Original article

Impact of Unmanned Aerial Vehicle (UAV) Transportation on Plasma Hemostasis Parameters

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Abstract: *Objectives* — To determine whether vertical take-off and landing (VTOL) drone transport affects parameters of a global hemostasis assay and to identify UAV transport conditions that preserve sample integrity.
Methods — Platelet-free plasma was prepared from whole-blood samples collected from 30 healthy volunteers (11 men, 19 women; ages 22-38 years) according to pre-analytical standard operating procedures. Thrombodynamics (Hemacore T-2, Russia) was employed to assess lag time (Tlag), initial and stationary clot-growth velocities (Vi, Vst), clot size (CS), clot density (D), and spontaneous clotting time (Tsp). Samples were evaluated under three conditions: (i) immediately after collection; (ii) after laboratory storage (reference); and (iii) after transport by the InnoVtol-3s VTOL UAV over distances up to 250 km.
Results — No statistically significant differences were observed among the Immediate, Reference, and UAV-transported groups for Vi, Vst, Tlag, CS, or D (Kruskal-Wallis test with Dunn–Holm; padj ≥0.05 for all pairwise contrasts.) Spontaneous clotting time (Tsp) was absent in all samples within the observation window. Across all groups, values remained within analytical variation (<4%), indicating assay stability under the tested transport conditions. This study is the first to demonstrate that transporting plasma samples via a VTOL UAV (InnoVtol-3s) does not significantly affect the analytical outcomes of global coagulation testing using the Thrombodynamics assay.
Conclusions — Under the examined conditions, VTOL UAV transport preserved the analytical integrity of Thrombodynamics in plasma from healthy donors. These findings are preliminary and warrant further investigation.

Keywords: UAV, VTOL, plasma transport, pre-analytical variables, Thrombodynamics, global hemostasis assay, vibration monitoring.

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Introduction

Recent advances in medical logistics have highlighted the critical need for rapid and reliable transport of biological specimens, especially in geographically remote or hard-to-access regions [1-3]. Blood plasma samples used for coagulation analysis are among the most sensitive biomaterials, requiring strict adherence to pre-analytical protocols – temperature control, processing time, and storage conditions – to preserve diagnostic integrity.

The Thrombodynamics assay, a sophisticated global coagulation test, exemplifies these stringent requirements [4-5]. By simulating vascular-wall injury and modeling the spatial dynamics of thrombus formation, it offers exceptional sensitivity to anticoagulant therapy and can effectively detect both thrombotic and bleeding tendencies. Given this high sensitivity, maintaining sample integrity during transport is essential for reliable results [6-7].

Traditionally, plasma stability has been limited to several hours post-collection, which markedly restricts diagnostic capabilities in areas lacking immediate laboratory infrastructure. Ground transportation often subjects samples to prolonged vibration, mechanical shocks, and temperature fluctuations, all of which can degrade sample quality. While air transport is faster, it is frequently cost-prohibitive and logistically demanding, particularly in sparsely populated or inaccessible regions [8-10].

Unmanned aerial vehicles, commonly known as drones, have emerged as a novel and potentially transformative solution for biological sample logistics. Several studies have demonstrated the feasibility of UAV-based transport for whole blood and other biomaterials (11-15). However, the impact of UAV transportation on the results of highly sensitive assays, such as Thrombodynamics, remains unexplored.

This study aims to fill that knowledge gap by evaluating the effects of UAV-based transportation on key Thrombodynamics parameters and establishing operational conditions that preserve plasma sample integrity during drone delivery. To achieve this, we employed the InnoVtol-3s VTOL UAV – a hybrid vertical-take-off and landing platform capable of covering distances up to 250 km with low mechanical load and tightly controlled temperature conditions.

Material and Methods

Study Design and Population

This prospective study enrolled 30 healthy adult volunteers (11 men and 19 women), aged 22-38 years (mean=30±8 years). All participants provided written informed consent before inclusion. The study adhered to national ethical regulations, the principles of Good Clinical Practice (GCP) of the Russian Federation, and the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of the Pacific State Medical University, Ministry of Health of the Russian Federation.

Blood Sample Collection and Plasma Preparation

Venous blood was drawn from each participant into three 3.6-mL vacuum tubes containing 3.2 % sodium citrate (0.106 mol/L). Platelet-free plasma was prepared according to standard pre-analytical laboratory protocols, including double centrifugation, and stored under controlled conditions before testing.

Experimental Groups

Plasma samples were divided into three groups:

- Reference group (control): Samples stored at room temperature (22 °C) without transportation.
- UAV transportation group: Samples transported by the InnoVtol-3s VTOL UAV over a distance of up to 250 km.
- Immediate analysis group: Samples analyzed immediately after blood collection without storage or transport.

Thrombodynamics Assay Procedure

Thrombodynamics testing was performed using the Thrombodynamics Analyzer T-2 system (HemaCore LLC, Moscow, Russia) with the appropriate reagent kits. Clot formation was initiated by contact of plasma with a surface-immobilized activator, and the following parameters were assessed:

- Lag time (Tlag, min): Delay between activator contact and clot initiation.
- Clot growth rate (V, μm min^{-1}): Average clot growth rate, calculated over an interval of 15-25 min after the start of growth.
- Initial clot growth velocity (Vi, μm min^{-1}): Average growth rate between 2-6 min.
- Stationary clot growth velocity (Vst, μm min^{-1}): Average growth rate between 15-25 min.
- Clot size (CS, μm): Maximum clot size at 30 min.
- Clot density (D, arbitrary units): Optical measurement reflecting fibrin network density.
- Spontaneous clotting time (Tsp, min): Time to appearance of spontaneous clots in plasma not contacting the activator.

UAV Transportation Conditions

The InnoVtol-3s VTOL UAV was used to transport the plasma specimens. This hybrid UAV combines an internal-combustion engine for horizontal flight with electric motors for vertical take-off and landing, thereby eliminating the need for launch devices. The drone is equipped with an advanced temperature-regulation system and vibration-dampening mechanisms. Temperature and vibration levels were continuously monitored throughout transport.

Statistical Analysis

Statistical analysis was performed using StatTech v. 4.7.3 (StatTech LLC, Russia). Quantitative indicators were evaluated for normality with the Shapiro-Wilk test. For normally distributed indicators, arithmetic means (M) and standard deviations (SD) described the sample distribution, and the 95% confidence interval (95% CI) was provided as a measure of representativeness for the mean values. For non-normally distributed data, the median (Me), lower quartile (Q1), and upper quartile (Q3) were used for description.

A comparison of three or more groups based on a quantitative indicator was performed using one-factor analysis of variance. Posterior comparisons were conducted with Tukey's test (assuming equal variances). If the Kruskal-Wallis test did not reveal significant differences, further pairwise comparisons were not performed, as the general test had already determined that no significant differences were observed between groups. If significant differences were found, we performed pairwise comparisons using the Dunn test with Holm correction, considering differences significant at $p<0.05$. Without correcting the significance level, the probability of obtaining false-positive results increases; for example, by applying the Bonferroni or Benjamini-Hochberg corrections.

Table 1. Growth-rate and related parameters by sample type

Parameter	*Sample type*	*Mean±SD*	*95% CI*	*n*	*p-value*
Clot growth rate (μm min^{-1})	UAV-derived	29.2±2.8	27.9-30.5	30	0.388
	Lab-stored reference	30.4±2.9	29.0-31.7	30	
	On-site analysis	29.4±2.8	28.1-30.7	30	
Lag time (min)	UAV-derived	0.9±0.1	0.8-0.9	30	0.737
	Lab-stored reference	0.9±0.1	0.8-1.0	30	
	On-site analysis	0.9±0.1	0.8-1.0	30	
Initial clot growth rate (μm min^{-1})	UAV-derived	56.9±4.3	54.8-58.9	30	0.779
	Lab-stored reference	57.8±4.1	55.9-59.7	30	
	On-site analysis	57.1±4.5	54.9-59.2	30	
Clot size (μm)	UAV-derived	1210.4±95.2	1165.8-1255.0	30	0.511
	Lab-stored reference	1244.0±102.9	1195.9-1292.2	30	
	On-site analysis	1216.4±93.8	1172.5-1260.3	30	
Clot density (AU)	UAV-derived	21092.0±1949.6	20179.6-22004.5	30	0.831
	Lab-stored reference	21382.0±1923.9	20481.6-22282.5	30	
	On-site analysis	21430.5±1824.0	20576.8-22284.1	30	

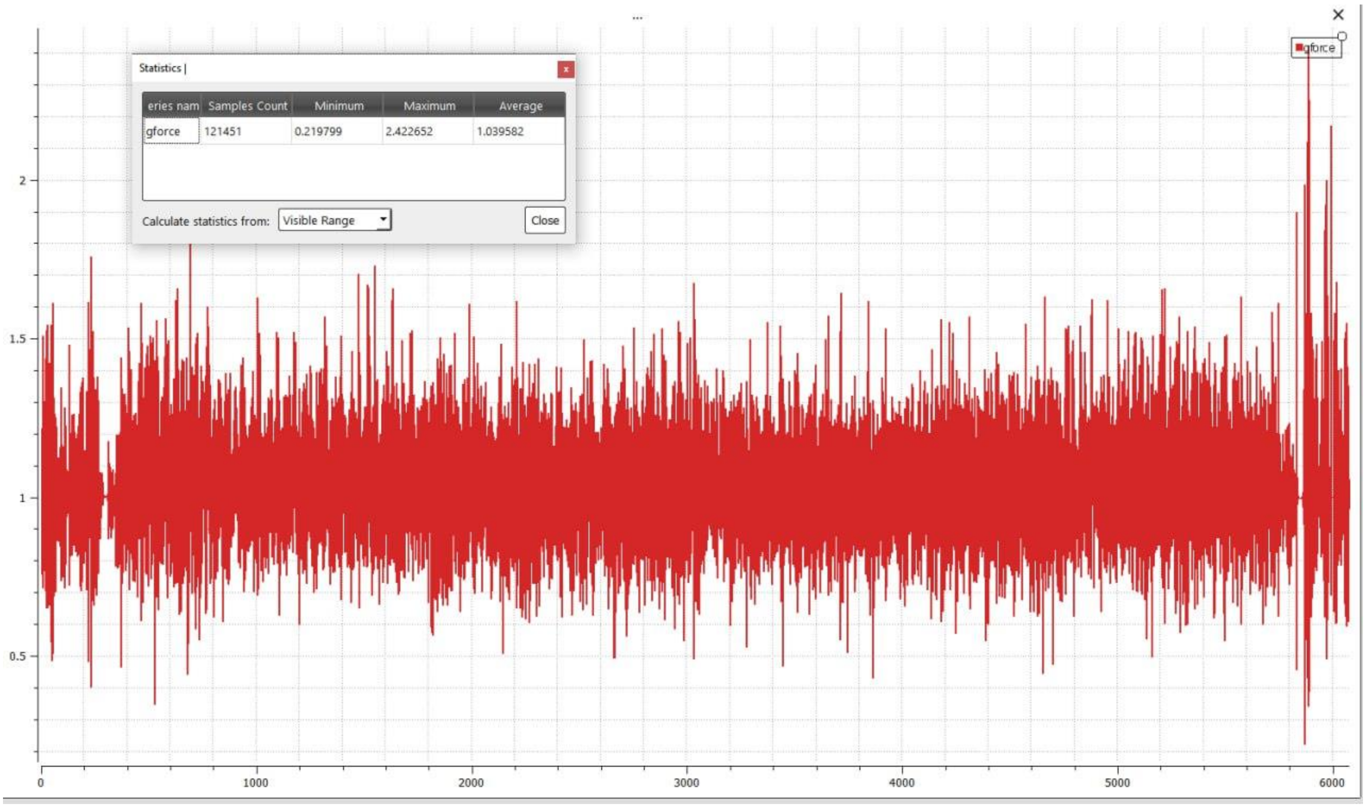

Figure 1. **Vibration level in the InnoVtol-3s UAV during test flights.**

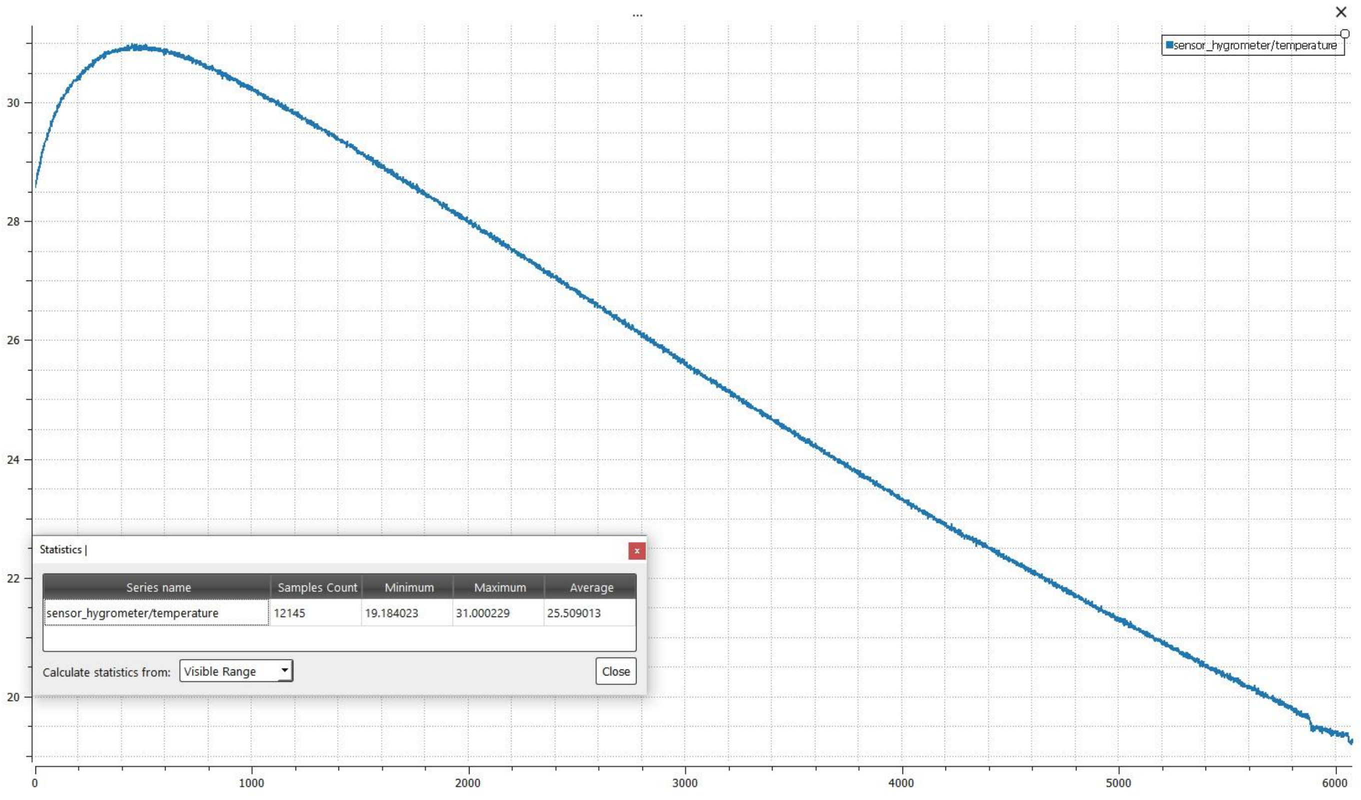

Figure 2. **Temperature fluctuations during plasma transportation.**

Results

UAV Transportation Conditions

To reduce environmental effects on plasma specimens during flight, the InnoVtol-3s VTOL UAV was fitted with an advanced temperature-control system and vibration-dampening mechanisms. Temperature and vibration parameters were continuously recorded throughout transport (*Figures* 1-2). Flight durations stayed within the time limits recommended by the Thrombodynamics assay manufacturer, thereby preserving plasma specimen stability.

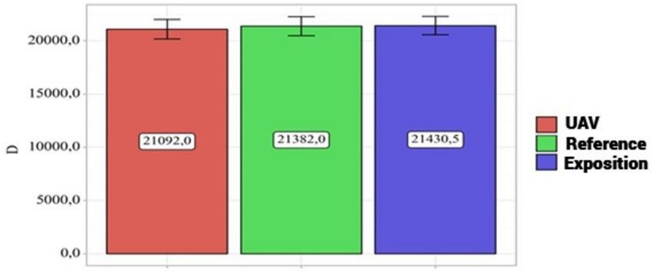

Figure 3. Analysis of clot density by sample type.

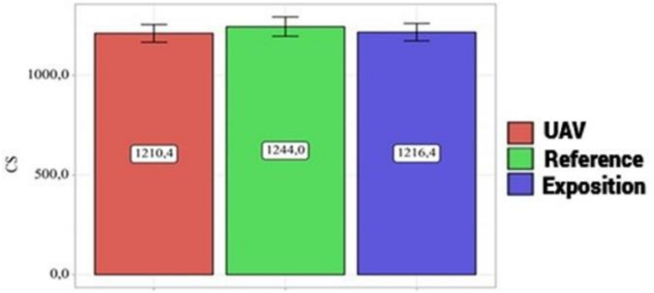

Figure 4. Analysis of clot area by sample type.

The InnoVtol-3s is a hybrid UAV that uses an internal-combustion engine for horizontal flight, giving it a longer range than multi-rotor UAVs. Although this design increases vibration during operation, tests have shown that all control and measurement systems remain within acceptable limits. Using the electric version of the UAV, which produces less vibration, would likely improve the stability of the bioassay container. Consequently, multiple UAV models can be employed to transport blood plasma for thrombodynamic analysis, while additional data could be collected by expanding the UAV fleet and increasing specimen volume.

Thrombodynamics Parameter Analysis

Analysis of the key Thrombodynamics parameters revealed no statistically significant differences among the three experimental groups (immediate analysis, reference, and UAV-transported specimens). As summarized in *Table* 1, clot growth velocities (Vi, Vst), lag time (Tlag), clot size (CS), and clot density (D) remained consistent across all groups. Statistical analysis confirmed that the variations were within acceptable analytical ranges (coefficient of variation <4%). Notably, we observed no spontaneous clot-formation events (Tsp) in any sample, indicating the absence of pre-analytical coagulation activation during UAV transport. This parameter is evaluated by the system as a binary presence/absence and is therefore not represented as a numeric value.

Figures 1-2 illustrate vibration levels and temperature fluctuations during UAV flights, while *Figures* 3-4 present clot density and clot size analyses, further supporting the absence of a significant impact from UAV transport.

A combined boxplot of standard deviations (*Figure* 5) confirms that overall variability across all measured parameters remained low and consistent among all groups.

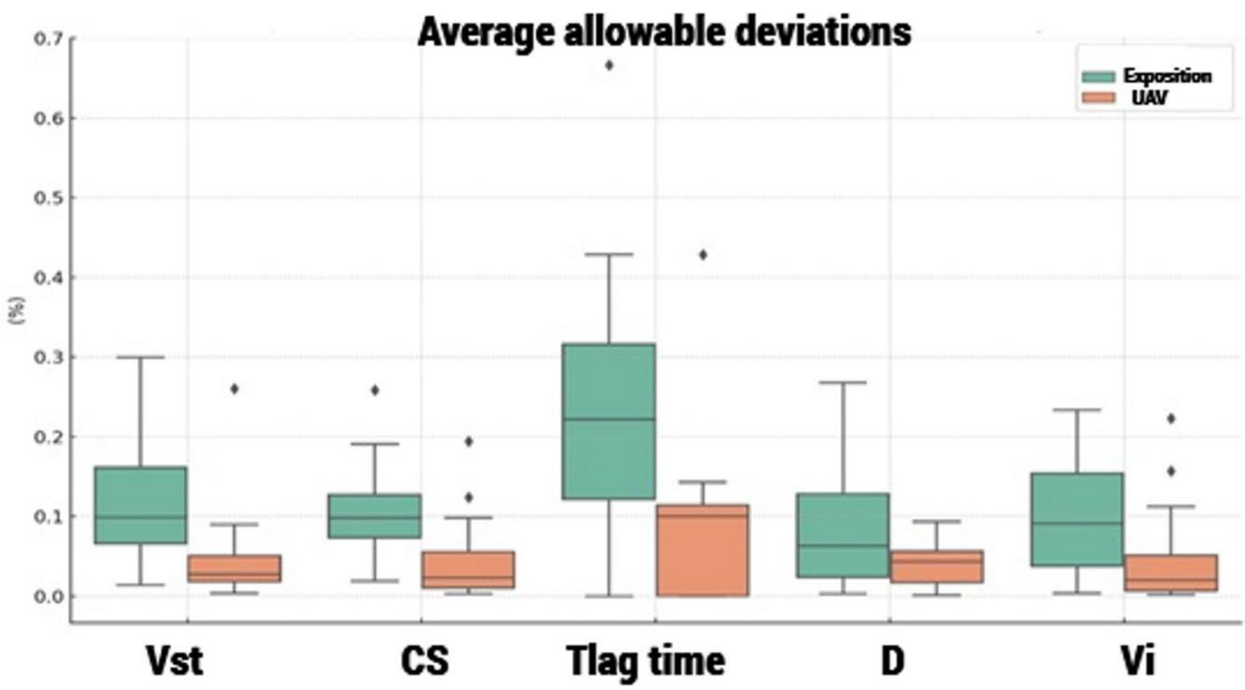

Figure 5. Graph of permissible deviations of the Thrombodynamics test parameters.

Table 2. Relevant statistical indicators paired-comparison analysis

Parameter	*Sample type*	*p-value*
Clot growth rate (μm min^{-1})	UAV-derived Exposition	0.411
Lag time (min)	UAV-derived Exposition	0.623
Initial clot growth rate (μm min^{-1})	UAV-derived Exposition	0.674
Clot size (μm)	UAV-derived Exposition	0.321
Clot density (AU)	UAV-derived Exposition	0.904

To test the hypothesis that there are no significant differences between the two groups, we conducted a paired-comparison analysis. The results, including relevant statistical indicators are presented in *Table 2*.

Discussion

This study provides the first systematic evidence that transporting plasma specimens via a UAV – specifically the InnoVtol-3s VTOL drone – does not substantially compromise the results of the highly sensitive Thrombodynamics global coagulation assay. The data show that UAV transport preserves plasma specimen quality and diagnostic reliability, as reflected by stable clot growth velocities (Vi, Vst), lag time (Tlag), clot density (D), and clot size (CS). Importantly, the absence of spontaneous clotting indicates that no pre-analytical coagulation activation occurred during transport.

These findings are clinically relevant, especially for overcoming logistical hurdles associated with biological sample transport in remote or hard-to-reach areas [8-10]. Ground transport often entails extended transit durations, mechanical impacts, and thermal instability [11-13]. While air transport offers speed, it is frequently costly and operationally complex. UAV-based delivery therefore emerges as a promising alternative that can surmount these limitations and ensure timely, reliable specimen transfer [12-15].

Prior studies have documented the negative impact of pneumatic tube systems on coagulation assays – including thrombin generation, ROTEM, and TEG – due to excessive mechanical stress [18-19]. In contrast, the InnoVtol-3s drone's hybrid design, vibration-damping features, and temperature-control systems likely contributed to the absence of such detrimental effects in this investigation.

Our findings support the broader adoption of UAVs in clinical laboratory logistics, offering a reliable method for transporting even highly sensitive specimens. By enabling prompt and dependable diagnostics in underserved or geographically isolated regions, UAV technology may improve clinical outcomes and promote healthcare equity.

Previous research on various transportation methods – such as pneumatic tube systems – has demonstrated measurable effects on coagulation assays, including ROTEM, TEG, and platelet aggregation tests, underscoring the need for rigorous validation of new transport technologies [18, 19]. Consequently, evaluating the potential impact of UAV-based transportation on global coagulation testing is a critical step toward its implementation in clinical laboratory practice.

Future studies should explore alternative UAV platforms, including fully electric VTOL drones, which may further reduce vibration and enhance transport stability. Additionally, assessing UAV performance under a broader range of environmental conditions, over greater distances, and for other sensitive biological materials will be essential.

Conclusion

This study is the first to demonstrate that transporting plasma specimens with a vertical-take-off and landing UAV (InnoVtol-3s VTOL) does not gravely compromise the analytical outcomes of global coagulation testing using the Thrombodynamics assay. All assessed parameters – clot growth velocity, lag time, clot size, and clot density – remained within clinically acceptable limits, and no pre-analytical activation of coagulation was detected.

These findings confirm that VTOL UAVs preserve plasma sample integrity during transit, enabling drone-based delivery for reliable, time-sensitive medical logistics. The approach has the potential to markedly improve access to high-quality diagnostic testing in remote, rural, and logistically challenging regions, thereby accelerating clinical decision-making, enhancing healthcare equity, and improving patient outcomes. Future research should evaluate UAV performance over longer distances and under diverse environmental conditions and explore applicability for other sensitive diagnostic materials.

In summary, VTOL UAV transportation offers a promising and practical solution for integrating advanced diagnostic services into broader healthcare delivery networks.

Limitations

It should be noted that our study was conducted on a relatively small sample size of 30 healthy volunteers, which may limit the ability to assess the stability of certain dynamic parameters, such as the hemostasis system. Consequently, the results cannot be generalized to patients with clotting disorders, those on anticoagulant therapy, or individuals with thrombophilia. These individuals may have more sensitive samples that are prone to external influences, which could potentially skew the results. Therefore, we recommend further research involving larger clinical populations to better understand the effects of these factors on blood clotting and hemostasis.

Author Contributions

Conceptualization: Shumatov V.B., Lebedev S.V., Markelova E.V., Dolgopolov M.S., Devitt D.

Methodology: Dolgopolov M.S., Devitt D.

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Data curation: Dolgopolov M.S., Devitt D.

Writing – original draft preparation: Dolgopolov M.S., Shevchenko O.V.

Writing – review and editing: Markelova E.V., Prosekova E.V. Supervision: Shumatov V.B., Lebedev S.V., Markelova E.V.

All authors have read and approved the final version of this manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with all relevant national regulations, the ethical principles of the Rules of Clinical Practice in the Russian Federation, and the Declaration of Helsinki of the World Medical Association. It received approval from the Ethics Committee of the Federal State Budgetary Educational Institution of Higher Education, Pacific State Medical University of the Ministry of Health of the Russian Federation.

Informed Consent Statement

The institute's opt-out registry was consulted to determine whether patients objected to participating in scientific research.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors upon request and may only be shared anonymously. This restriction is due to hospital policies that prohibit data sharing without clearly defined purposes. Data transfer agreements must be in place before data can be shared.

Conflicts of Interest

The authors declare no conflicts of interest. Funders had no role in the study design, data collection, analyses, interpretation, manuscript writing, or decision to publish.

AI Disclosure Statement

During manuscript preparation, the authors did not use any generative AI or AI-assisted tools for content generation, data analysis, or figure production.

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