Systematic Review and Meta-Analysis

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Drone for medical products transportation in maternal healthcare

A systematic review and framework for future research

Mohamed Afiq Hidayat Zailani, MBBCh[a], Raja Zahratul Azma Raja Sabudin, MPath[a], Rahana Abdul Rahman, PhD[b], Ismail Mohd Saiboon, DrOrtho&Trauma[c], Aniza Ismail, PhD[d], Zaleha Abdullah Mahdy, MD[b,*]

Abstract

Introduction: Medical products transportation has become an important research topic requiring multidisciplinary collaboration among experts in medicine, engineering, and health economics. Current modes of transportation are unable to overcome the limited settings in maternal healthcare, particularly during the event of obstetric emergencies. The drone is a promising medical product aerial transportation (MedART) that holds an enormous potential for delivery of medical supplies in the healthcare system. We conducted a systematic review to examine scientific evidence of positive impact of drone transportation on maternal health.

Methods: The following electronic databases were searched from inception to July 2019: ScienceDirect, PubMed, and EMBASE. The report was made in accordance with the principles of PRISMA guidelines. The search terms used were related to drones including unmanned aerial vehicle (UAV) and unmanned aerial system (UAS), and related to obstetric/maternal including obstetric emergencies and postpartum hemorrhage. Studies were selected if the intervention used were drones, and if any direct or indirect maternal health indicators were reported. Meta-analysis was not done throughout the study in view of the anticipated heterogeneity of each study.

Results: Our initial search yielded a total of 244 relevant publications, from which 236 were carried forward for a title and abstract screening. After careful examination, only two were included for systematic synthesis. Among the reasons for exclusion were irrelevance to maternal health purpose, and irrelevance to drone applications in healthcare. An updated search yielded one additional study that was also included. Overall, two studies assessed drones for blood products delivery, and one study used drones to transport blood samples.

Conclusion: A significant deficiency was found in the number of reported studies analyzing mode of medical products transportation and adaptation of drones in maternal healthcare. Future drone research framework should focus on maternal healthcare-specific drone applications in order to reap benefits in this area.

Abbreviations: CEMD = Confidential Enquiry into Maternal Deaths, MedART = Medical products Aerial Transportation, MedGRT = Medical products Ground Transportation, MMR = Maternal Mortality Ratio, MPV = mean platelet volume, PLT = platelet, PPH = postpartum hemorrhage, RBC = red blood cell, UAS = unmanned aerial system, UAV = unmanned aerial vehicle, USA = United State of America, WHO = World Health Organization.

Keywords: drone, hemorrhage, medart (medical air transportation), obstetric, review

1. Introduction

Medical products transportation refers to the delivery of medical supplies such as delivery of blood products, blood samples, medical equipment, vaccines, test kits, and medical aid. Currently, the commonest mode of medical products transportation is ground transportation (MedGRT) such as ambulances and cars, and air transportation (MedART) such as helicopters

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[a] Department of Pathology, [b] Department of Obstetrics and Gynecology, [c] Department of Emergency Medicine, [d] Department of Community Health Faculty of Medicine, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysi.

[*] Correspondence: Zaleha Abdullah Mahdy, Department of Obstetrics and Gynecology, Universiti Kebangsaan Malaysia Medical Center, Jalan Yaakob Latif, 56000 Cheras, Kuala Lumpur, Malaysia (e-mail: zaleha@ppukm.ukm.edu.my).

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and aeroplanes.[1] Globally, with rapid technological advancement, drones or unmanned aerial vehicle (UAV) has been introduced to increase mobility over challenging geographical barriers,[2] reduce carbon emission,[3] and may also improve cost effectiveness of healthcare delivery.[4]

Drones have been used during disasters in Haiti,[5] United States,[2] Canada,[2] Carribean,[2] and Nepal[6] in delivering medical supplies. It was also used to deliver Automated External Defibrillator (AED) to heart-attack victims in Netherlands,[7] and HIV testing kits in Malawi, Africa.[8,9] These examples show the expanding usage of drones as a future medical products transportation worldwide. Nonetheless, much remains to be done by researchers to provide evidence of benefit and improve the use of this technology to its maximum potential including the application of drones for maternal health outcomes.

Malaysia, a rapidly developing country in Asia, is committed to improving maternal health through multiple strategic initiatives such as the introduction of the Confidential Enquiry into Maternal Deaths (CEMD) and the development of rural health services.[10] One of the important parameters of maternal health is Maternal Mortality Ratio (MMR). Tremendous success was achieved in the beginning, however, the MMR subsequently plateaued and Malaysia failed to meet the WHO MDG-5 target to reduce MMR by 75% by the year 2015.[11]

Three most common causes of maternal mortality in Malaysia recorded in the CEMD for the year 2016 were associated medical conditions, postpartum hemorrhage (PPH), and obstetric pulmonary embolism.[12] The prominence of PPH signifies the importance of a rapid blood delivery system in the management of obstetric emergencies. A new and more aggressive type of intervention is urgently needed to further reduce our MMR. One of the potential interventions is the use of the drone or UAV in obstetric emergencies particularly in rural areas especially in Sabah and Sarawak (which are vast geographical areas consisting of mountainous regions, beaches and tropical rainforests). Therefore, specific scientific evidence of positive impact of drone transportation on maternal health and obstetric emergencies is imperative.

Despite the keen interest, there is currently no systematic review on the use of drones or UAVs in maternal healthcare. We therefore sought to fill this knowledge gap by embarking on a systematic review on the use of drones in improving maternal health, especially during obstetric emergencies such as PPH. The aim of this paper also is to highlight the potential framework of future research in maternal health-specific drone development.

2. Method

2.1. Study design

This was a systematic review of literature, following the principles of PRISMA guidelines (Supplementary Material 1 http://links.lww.com/MD/E847).[13]

2.2. Eligibility criteria

Studies were selected for this review according to the PICOS components (Problems, Intervention, Comparison, Outcome, and Study Design) for an effective search strategy. Problems: the selected studies focused on assessment of blood products transportation in relation to maternal healthcare. Intervention: studies were included only if the intervention used were drones or UAVs. Comparison: studies were selected if there was availability of comparator or control, which was the prevalent mode of transportation. Outcome: studies were considered eligible for synthesis if any direct or indirect maternal health indicators were reported. Direct outcome measures included association of usage of UAVs with maternal sequelae such as MMR, whilst indirect outcome measures included association with study of blood products, blood components, or blood samples. The gold standard in the management of obstetric hemorrhage and saving maternal lives is rapid access to, and transfusion of, blood products for hemostatic resuscitation.[14] Study design: or type of studies included were limited to experimental studies only, as it is the strongest scientific evidence for any health intervention. Systematic reviews, meta-analyses, and studies published in a predatory journal were excluded.

Table 1

Search terms used for this systematic review.

Categories	Search terms
Drone-related	Drones
	Unmanned aerial vehicles (UAV)
	Unmanned aerial system (UAS)
Obstetric/maternity-related	Obstetric emergency
	Obstetric case
	Maternal mortality ratio
	Post-partum hemorrhage
	Blood supply
	Blood delivery
	Blood products delivery

2.3. Search strategy

The following electronic databases were searched from inception to July 2019: ScienceDirect, PubMed, and EMBASE. No grey literature was searched as to conform with the eligibility criteria. The search term used were according to MeSH terminology and divided into two categories, that is, drone-related and obstetric/maternity-related (Table 1). An example of a search strategy for the electronic databases is shown in Table 2 for ScienceDirect, the Medical Subject Heading of "drones" was used to combine with the following keywords "obstetric emergency," "obstetric case," "maternal mortality ratio," "postpartum hemorrhage," "blood supply," "blood delivery," or "blood products delivery."

2.4. Study selection

The selection was carried out independently by two reviewers. Meta-analysis was not done throughout the study in view of the anticipated heterogeneity of each study involving drones for direct and indirect maternal health related outcomes.

Table 2

Search strategy example for electronic database: ScienceDirect.

MeSH term	Drones	
	1. obstetric emergency/	(6)
	2. obstetric case/	(2)
	3. maternal mortality ratio/	(4)
	4. post-partum hemorrhage/	(3)
	5. blood supply/	(53)
	6. blood delivery/	(5)
	7. blood products delivery/	(3)
	8. (((((((1) OR 2) OR 3) OR 4) OR 5) OR 6) OR 7)/	(71)

2.5. Data extraction

Data were extracted independently by two reviewers on location of the studies, type of experimental studies, type of control, duration of drone flight, sample used, main results, any adverse event data, and key conclusions. A data extraction form was developed by the reviewers based on the research question with no further validation process.

2.6. Data synthesis

A narrative synthesis was conducted by the reviewers following data extraction. Patterns of effects, and similarities or differences between selected studies, were investigated by adopting a systematic approach. Comments were given by the reviewers on the finding summaries and maternal-related outcome assessed.

3. Results

Our initial search yielded a total of 244 relevant publications, from which 236 were carried forward for a title and abstract screening. Eleven full-text articles were assessed for eligibility. These studies were examined and only two were included for systematic synthesis. Among the reasons for exclusion were irrelevance to maternal health purpose, and irrelevance to drone applications in healthcare (Fig. 1). The updated search after 1 month yielded one new finding from a Q1 magazine called IEEE Spectrum, which was included for systematic synthesis. Overall, after two rounds of search, three studies were included in our review.

Findings revealed that delivery of blood products and blood samples by drone does not compromise quality of the blood, and in fact increases geographical connectivity and accessibility. However, the blood parameters studied were limited, and the ambience in terms of temperature and weather was also restricted to the local geographical research setting. In a subsequent study, the source of random errors in the experimental blood samples could not be determined. It was also demonstrated that drones were useful in eliminating blood supply wastage, but the transport cost of drones appeared to be more expensive than ground vehicles. These results are summarized in Table 3.

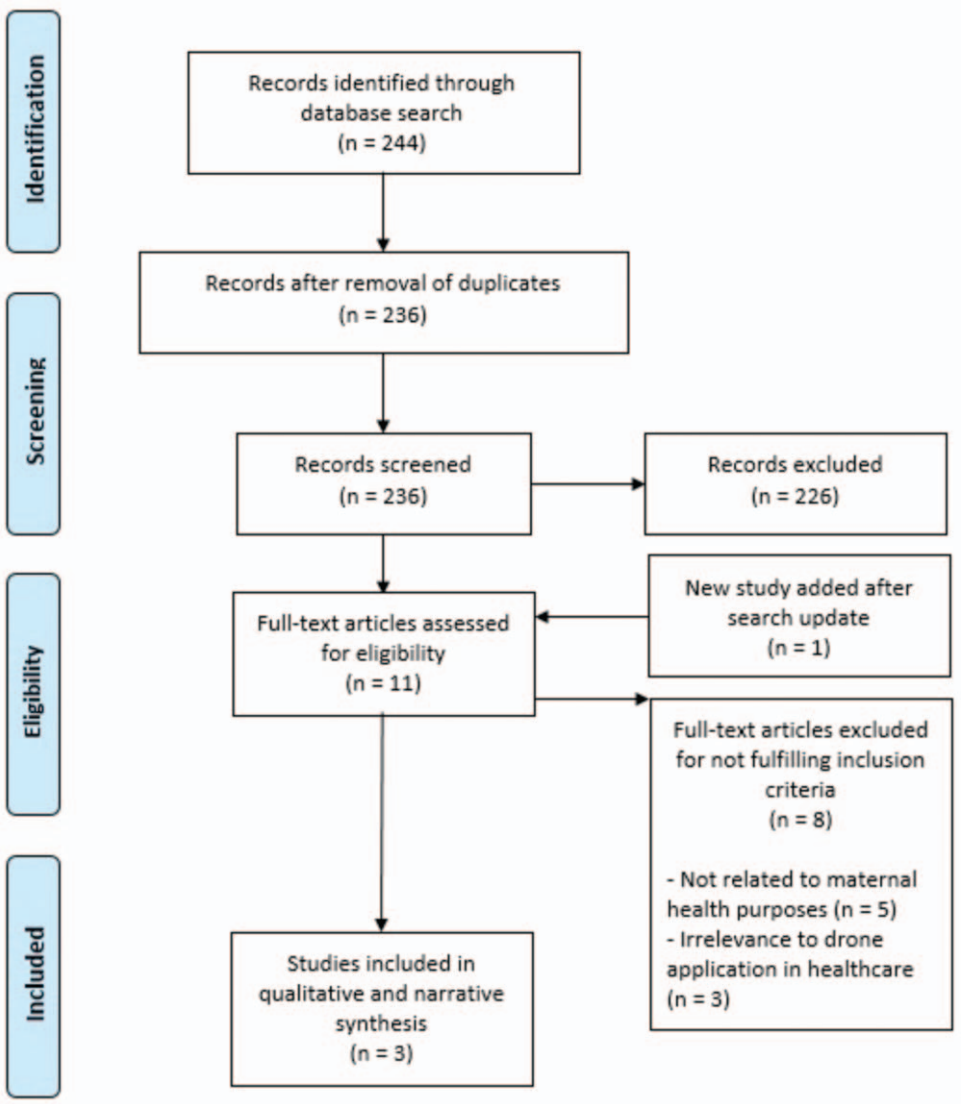

Figure 1. Systematic flow diagram of relevant article search for qualitative synthesis.

Table 3

Summary of studies included in this systematic review.

	Author	Journal and year of publication	Title	Location of experiment	Maximum duration of drone flight	Samples	Study design	Maternal-related outcome assessed	Finding summary	Comments
1.	Amukele et al[15]	Transfusion (2016)	Drone transportation of blood products	Baltimore, MD, USA	26.5 min	6 leukoreduced red blood cell (RBC) units 6 apheresis platelet (PLT) units 6 unthawed plasma units frozen within 24 h of collection (FP24)	Case–control study	Quality of frequently used type of blood products (RBC, PLT, and FP24) using drone transportation.	The stability of blood products is well maintained including products lysis, temperature, pH, platelet count, and MPVs. For environmental variables, there is no specific measures that is needed to stabilize the temperature or pressure of the storage, when the ambient conditions are not extreme.	The study did not address the full range of products, physiological tests, or functional assays that are clinically relevant. Another limitation of the study is not flying the drone in warmer temperatures (maximum ambient temperature studied was 29–30°C without flying the products.)
2.	Amukele et al[16]	PLoS One (2015)	Can unmanned aerial systems (drones) be used for the routine transport of chemistry, hematology, and coagulation laboratory specimens?	Baltimore, MD, USA	37.5 min	336 tubes of blood samples (168 samples were flown, and 168 samples were held stationary on the field)	Case–control study	Viability of drone transportation for delivery of blood samples in tubes.	33 most common chemistry, hematology, and coagulation clinical laboratory tests were done and shown no systematic differences in results from flown vs terrestrial specimens.	There were random errors in the study that resulted in a slightly poorer precision in the experimental sample, compared to analytics' Coefficients of Variation (CoV). The study was unable to conclusively determine the cause of random errors (either due to UAS transport, or protracted time from initial phlebotomy to the analyte measurement)
3.	Evan Ackerman, Michael Koziol [17]	IEEE Spectrum (2019)	The blood is here: Zipline's medical delivery drones are changing the game in Rwanda	Rwanda	45 min	Two units of RBCs, with total payload of 1.3 kg	Cross-sectional design with descriptive analysis.	Accessibility and connectivity of drone transportation of blood products in term of duration, distance, and geographical coverage.	Able to achieve a distance of 80 km and served 25 hospitals and clinics daily. Average duration of 10 min was required to launch a blood order from the facility. Able to eliminate blood expiry from seven to zero in year 2018.	A remodeled version is currently being developed for a payload of 1.75 kg (3 units of blood). The operational cost per delivery is currently higher than ground vehicles, and the cost vs sustainability is in need of further study.

4. Discussion

4.1. Summary of evidence

This systematic review was conducted using three search engines. We found zero report of studies on the use of drones or UAVs in direct relation to maternal health outcomes, and three reports that were related to indirect maternal health purposes. These include two reports on delivery of blood products and one on the delivery of hematology specimens.[15,16] None of the studies reported any losses or falls during drone transportation, or any injuries to civilians, drone operators or healthcare professionals. Of note, there was no health economic assessment of any drone-based medical transportation system.

The latest, reported in 2019, was a study in the Republic of Rwanda, a small country in Central East Africa[17] as compared to two previous studies that were conducted in Baltimore, USA. This was probably due to the fact that Rwanda has a high necessity for rapid blood supply to their remote rural areas. Furthermore, most studies were still in the simulation or experimental stages, with a large window for future research needs in real life situations in obstetric emergencies.[18]

There was also concern with regard to climate issues in which drones can be used in reality. No study has been conducted in tropical climates such as Malaysia where heavy rains and monsoon seasons are experienced on a regular basis. Despite the technological development in the area of liquid ingress protection such as waterproofing and water resistance, drones are generally unable to fly in heavy rain and weather hazards due to potential loss of communication, diminished aerodynamic performance, and reduced operator effectiveness.[19]

On the other hand, we also found that reviews on MedGRT and MedART are increasing in numbers for the past 10 years from 2009 to 2019. This positive trend signifies an increase in awareness among healthcare providers in improving the efficiency of healthcare delivery and survival rates among patients.[20] However, unlike this systematic review, most of the previous studies were done separately either focusing on efficiency of MedGRT or MedART without comparing one to the other.

4.2. Comparing non-medical drones application

Following this systematic review, we noted an obvious deficiency in research on drone application in healthcare as compared to non-medical use cases. Back in the early days of the advent of drones, the technology was expensive and not popular. Usage was limited and perception was negative. They were primarily used in active combat and military target killing. This perception affected our societal values and beliefs, and consequently our behavior towards the drone.[21]

Nowadays, drones are used widely in more than 50 different applications; for example, goods and food delivery services, agriculture, security systems, recording and aerial photography, archeological surveys, and meteorological analysis.[22]

For a medical drone, this changing paradigm from a life damaging to a lifesaving perception certainly required a lot more than simply innovation. Campaigns should be strategically planned to disseminate widespread public awareness on the medical benefits of the drone. A quantitative survey of public acceptance of drones using a Knowledge Attitude Practice (KAP) model and statistical analysis revealed that drones were not well accepted at present except for safety purposes and scientific research.[22] This low general public acceptance is conclusively due to its early reputation as weapons and privacy interrupters. Hence, it is important for future researchers to improve not only the application but also spreading awareness and mitigating risk in order to win public acceptance.

4.3. Framework for future research

Various medical drone applications are identified and continue to be discovered by researchers. Until this systematic review was completed, there were eight additional journal publications in relation to drone applications in healthcare in general, four in cardiac arrest emergencies, three in search and rescue missions, and one in remote telemedicine.[18]

Maternal healthcare-specific drone application in the future may include the delivery of blood products in obstetric services especially during obstetric emergencies, delivery of important laboratory specimens or medical supplies to and from remote maternity services, locating and attending as first responder to homebirth or birth before arrival (BBA) cases, serving as a remote midwifery educator, and other possibilities in drone technology.

As yet, no published data exists to support the claim that UAVs reduces maternal mortality or other measurable maternal health outcomes. This may be attributable to certain obstacles. For instance, unlike goods and meals, red blood cells need to be stored and maintained at temperatures between 2°C and 4°C, and platelets at 22°C to 24°C with constant agitation.[23] Errors in the collection, storage, processing and administration of blood components carries a number of significant risks for patients.[24]

Other than environmental factors, the capability of drones to deliver blood products depends on payload limitation and drone battery life. This adds to the challenges for researchers to be able to deliver safely an adequate amount of blood components. In any obstetric emergency, at least 2 to 4 units of red blood cells are needed to save a patient's life. Future drone use in such real life scenarios requires the ability to carry a payload of at least 1.5 to 2.5 kg.

A sound standard operating procedure in carrying out the task is also of paramount importance. Training drills will help prevent product wastage and accidents in transit. Success in overcoming these challenges may well expand the potential use of drones into other areas of healthcare.

4.4. Limitations

Several limitations were encountered during this systematic review. First, the instruments for extracting the information from the identified sources were not validated. We used basic word processor software such as Microsoft Word and electronic files such as emails for instant sharing as our main data extraction tools. Relevant knowledge from the included studies could not be discussed nor presented in our review. However, we believe this instrument retrieved sufficient amounts of important details to answer our research question. We extracted as much information as possible from the reports and summarized the findings, as in Table 3.

Secondly, we did not search using the specialized search engines for engineering based and information technologies-based databases. Consequently, this may have resulted in limited information and articles retrieved regarding technological aspects of drone utilization in obstetric emergencies. However, we believe that healthcare usage of drones is almost exclusively published in biomedical subscription databases.

Thirdly, our systematic review found only one study that disclosed the distance travelled and that study was done in a rural area.[14] Meanwhile, the other two studies were performed in a larger metropolitan area of Baltimore, MD, USA.[12,13] The impact and effect of UAVs in a metropolitan area might not be appropriate for extrapolation to rural areas of Malaysia such as Sabah and Sarawak.

Regardless, we believe this systematic review is the first to be conducted pertaining to the use of drones in maternal healthcare. Additionally, three search engines were used to ensure that our review was comprehensive and deductive.

5. Conclusion

Our systematic review on the utilization of drones for medical products transportation in maternal healthcare identified three studies, none of which dwelt on a direct outcome on maternal health. This reveals a wide knowledge gap in studying the relationship between drones or UAVs usage with achieving maternal healthcare benefit.

The output of this review serves as a framework for future research activities into maternal healthcare-specific drone applications. Among the suggestions are looking into the effect of drones on maternal mortality and morbidity, studying the cost-effectiveness of drones over ambulances in saving maternal lives, the impact of drones on telehealth midwifery education, and maternal healthcare providers' acceptance of drone technology application.

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Author contributions

Afiq Hidayat M led the review, was responsible for managing the synthesis, data extraction and drafted the report. Azma RZ provided expert clinical advice (pathology), Rahana AR provided expert clinical advice (obstetrics), Ismail MS provided expert clinical advice (emergency medicine), Aniza I provided advice for the systematic review and methodology. Mahdy ZA provided advice on the methodology and systematic review, made critical comments that helped in the interpretation of the results, and helped in writing sections of the report. All authors read and commented on draft versions of the report and reviewed the final report.

Conceptualization: Raja Zahratul Azma Raja Sabudin, Rahana Abdul Rahman, Ismail Mohd Saiboon, Aniza Ismail, Zaleha Abdullah Mahdy.
Data curation: Mohamed Afiq Hidayat Zailani.
Funding acquisition: Zaleha Abdullah Mahdy.
Methodology: Raja Zahratul Azma Raja Sabudin, Aniza Ismail, Zaleha Abdullah Mahdy.
Project administration: Zaleha Abdullah Mahdy.
Validation: Mohamed Afiq Hidayat Zailani, Rahana Abdul Rahman, Zaleha Abdullah Mahdy.
Writing – original draft: Mohamed Afiq Hidayat Zailani.
Writing – review & editing: Mohamed Afiq Hidayat Zailani, Raja Zahratul Azma Raja Sabudin, Rahana Abdul Rahman, Ismail Mohd Saiboon, Aniza Ismail, Zaleha Abdullah Mahdy.

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