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Jiao Feng
West China Hospital, Sichuan University/West China School of Nursing
Anqing Lu
West China Hospital, Sichuan University/West China School of Nursing
Xiaohua Chen
1306891740@qq.com

West China Hospital, Sichuan University/West China School of Nursing

Article

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Application Practice of Unmanned Aerial Vehicles in Cross-Campus Blood Specimen Transport

Jiao Feng[1], Anqing Lu[1] and Xiaohua Chen [1]

[1] Department of Transportation Central, West China Hospital, Sichuan University/West China School of Nursing, Chengdu 610041, China; Email: fj18843146990@163.com
Correspondence: Xiaohua Chen, Email: 1306891740@qq.com

Highlights

What are the main findings?

- **Compared with traditional ambulance transport,** UAVs reduced cross-campus (between two hospital campuses) blood sample transport time by 39.3%, from 28±3 min to 17±2 min, with an absolute savings of 11 min per trip (t≈63.5, P<0.001).
- UAV delivery achieved 100% specimen integrity, whereas ambulance transport reached 99.55% with two leakage incidents, indicating a minor superiority in terms of specimen safety for UAVs.
- UAVs serve as a time-efficient, cost-saving and reliable alternative for intercampus blood logistics and reduce reliance on ground ambulances.

Abstract

Background: Driven by the rapid expansion of multicampus medical institutions, the clinical demand for fast, stable cross-campus blood specimen delivery has increased substantially. Conventional ambulance transport is frequently delayed by urban traffic congestion, which compromises timely laboratory testing and accurate clinical diagnosis. This study aimed to systematically evaluate the practical performance and standardized management framework of unmanned aerial vehicles (UAVs) for blood sample transportation between two geographically separated hospital campuses.

Methods: This retrospective observational study included a total of 873 sample batches containing 168,474 venous blood samples transported between two campuses of a tertiary hospital in Sichuan Province from January to May 2026. All the batches were divided into a UAV transport group (426 batches) and an ambulance ground transport group (447 batches). Core evaluation indicators, including one-way transport duration, specimen integrity and comprehensive logistics costs, were compared between the two cohorts.

Results: The average transit time was significantly shorter for the UAV group (17 ± 2 min vs. 28 ± 3 min, t ≈ 63.5, df ≈ 871, P < 0.001), corresponding to a 39.3% reduction in delivery time and an absolute 11 min time savings for each delivery cycle. All the samples transported by the UAVs remained intact with zero-quality defects, whereas two leakage incidents and a 99.55% specimen integrity rate were observed during the ambulance transport. UAV delivery was barely affected by rush-hour traffic fluctuations, exhibited smaller time variability, and effectively reduced hospital expenditures on labor and vehicle maintenance.

Conclusions: Compared with traditional ambulance delivery, UAV-based cross-campus blood sample transport has outstanding advantages in terms of delivery efficiency, transport stability and economic performance. When supported by standardized full-cycle management specifications, UAV logistics can be implemented as a standardized, routine specimen transportation solution for multicampus hospitals.

Keywords: unmanned aerial vehicles; cross-campus specimen transport; multi-campus hospital; blood specimen; time efficiency; cost-effectiveness

1. Introduction

With the continuous advancement of the "one hospital, multiple campuses" construction model in public hospitals, cross-campus diagnostic collaboration has become increasingly frequent, leading to a growing workload of clinical specimen transport between different hospital campuses. Clinical blood specimens require high timeliness, as transport delay is a critical concern that may compromise test results and subsequent clinical decision-making [1,2]. Traditional ambulance-based transport is vulnerable to urban traffic congestion, road restrictions, and traffic control measures, resulting in prolonged and unpredictable transport times that fail to meet the demands of timely laboratory testing and rapid clinical diagnosis in multi-campus settings [3,4].

Recent technological advances in logistics UAVs have provided new pathways for the low-altitude delivery of medical specimens. Early feasibility studies have demonstrated the technical viability of drone transportation for blood products [5], while subsequent research has confirmed the stability of biochemical, coagulation, and hematological parameters following UAV transport [6]. Standardized approaches to specimen handling and pre-analytical stability are fundamental to integrating UAVs into healthcare logistics [7]. Randomized controlled evidence has further demonstrated that UAV technology maintains high quality and safety standards for medical material transport [8]. Additionally, foundational studies have provided practical microbiological and handling guidance for clinical specimen transport using UAVs [9].

Although previous studies have separately examined the feasibility, stability, and cost-effectiveness of UAV-based medical logistics [5,6,8,11], few have systematically evaluated its practical implementation in routine cross-campus blood specimen transport within a real-world multi-campus hospital setting, nor have they provided a comprehensive management framework to support normalized operations. Therefore, this study aims to (1) compare the transport efficiency, specimen integrity, and operational costs between UAV and ambulance transport for cross-campus blood specimen delivery and (2) share our institutional experience in developing standardized protocols for sustainable UAV deployment in a multi-campus hospital setting.

2. Materials and Methods

2.1. Study Setting and Subjects

This study was conducted at a tertiary comprehensive hospital in Sichuan Province, China, which operates an integrated "one hospital, three campuses" management model. Clinical blood samples requiring cross-campus transport between two hospital campuses from January 2026 to May 2026 were selected as study subjects. The specimens included routine venous blood samples for hematology, biochemistry, coagulation, and immunology, as well as pathology samples. All the samples were properly packaged and met routine transport criteria.

A total of 873 eligible batches were included and divided according to transport modality: the UAV group (426 batches, 83,259 individual samples were transported) and the ambulance group (447 batches, 85,215 individual specimens were transported). There

were no statistically significant differences in specimen types, transport time periods, or daily transport volumes between the two groups (P>0.05), ensuring baseline comparability.

2.2. Transport Modalities

UAV Group: The hospital collaborated with a commercial UAV service provider to establish a fixed cross-campus route, with airspace approval and route registration completed and a dedicated rooftop takeoff/landing platform installed at each campus. After blood collection, the samples were capped, sealed, labeled, handed over to the UAV station, and then placed into a dedicated shock-proof transport container. The UAV autonomously navigated along the preset route and landed at the target campus, where designated staff retrieved and delivered the specimens to the laboratory. All the UAV operators were trained and certified.

Ambulance Group: A dedicated hospital ambulance was used for cross-campus transport, with a full-time driver and transport personnel manually delivering specimens along ground roads. Transport was subject to traffic signals and peak-hour congestion, following the hospital's standard operating procedures for specimen transport.

2.3. Outcome Measures

The following indicators were assessed for both groups:

① One-way transport time: Time from specimen handover at the departure campus to laboratory reception at the target campus (in minutes).

② Specimen integrity rate: Percentage of batches with no tube breakage, leakage, label detachment, or contamination. Both groups were monitored using the same criteria.

③ Transport stability: Time variability during off-peak vs. peak periods, expressed as the standard deviation (SD).

④ Manpower and operation/maintenance costs: Dedicated staffing requirements and vehicle operation and maintenance expenses were compared descriptively [10,11].

2.4. Statistical Analysis

Statistical analysis was performed using SPSS 26.0 (IBM Corp, Armonk, NY, USA). Continuous data (transport time) are expressed as the mean ± standard deviation (SD) and were compared using an independent-sample t-test. Categorical data (specimen integrity rate) are described descriptively, as the number of adverse events was very low (only 2 in the ambulance group). A P-value <0.05 was considered to indicate statistical significance.

2.5. Ethical Statement

This retrospective observational study is a hospital quality-improvement project that only addresses logistics management of sealed blood-specimen containers. No identifiable patient-related personal information was collected and no clinical interventions were conducted. The requirement for ethical approval for this study was waived by the Ethics Committee on Biomedical Research, West China Hospital of

Sichuan University. The need for informed consent was waived by the Ethics Committee on Biomedical Research, West China Hospital of Sichuan University. All methods were performed in accordance with the relevant guidelines and regulations.This quality-improvement initiative has been formally implemented within West China Hospital.

2.6. GenAI Declaration

No generative artificial intelligence was used in the design, execution, or interpretation of this study. The manuscript was written by the authors without the use of GenAI tools for content generation.

3. Results

3.1. Transport Time Comparison (Table 1)

Table 1 Comparison of transport time and safety indicators between two transport modes

Group	Batches	Mean Transport Time (min)	Specimen integrity (%)
UAV	426	17 ± 2	100
Ambulance	447	28 ± 3	99.55
P-value	-	t≈ 63.5, P < 0.001	-[1]

[1] (Note: Because of very low adverse event counts, no statistical test was performed for integrity.)

The mean transport time of the UAV group was 17 ± 2 min, which was significantly shorter than that of the ambulance group (28±3 min; t ≈ 63.5, df ≈ 871, P < 0.001). This represents a 39.3% reduction and an absolute savings of 11 min per trip. The UAV showed minimal time fluctuation across different periods (SD=2 min), whereas the ambulance exhibited greater variability (SD=3 min) because of peak-hour congestion. These findings are consistent with previous research examining the effects of UAV transport, including its effects on routine laboratory parameters [12] and significant time savings compared with those of ground transport [13].

3.2. Specimen integrity

The UAV group achieved 100% specimen integrity (0 adverse events out of 426 batches). The integrity of the ambulance group was 99.55%, with 2 leakage events caused by insufficiently tightened caps during bumpy road transport. Both methods meet quality standards overall, which is consistent with earlier reports on transport stability and pre-analytical integrity [6,7], although UAVs provided slightly better stability.

3.3. Manpower and Cost Comparison

Ambulance transport requires dedicated drivers and transport personnel on a full-time basis, with high vehicle maintenance, fuel, and annual inspection costs. During the study period (January–May 2026), the number of routine ambulance sample transport trips decreased from 604 to 447, a reduction of 157 trips, allowing more ambulance availability for emergency and other transport tasks, thereby reducing hospital logistics costs. In contrast, the UAV group required only one hospital staff member for takeoff/landing retrieval and specimen verification. The service provider covered route maintenance, aircraft servicing, and airspace coordination. This staffing reduction significantly lowered hospital operational costs. Previous economic evaluations have reported that compared with ground transport, UAV delivery saves substantial transport time and reduces costs [2,11].

4. Discussion

4.1. Advantages of UAVs for Cross-Campus Blood Specimen Transport

Clinical blood specimens demand high timeliness, stability, and information integrity, as transport delays may cause hemolysis or distortion of test results, directly affecting diagnostic accuracy. Traditional ground transport is constrained by urban road networks and unpredictable peak-hour factors [3,4]. UAVs, with fixed low-altitude routes independent of ground traffic, can reliably reduce the inter-campus delivery time and ensure that specimens can reach the valid testing window.

The 11.2-min time savings observed in our study are remarkably consistent with the findings of Homier et al. [1], who reported an 11.8-min reduction in UAV delivery of simulated blood products in an urban trauma center. This consistency across different geographical and operational contexts strengthens the generalizability of UAV time-saving benefits. Furthermore, the reduced time variability during peak hours (UAV: SD = 1.6 min vs. ambulance: SD = 2.9 min) supports the operational stability advantage of UAVs, as also observed by Ganić et al. [13] in Madrid.

Studies in regional and county-level healthcare settings have also demonstrated that UAV flight times are significantly shorter than road transport times [4]. Recent feasibility studies have similarly confirmed that compared with ground transport, UAV transport of blood products is faster and more stable [11]. Additionally, UAVs have smooth flight characteristics and shock-proof containers, reducing tube breakage, leakage, and label detachment, thus improving transport quality. Compared with the RCT findings of Wiltshire et al. [8], which confirmed the maintenance of blood component quality under controlled laboratory conditions, our real-world results further validate the operational reliability of UAV transport in routine clinical logistics.

Cumulatively, the 11.2-min savings per trip across 426 UAV deliveries represents a total time savings of approximately 4,771 min (79.5 h) during the 5-month study period. For time-sensitive specimens requiring urgent analysis, this reduction may directly contribute to faster clinical decision-making and improved patient care. Our findings, which revealed a 39.3% reduction in transport time (from 28.4 ± 2.7 min to 17.2 ± 1.8 min), confirm these advantages in a real-world hospital setting, and the UAV group achieved 100% specimen integrity, whereas the ambulance group achieved 99.55% integrity (with 2 leakage events), confirming that UAVs are at least as reliable as ground transport.

4.2. Key Management Aspects for UAV Transport of Blood Specimens

On the basis of our experience, the following management aspects are critical for safe and efficient UAV sample transport:

Personnel training: All staff involved in loading/unloading and battery replacement received training and obtained a UAV operation certificate before performing any operational tasks.

Transport container requirements: The container must be sealed, dustproof, waterproof, and slip-resistant after closing. The exterior and interior surfaces should be smooth, flat, and crack-free, preventing liquid leakage, and easy to clean and disinfect.

Disinfection and monitoring: Transport containers were wiped with 500 mg/L chlorine-containing disinfectant immediately after each use. In the case of leakage, absorbent paper was used to cover the spill, followed by disinfection with 2000 mg/L chlorine-containing disinfectant for 30 minutes. Regular biological monitoring of the inner surface of the container was performed monthly, with bacterial colony counts ≤10 CFU/cm².

Route and airspace management: Dedicated routes were designated, and airspace registration was completed. Regular inspections of route obstacles and landing-site clearance were performed to ensure flight safety [9].

Pre-transport specimen management: Clinical departments strictly followed specimen collection protocols, including the use of tightening caps, sealing, and clear labeling. Improperly packaged samples were not accepted for transport, enhancing safety from the source.

Handover and traceability: Double-person verification and scanning were implemented from departmental handover to UAV loading, landing retrieval, and laboratory reception, ensuring a closed-loop traceability system to prevent loss or misidentification [10].

On-site security: Physical barriers and restricted zones were established around takeoff/landing areas. Unauthorized access was prohibited, and infection control and flight safety measures were maintained [9,10].

Emergency backup: During the study period, 6 emergency backup events were recorded because of adverse weather (heavy wind, rain, and fog) or temporary airspace restrictions. Under such conditions, the ambulance backup plan was immediately activated to ensure uninterrupted specimen transport [11,12].

4.3. Limitations and Optimization Directions

This study has several limitations. First, this was a single-center study; the results may not be generalizable to other hospitals with different geographic, regulatory, or operational contexts. Second, the cost analysis considered only direct operational costs and did not include capital investment in UAV infrastructure. Third, while transport time was significantly reduced, we did not assess the clinical impact of this reduction on patient outcomes. Fourth, the 100% integrity rate in the UAV group, while positive, should be interpreted with caution given the study duration and sample size. Future research should include multicenter studies, incorporate economic evaluations of long-term cost-effectiveness, and assess clinical endpoints such as turnaround time to final diagnosis and patient outcomes.

Currently, UAVs are suitable for small-batch routine blood specimens with a limited payload capacity (up to 3.5 kg per trip). Adverse weather and airspace restrictions still require ground backup. Other authors have noted that UAVs face technical bottlenecks in payload, range, and severe weather response [12,13]. Future efforts should focus on enhancing payload and weather adaptability, increasing flight frequency, and developing unified standard operating procedures for UAV specimen transport, promoting normalized and standardized applications across multicampus hospitals.

5. Conclusions

UAV-based transport of cross-campus clinical blood samples offers superior transport efficiency, specimen integrity, operational stability, and cost- effectiveness compared with traditional ambulance transport. Through standardized route/airspace management, specimen packaging, closed-loop handover, on-site monitoring, and emergency backup, UAVs can ensure safe, timely, and complete specimen delivery. This approach meets the diagnostic synergy needs of multicampus hospitals and holds promise for broader application in similar settings. To further validate these findings, multi-center studies with longer follow-ups and clinical outcome assessments are warranted.

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Abbreviations

UAV	Unmanned Aerial Vehicle
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences

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