units of RCC.

This study aimed to determine the effect of air transportation followed by parachute drop, recovery, and subsequent onwards vehicular ground transport, on the quality of RBCs in concentrates in SAGM (RCC), and both RBCs and plasma coagulation parameters in WB over a period in excess of the anticipated shelf life of 35–42 days.

2 | METHODS

The study was conducted as a prospective randomized controlled laboratory investigation between February and March 2019.

2.1 | Supply of blood products

All blood products were supplied by National Health Service Blood and Transplant (NHSBT) UK to the Centre of Defense Pathology (CD Path) in Birmingham. The units of RCC were all 8 days after donation, and units of non-leucodepleted WB were all 6–7 days after donation on the day of parachute drop (day 0 of this study), 1 day after receipt at Dstl Porton Down. Volunteer consent, including consent for potential research use, is part of the routine UK blood donation process. All units were anonymized.

NHSBT collects WB from donors, 475 ± 47.5 ml into 66.5 ml citrate-phosphate-dextrose in MacoPharma collection systems (LQT614B and FQE6283LB MacoPharma, Twickenham, UK) designed for component production but at the time of study did not provide WB for clinical use. NHSBT supplied 22 units of leucodepleted RCC in SAGM and 22 units of nonclinical issue ‘Whole Blood’ (WB). The WB was supplied in a primary collection pack without leucodepletion. All units were moved by ground in temperature-controlled conditions (Credo Cubes, Series 4 16 L, PeliBiothermal) to Dstl Porton Down, and on receipt were stored at $4 \pm 2^\circ\text{C}$ in a validated and temperature-mapped blood bank (LabCold RDBB1160MD). All reference to Credo Cube in this paper relate to Credo Cube Series 4 16 L. These are sometimes referred to colloquially as “Golden Hour Boxes”, although this is an incorrect use of the term, which is applied to a subset of Credo Cubes (but not Series 4 16 L) on the manufacturer’s website.

All blood products were sampled aseptically on receipt at Dstl to establish a baseline (day minus 1,-1, note this is approximately 7 days after donation, see footnote). Twelve units of each product were allocated randomly to groups destined for parachute delivery (parachute) and 10 units of each product for continued storage in the monitored blood bank at Dstl without parachute delivery (control). The units for parachute delivery were packaged in Credo Cubes that maintained the units’ temperature at $4 \pm 2^\circ\text{C}$, for air drop as described below. These Credo Cubes are the validated transport containers used by CD Path for the movement of RCC.

2.2 | Preparation and packaging for parachute drop

2.2.1 | Whole blood

WB units were contained in WB storage bags (3MAFQ614B, MacoPharma). A Credo Cube can hold

16 units of WB. Twelve units of WB were divided among three Credo Cubes (four WB in each). The remaining space in each Credo Cube was packed with 12 units of simulated WB units (SWB, WB storage bags filled with 0.9% saline to a total mass of 513 g and sealed, Sebra Omni RF sealer, Sebra 2600). The WB units were placed at each corner of the lower layer within the Credo Cube (Figure 1). Temperature within the Credo Cube was recorded continuously with temperature loggers placed centrally among blood bags (SL151T TempIT Tags, Signatrol, UK, calibrated across the range 0–10°C). The ground impact acceleration (physical insult) was recorded by two data loggers (both a MSR 165 and a MSR 166, MSR Electronics GmbH, Germany) mounted rigidly to a three Ply board,

placed in the Credo Cube below the clinical (yellow) bag that contained the units of WB/SWB.

2.2.2 | RBC concentrate

RCC units were contained in RCC storage bags (2MAFQE614B, Macopharma). A Credo Cube can hold 22 units of RCC. Twelve units of RCC were divided among three Credo Cubes (four RCC in each Credo Cube). The remaining space in each Credo Cube was packed with 18 units of simulated RCC (SRCC, RCC storage bags containing 0.9% saline to a total mass of 330 g, vented and sealed as for WB). The RCC units were placed in the middle layer (Figure 1). Temperature was recorded

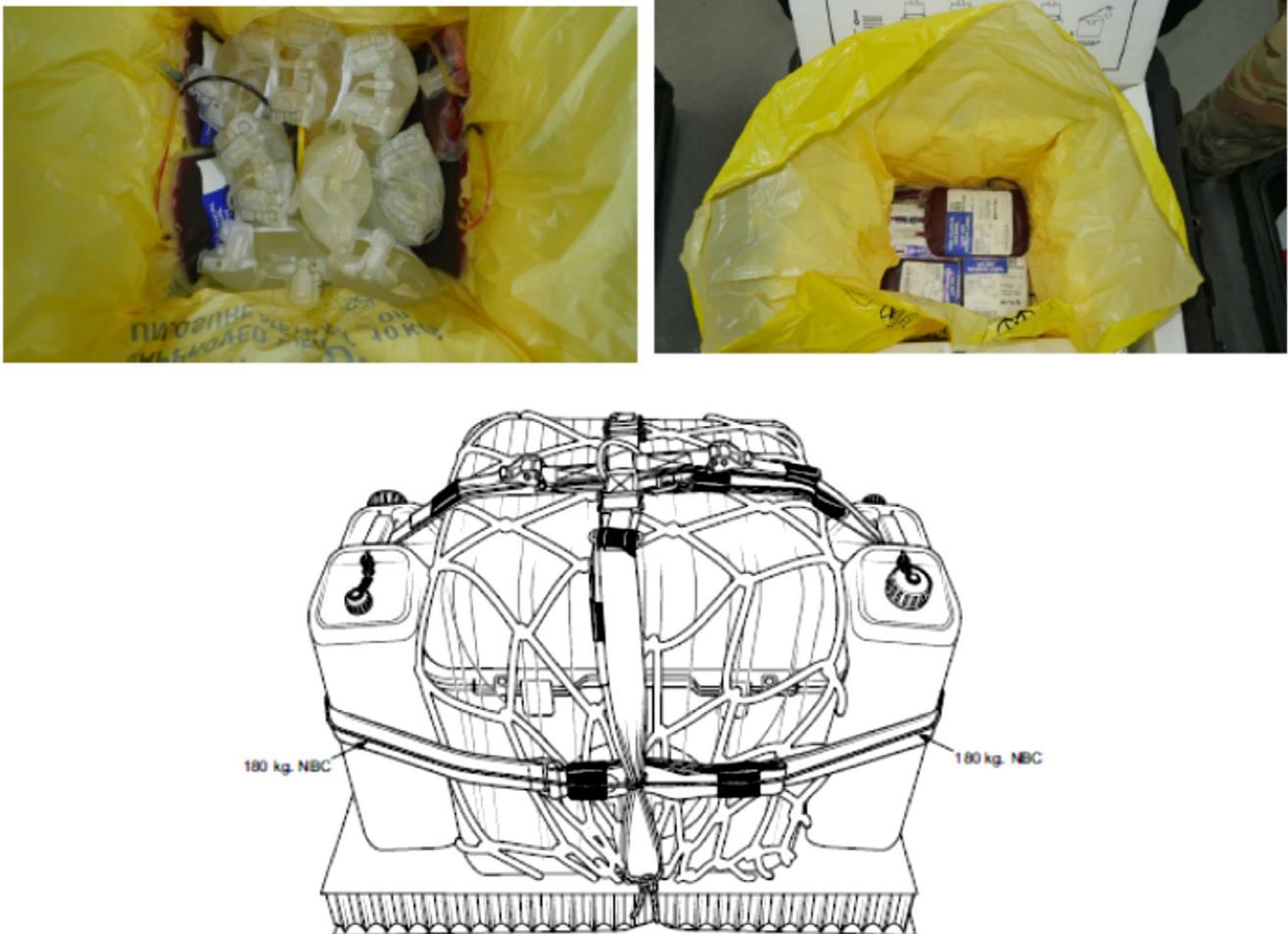


FIGURE 1 Packing layers for units of whole blood (WB, upper left) and RBC concentrate (RCC, upper right) in credo cubes. Note that units of clinical issue blood products are dark red while simulated units contain 0.9% saline and therefore appear light/clear. Bags of WB were placed vertically against the thermal isolation chamber, credo cube, while the Centre of the space was filled with bags of simulated WB. Bags of RCC (or SRCC) were placed horizontally flat within the cube in an overlapping brick pattern, repeated in concentric layers to fill the space with 22 bags. Each credo cube was placed singly in a Peli case and rigged as a blood harness pack (BHP) as shown in the lower panel (reproduced from 101A-1102-1B air transport operations manual: Construction procedures for aerial delivery loads, light stores dropping, 3rd edition 2020, Ministry of Defense)

continuously with TempIT Tags and two MSR data loggers measured the accelerations on ground impact as described for WB.

2.3 | Parachute delivery and recovery of blood products

Each Credo Cube was placed into a Peli Case (Peli 0350, Peli Products UK Ltd, UK), and held firmly in place with the Peli Case foam inserts. The six packed and sealed Peli cases were transported to Joint Air Delivery Test & Evaluation Unit (JADTEU), Royal Air Force (RAF) Brize Norton using a short wheelbase Ford Transit van and rigged as Blood Harness Packs (BHPs) by JADTEU staff for parachute delivery in accordance with AP 101B-1102-1B¹² (Figure 1). At this point, the BHPs were loaded as freight into a C130 aircraft at RAF Brize Norton, which proceeded on a 4-h tactical training sortie prior to dispatching the six BHPs over six individual approaches at an altitude of 250–400 ft (approximately 75–125 m, representing the Standard Operating Procedure for operational delivery) onto a designated area on Salisbury Plain (UK).

Following the parachute drop, the BHPs were de-rigged, leaving the Peli Cases sealed. The Peli cases were visually inspected for obvious damage and transported for approximately 30 min by van to Dstl Porton Down. The Peli cases were opened at Dstl Porton Down and the contents were inspected. No physical damage was observed with the WB and RCC units, which were then returned to the blood bank to maintain the correct storage temperature. The MSR data loggers were recovered and data were extracted and analyzed. The TempIT tags were analyzed and all Credo Cube were found to have maintained the internal temperature within the range of 2–6°C.

2.4 | Sampling

The day of the parachute drop was designated day 0 for this trial. Serial sampling of each unit of RCC and WB was performed aseptically on the day before parachute drop (day –1, Baseline), and subsequently on days 1, 7, 14, 21, 28, 35, and 42/43 after parachute drop. Note that for RCC “day 0” (shown on all figures in the results section) corresponds to 8 days after blood collection, and for WB “day 0” corresponds to 6–7 days after collection.

2.5 | Assays

The parameters used to assess the quality of the RCC, and WB were derived from the list presented in the

Guidelines for Blood Transfusion Services 8th Edition,¹³ Section 8.2. Full details of the assays are presented in Appendix S1, which were conducted in accordance with published methodology. Hematology was performed using a standard laboratory analyzer (Siemens Advia 2120i Hematology Analyzer, Siemens Healthcare GmbH, Germany). Clinical chemistry assays (glucose, lactate, sodium, potassium, and hemoglobin) were performed with a Randox RX Daytona+ clinical chemistry analyzer, and hemolysis determined using a published formula.^{14,15}

RBC microparticles were determined using flow cytometry^{16,17} and ATP and 2,3 DPG using published assays.¹⁸ Clotting factor and coagulation analyses were performed with an ACL TOP 300 CTS (Werfen, UK).

2.5.1 | Microbiological analysis

To ensure no microbiological contamination was introduced through the collection process, the samples were taken on days 7 and 43 into Bact/ALERT SA and SN aerobic and anaerobic containers, which were dispatched to CD Path Birmingham for culture and analysis.

2.5.2 | Statistical analysis

The data were analyzed by linear mixed model analysis of variance (ANOVA) with repeated measures over time, using baseline values as a covariate, to compare blood product subjected to parachute delivery with control product that had been stored concurrently without parachute delivery. Statistical analysis was performed using the NCSS Version 11 statistical package. RCC and WB were analyzed separately and $p < .05$ was taken as statistically significant.

3 | RESULTS

All six airdrop loads were successfully recovered. All blood units appeared physically intact, and temperature data logs confirmed that none had been subjected to temperatures outside of the range 2–6°C during the logistic journey.

3.1 | Baseline

Each unit of RCC was within specification for clinical issue when delivered to Dstl Porton Down with no excess hemolysis. In contrast, 15 of 21 units of WB showed hemolysis greater than 0.8% of the total RBC mass, while one further unit of WB could not be analyzed for

hemolysis due to the turbidity of the plasma. The degree of excess hemolysis in these units was small, within the units with hemolysis above 0.8% RBC mass, the median was 1.1% and range 0.9%–1.9%. Random allocation of WB units resulted in 9 units with hemolysis above 0.8% plus the one unit that could not be assessed being allocated to the Parachute group ($n = 12$). The remaining 6 units with hemolysis above 0.8% were allocated to the Control group ($n = 10$). Mean values (range) for key parameters are shown in Table 1.

There were no statistically significant differences between the groups destined for parachute drop and their corresponding Control groups at baseline (pre-drop).

3.2 | Effects of parachute delivery

3.2.1 | Physical insults

The largest accelerations measured below the WB and RCC occurred during the initial ground impact. Accounting for accelerations in orthogonal directions, the greatest of these was 1038 m s^{-2} (105.8 g, g-force), and the lowest were 390 m s^{-2} (39.8 g) and 341 m s^{-2} (34.8 g), respectively. These are likely to be underestimates because these are very brief events with some frequency content beyond the response of the data loggers.

3.2.2 | Unit quality and stability

Visual inspection of the units after parachute delivery indicated that all units were intact, as were the control units that had been retained at Dstl Porton Down. Data from the temperature loggers indicated that no unit had been transported outside of the range $2\text{--}6^\circ\text{C}$. There were small reductions in unit volumes and hemoglobin content between day minus 1 and day 1, which were accounted for by sampling volumes. There was no significant difference between Control and Parachute group unit volumes for RCC ($p = .1902$) or WB ($p = .6705$) or hemoglobin content (RCC $p = .1208$, and WB $p = .2938$).

All units of RCC remained within specification for blood issue 1 day after parachute delivery in both Parachute and Control groups (day 1, Table 1). No unit of RCC showed hemolysis greater than 0.8% RBC mass on day 1.

Although several WB units had shown slight, but clinically significant, hemolysis at baseline, no additional units of WB showed hemolysis greater than 0.8% RBC mass on day 1 after parachute delivery (Parachute group). One additional control unit of WB displayed hemolysis greater than 0.8% on day 1 (increase from 0.8% to 0.9% RBC mass).

Over the time course of the study, there was clear evidence of storage lesions in both RCC and WB, but no

TABLE 1 Baseline and day 1 post-drop values for key quality parameters specified in the red book (sections 7.6.4 and 7.4.4, guidelines for transfusion services in the UK 8th edition) for RBC concentrate (RCC) in additive solution and WB (non-leucodepleted whole blood) in citrate, phosphate, dextrose (CPD)

	Pre-drop (Baseline)		1-day post-drop (Day 1)	
	Control	Parachute	Control	Parachute
RBC concentrate (RCC)				
Days since blood collection	7	7	9	9
Number of units	10	12	10	12
Unit volume (ml)	288 (253–318)	284 (250–322)	266 (192–298)	269 (234–306)
Hb (g/unit)	53 (45–62)	54 (43–63)	50 (35–58)	50 (41–61)
Hemolysis (% RBC mass)	0.0 (0.0–0.0)	0.1 (0.0–0.5)	0.3 (0.2–0.4)	0.4 (0.3–0.6)
White cell count ($10^9/\text{L}$)	0.03 (0.02–0.05)	0.03 (0.02–0.05)	0.02 (0.01–0.03)	0.02 (0.01–0.03)
Whole blood (WB)				
Days since blood collection	5–6	5–6	7–8	7–8
Number of units	10	12	10	12
Unit volume (ml)	437 (371–510)	443 (380–508)	408 (342–481)	413 (351–479)
Hb (g/unit)	53 (39–73)	50 (41–59)	50 (36–70)	47 (38–57)
Hemolysis (% of RBC mass)	1.0 (0.6–1.3)	1.1 (0.7–1.9)	1.0 (0.7–1.9)	1.1 (0.7–1.9)
White cell count ($10^9/\text{L}$)	6.06 (4.65–8.05)	4.86 (3.18–7.44)	5.74 (4.02–7.46)	4.74 (3.12–7.21)

Note: Values presented as mean (range).

significant difference between groups (parachute vs control) in either product.

There was a significant increase in hemolysis over time in both RCC ($p < .001$) and WB ($p < .001$), which were clearly capable of showing increased hemolysis above baseline. There were no significant differences in hemolysis between groups for either product ($p = .7029$ and $p = .7230$, respectively, Figure 2). In the case of RCC, the hemolysis was of no clinical significance because it remained below 0.8% RBC mass (Figure 2). In the case of WB, the hemolysis was clinically significant (greater than 0.8% RBC mass) in some units at Baseline (see above). All units of WB displayed greater than 0.8% RBC mass hemolysis by day 21 in the Control group, and by day 35 in the Parachute group (all 11 of the 12 units that could be measured).

RBC microparticle levels also increased significantly over time in RCC ($p < .001$) and WB ($p < .001$) units, but there were no differences between Parachute and Control groups for either product ($p = .9994$ and $p = .2978$ respectively, Figure 2).

There were fluctuations in hematocrit, hemoglobin levels and mean RBC volumes over time in both RCC and WB all of which attained significance ($p < .0001$ in each case) except for RCC hemoglobin levels ($p = .2606$), and none of which were clinically significant. There were no significant differences between groups for any of these variables in either product.

3.2.3 | Chemistry

There were significant increases in supernatant/plasma potassium and falls in sodium and pH (Figure 3), which were both statistically and clinically significant in RCC and WB ($p < .001$ in each case). However, there were no significant differences between Parachute and Control groups for any of these variables, except for supernatant sodium in RCC ($p = .0289$, but this difference is unlikely to be of clinical significance, Figure 3).

3.2.4 | Metabolic

There were significant falls in supernatant/plasma glucose and RBC ATP and 2,3DPG, and a rise in supernatant/plasma lactate for both RCC and WB ($p < .001$ in each case, Figure 4).

In RCC, there were significant differences between Parachute and Control group glucose and lactate ($p = .0023$ and $p = .0176$); glucose tended to be higher and lactate lower in the Parachute compared with the Control group (Figure 4). However, the differences were small and unlikely to be of clinical significance. The remaining parameters (RBC ATP and 2,3DPG) were not different between groups in RCC (Figure 4).

None of the metabolic parameters were worse in the Parachute compared with the Control groups in WB (Figure 4).

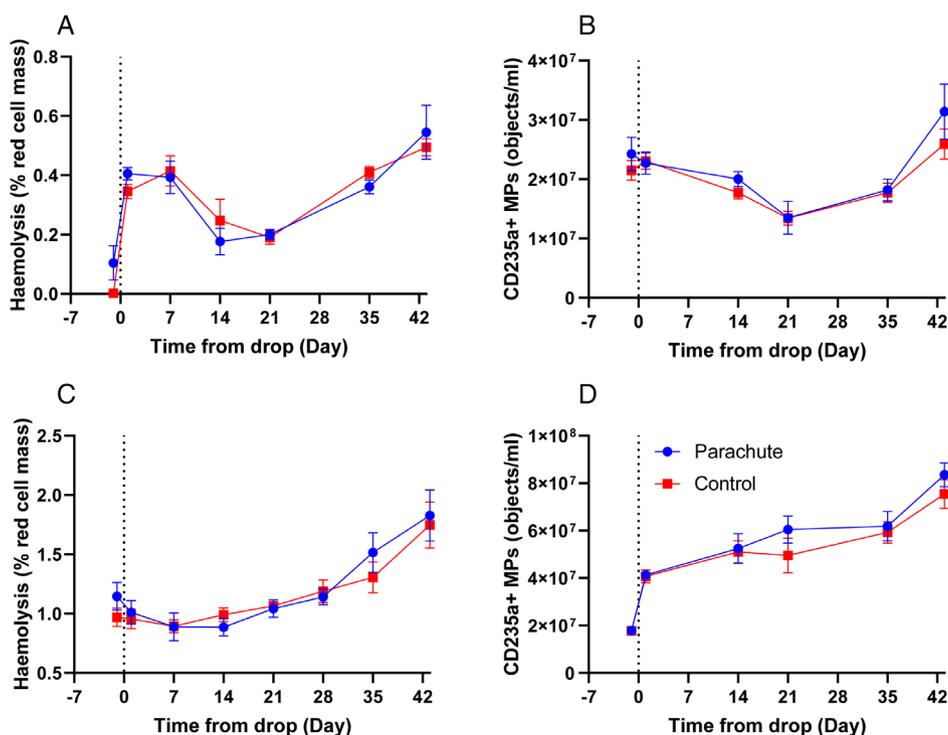


FIGURE 2 Hemolysis and RBC microparticles (CD235a⁺ MPs) before and after parachute delivery (parachute) or at corresponding timepoints without parachute delivery (control) in units of RBC concentrate (RCC) (A,B) and whole blood (WB) (C,D). Day from collection can be calculated by adding 8 days (RCC) or 6–7 days (WB) to the time from drop on each abscissa. Data are mean \pm SEM

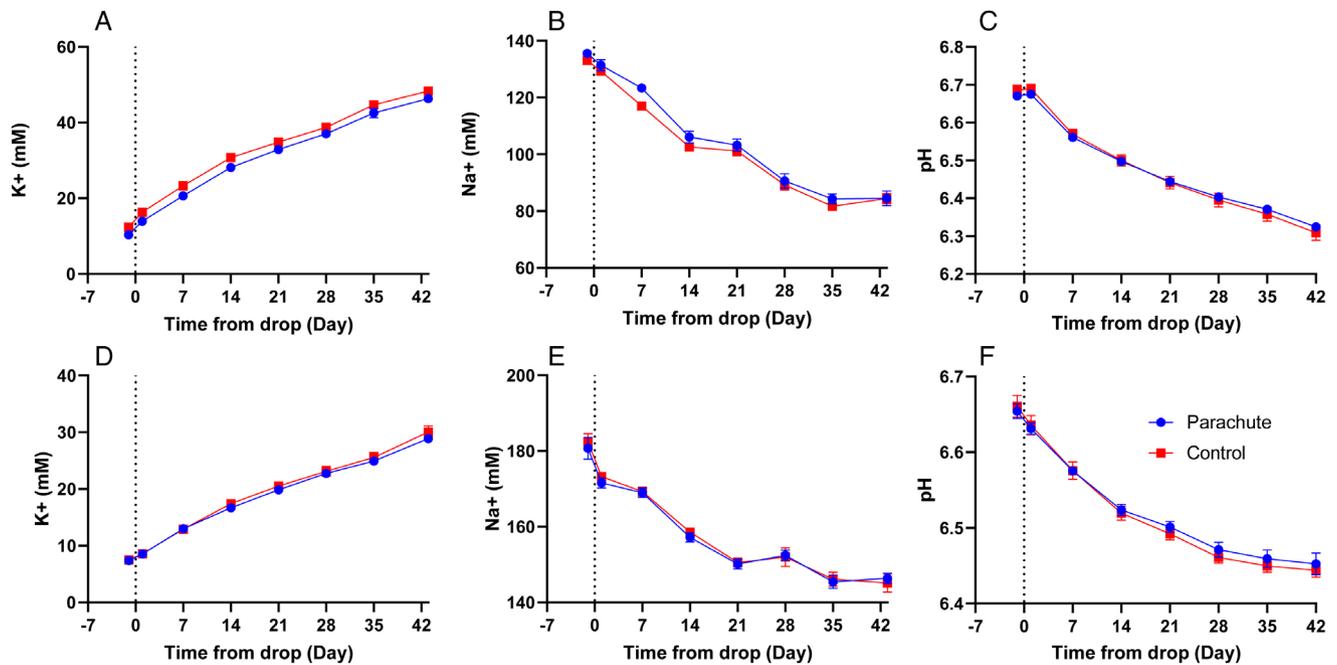


FIGURE 3 Supernatant potassium (K^+), sodium (Na^+) and pH before and after parachute delivery (parachute) or at corresponding timepoints without parachute delivery (control) in units of RBC concentrate (RCC) (A–C) and whole blood (WB) (D–F). Day from collection can be calculated by adding 8 days (RCC) or 6–7 days (WB) to the time from drop on each abscissa. Data are mean \pm SEM

3.2.5 | Clotting factors and coagulation (WB only)

There were significant falls in fibrinogen and clotting Factors V, VII, and VIII over the timescale of the study ($p < .001$ in each case, Figure 5). However, there were no significant differences between groups in any of these parameters (Figure 5). There was a significant deterioration in clotting, indicated by significant elevations in prothrombin time and activated partial thromboplastin times over the timecourse of the study ($p < .001$ in each case, Figure 5). Concurrently, there were significant falls in the plasmin inhibitor alpha2-antiplasmin and free Protein S ($p < .001$ in each case, Figure 5). However, there were no differences between Parachute and Control groups in any of these parameters (Figure 5).

3.3 | Microbiology

All samples were found to be negative for microbiological contamination.

4 | DISCUSSION

This study has shown that parachute delivery of RCC in SAG-M on to land did not cause immediate deterioration

or shortening of the shelf life of the units. Furthermore, the units of non-leucodepleted WB did not show any immediate effects of parachute drop, or subsequent accelerated deterioration over a 42- or 43-day period after parachute delivery (7–50 days after venipuncture). In the United Kingdom, trial WB currently has a shelf life of 14 days, which may in the future be extended to 21 days. The data shown in Figure 2 suggest that parachute delivery would have no effect on this since hemolysis does not begin to rise in either Parachute or Control groups within 21 days of parachute delivery (27–28 days after blood collection). These findings agree with, and build upon, previous reports of a simulated parachute drop of RCC in SAG-M into sea water,⁹ and a simulated HALO parachute drop followed by a simulated foot patrol.¹⁰ The present study was conducted using relatively fresh RBCs representative of those issued as standard to the MoD: the day of parachute delivery was 8 days post-donation for RCC and 6–7 days after donation for WB. It is known that the physical properties of RBC membrane change with time after donation (e.g. there is increased stiffness), consequently the conclusions regarding the effects on shelf life should be bounded to fresh units of RCC and WB. However, Javaudin et al.¹¹ demonstrated that parachute delivery caused no immediate detriment to the units of RCCs that were significantly out of date. Therefore, our conclusion can be extended to include parachute delivery of any in-date RBCs for their immediate use.

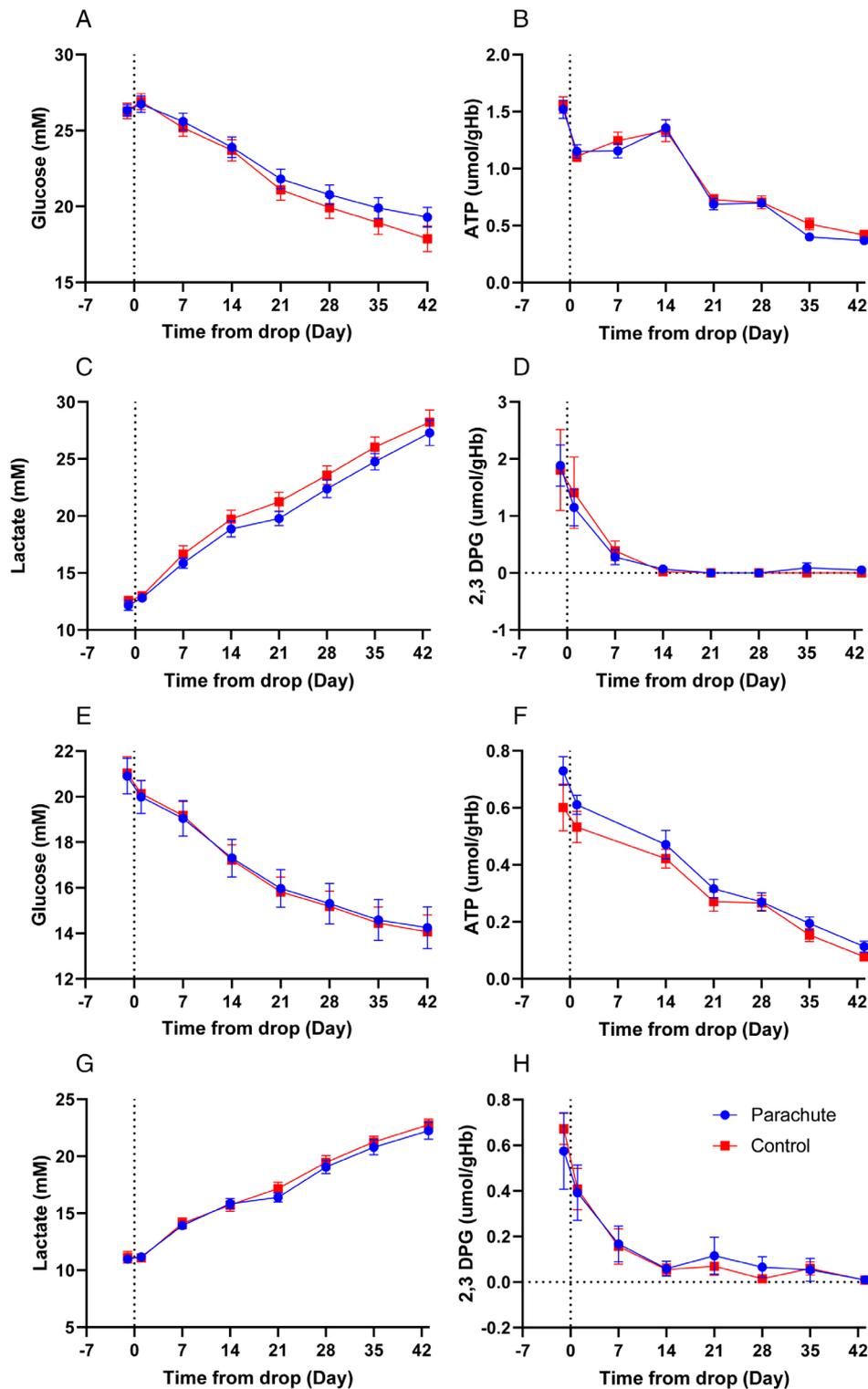
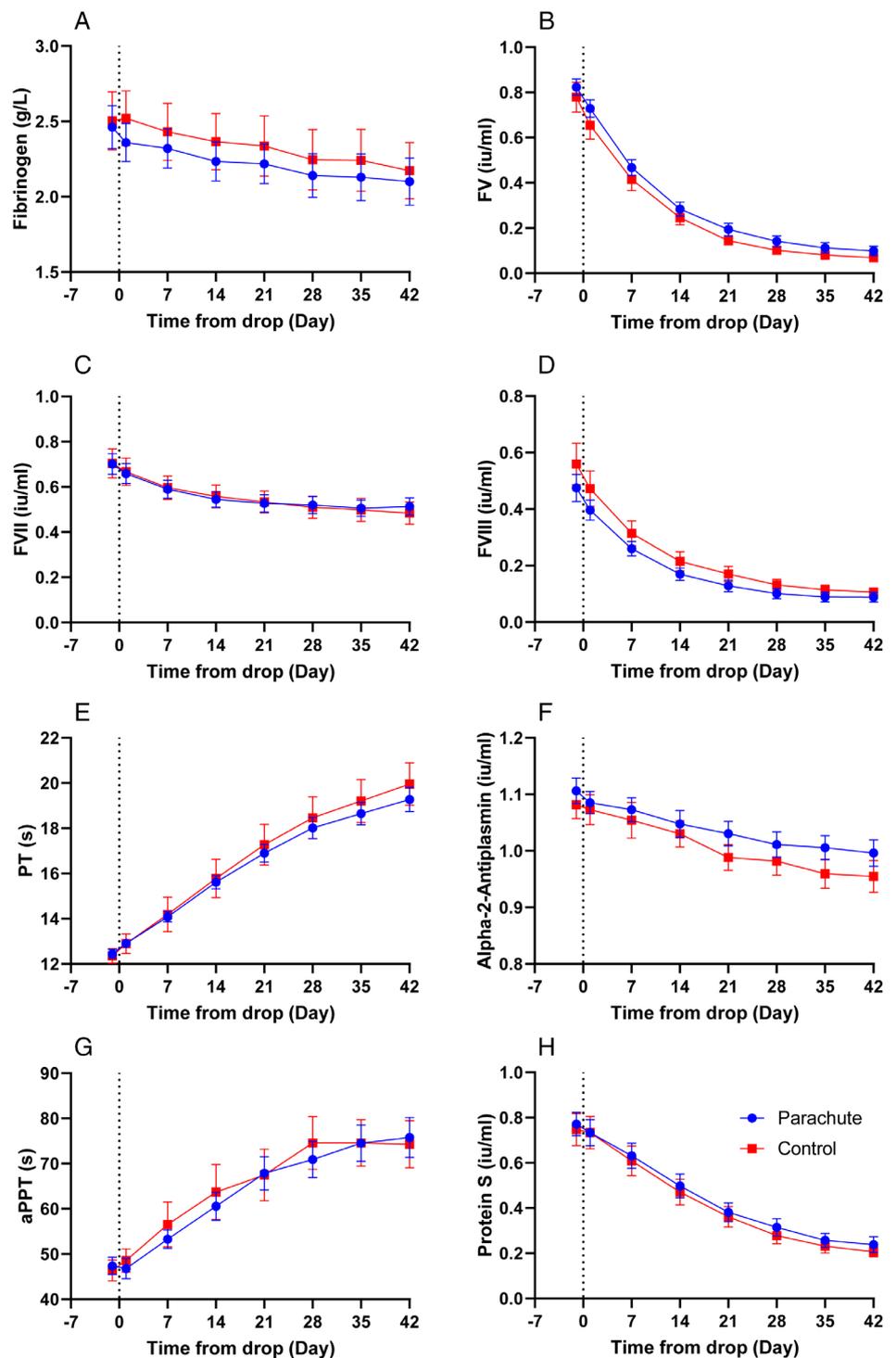


FIGURE 4 Supernatant glucose, adenosine tri-phosphate (ATP), lactate and 2,3 diphosphoglycerate (2,3 DPG) before and after parachute delivery (parachute) or at corresponding timepoints without parachute delivery (control) in units of RBC concentrate (RCC) (A–D) and whole blood (WB) (E–H). Day from collection can be calculated by adding 8 days (RCC) or 6–7 days (WB) to the time from drop on each abscissa. Data are mean \pm SEM

Using accelerometers and data loggers, we determined a range of accelerations the Credo Cubes were subjected to on ground impact. Because the physical impact is a very brief event, with some frequency content above the range of the data loggers, it is likely that the data presented here may be an underestimate of the peak acceleration. However, provided any parachute delivery

does not exceed the values recorded here, this can be viewed as an additional safety margin when evaluating the potential effect of parachute delivery on blood for transfusion. Parachute delivery that does not exceed the lower bound accelerations reported is unlikely to ‘damage’ blood as defined by the criteria stipulated in the Red Book.¹³

FIGURE 5 Fibrinogen, factors V, VII and VIII (FV, FVII and FVIII respectively), prothrombin time (PT), activated partial thromboplastin time (aPTT), alpha₂-antiplasmin and free protein S (protein S) in units of whole blood (WB) before and after parachute delivery (parachute) or at corresponding timepoints without parachute delivery (control). Day from collection can be calculated by adding 8 days (RBC concentrate) or 6–7 days (WB) to the time from drop on each abscissa. Data are mean \pm SEM



Supply and resupply of small, distant, medical units with blood products will always provide challenges. One possible solution is to use parachute delivery; however, it is important to establish whether this causes not only immediate damage to RBCs, but also a more subtle long-term deterioration. These considerations are important because aged RBCs (greater than 22 days old, but still within regulatory shelf life) are associated with increased mortality when used for massive transfusion (greater

than 10 units) in seriously injured casualties.¹⁹ Therefore, knowledge of the effect of parachute delivery on RBC aging is important not only for regulatory purposes but also for clinical confidence in their use in battlefield casualties. The results of the current study show the expected storage lesion in control units of RCC, and WB. Parachute delivery did not cause any clinically significant worsening of the storage lesion. Finally, a new packing protocol, developed as part of this study, has

now become incorporated into the current CD Path Standing Operating Procedure. This packing protocol (based on the evidence of subsequent simulated and the six real parachute drops) protects the units of RCC and WB from rupture during parachute delivery.

The negative findings of the microbiological assessment of the units of blood product in this study shows that there was no contamination of the units up to 42 days after parachute delivery. This confirms that neither the sampling process caused contamination nor, importantly, that parachute delivery caused micro-lesions in the packaging to allow microbiological ingress into the units.

One of the limitations of the current study is that many of the units of WB displayed clinically significant hemolysis at baseline. It is unclear why the units displayed hemolysis at baseline. It is possible that it was related to the age of the units (5–6 days post-donation) and that the units had not been leucodepleted, although some studies show that leucodepletion has little effect on hemolysis.²⁰ The presence of hemolysis, although small, was above the clinical threshold for clinical issue. However, this did not prevent the assessment of the effect of parachute delivery on the quality of the units, as they were clearly capable of demonstrating further increases in hemolysis (apparent as a developing storage lesion as the study progressed in both control and parachute delivered units). Since there was no difference between parachute-delivered and control units over the time course of the study, in our opinion parachute delivery of WB is not detrimental. This conclusion is further strengthened by a report that RCC in SAGM are more susceptible to physical forces (centrifugation and shaking) that cause hemolysis than more diluted RBCs in plasma (WB).²¹ Therefore, should parachute delivery have caused significant problems in any product, it was more likely to be RCC than WB. Taken together, these considerations suggest within the boundaries and limitations of this study, that parachute delivery is unlikely to cause damage in the units of WB. Finally, assessment of platelet function was outside of the scope of this study, so no conclusions can be drawn regarding platelets.

5 | SUMMARY AND CONCLUSIONS

This study shows clearly that a 4-h flight in a C130 aircraft, followed by parachute delivery, does not cause post-storage detriment to fresh units of RCC SAG-M or WB. We conclude that appropriately packaged aerial delivery by parachute can be successfully used for blood supply and storage of fresh (6–8 days) units. In addition,

based on information in the published literature, this conclusion can be extended to all in-date units of RCC and WB for their immediate use. It is of note that since the completion of this study and preliminary reporting, units of RCC have been successfully delivered by parachute to a deployed facility.

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CONFLICT OF INTEREST

The authors have disclosed no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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