Drones for Medical Products Transportation In Obstetric Emergencies: A Systematic Review and Framework For Future Research

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Research article

Keywords: MedART (medical air transportation), drone, obstetric, haemorrhage, review

Posted Date: November 11th, 2019

DOI: https://doi.org/10.21203/rs.2.17105/v1

Abstract

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 the event of obstetric emergencies. The drone is an immensely promising medical products aerial transportation (MedART) that holds an enormous potential for delivery of medical supplies, thereby enhancing the efficiency of our healthcare system. We conducted a systematic review to examine scientific evidence of positive impact of drone transportation on maternal health and management of obstetric cases.Methods Three search engines were used for this review; ScienceDirect, Pubmed, EMBASE databases, and the report made in accordance with the principles of PRISMA guidelines. The search terms used are related to drones and obstetric/maternal. Studies were selected if the intervention used were drones or Unmanned Aerial Vehicles (UAVs), and if any direct or indirect maternal health indicators were reported.Results Two out of 244 publications met the inclusion criteria and were included for systematic synthesis. An updated search yielded one additional study that was also included. Overall, two studies assessed drones for blood products delivery, and one study used drone 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.

Key Messages

1. **Implications for policy makers**

The result of this research identified and analyzed modes of medical products transportation, and the utility of drones in maternal healthcare. This may facilitate policy makers in determining and improving cost effectiveness of deployment of drones in maternal healthcare transportation. Moreover, the drone research may help in legal reform of existing laws regulating air transportation to keep up with the rapidly progressing technological advancement for the benefit of mankind

2. **Implications for public**

This research will broaden the public's horizons by increasing their knowledge and understanding of potential drone utility in maternal healthcare. Consequently, the discussion on drone usage will increase public acceptance and awareness of the importance and significant role of drones in the current transportation and healthcare landscape. At the end of the day, any positive change of policy in favor of facilitating drone transportation of medical products likely will benefit public healthcare immensely.

Background

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 and aeroplanes (Yanagawa et al., 2018).

Globally, rapid technological advancement has revolutionized medical products transportation with the advent of the drone. Drones increase mobility over challenging geographical barriers (Balasingam, 2019), reduce carbon emission (Goodchild et al, 2018), and may also improve cost effectiveness of healthcare delivery. Nonetheless, much remains to be done worldwide to provide evidence of benefit and improve the use of this technology.

An international campaign to improve maternal health was established with the launching of WHO's Safe Motherhood Initiative in 1987, followed by the incorporation of maternal health as one of WHO's Millennium Development Goals (MDG) in year 2000 (Achanna et al., 2018). Being a rapidly developing country in Asia, Malaysia has adopted the initiative to improve maternal health with the introduction of the Confidential Enquiry into Maternal Deaths (CEMD) in 1991. Tremendous success was achieved in the beginning, however the ratio plateaued and Malaysia failed to meet the WHO MDG-5 target to reduce Maternal Mortality Ratio by 75% by the year 2015 (World Health Organization, 2018).

To date, the maternal mortality rate in Malaysia had remained static for the past 17 years. New and more aggressive interventions are urgently needed to further reduce our maternal mortality rate. One of the potential interventions is the use of drone or Unmanned Aerial Vehicles (UAVs) in obstetrics emergencies particularly in the rural areas especially in Sabah and Sarwak. Therefore, specific scientific evidence of positive impact of drone transportation on maternal health and obstetric cases is imperative.

Despite the keen interest, there is currently no systematic review on the use of drones or Unmanned Aerial Vehicles (UAVs) in maternal healthcare. We therefore strive 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 postpartum hemorrhage (PPH). The output of this review will serve as a framework for future research.

Methods

Study Design

This was a systematic review of literatures, following the principles of PRISMA guidelines (Supplementary Material 1).

Search

Studies were selected for this review if the intervention used were drones or Unmanned Aerial Vehicles (UAVs), and if any direct or indirect maternal health indicators were reported. Direct outcome measures include comparison of usage of UAVs with maternal sequelae such as Maternal Mortality Ratio (MMR), whilst indirect outcomes measures include 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 through rapid transfusion of blood products for hemostatic resuscitation (Gutierrez et al., 2012).

Our search only focused on experimental studies, as it is the strongest scientific evidence for any health intervention. The search was conducted using three different databases, namely ScienceDirect, PubMed, and EMBASE, from 2nd June 2019 until 15th July 2019. No grey literature was searched. The terms used are divided into two categories i.e drone-related and obstetric/maternity-related (Table 1: Search terms used for this systematic review).

Study Selection

Articles from each search engine were downloaded and duplicates were removed. Subsequently, screening was conducted through the initial reading of the abstract. All information was sufficient in the research papers, therefore no extra details were requested from the investigators of each study. 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. Characteristics of the study were summarized in Table 2 (Table 2: Summary of studies included in this systematic review) .

Results

Our initial search yielded 244 relevant publications, from which 141 were carried forward for a title and abstract screening: 81 from ScienceDirect, 18 from PubMed, and 44 from Embase. These 141 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. The updated search after one month yielded one new finding from a Q1 magazine, which was included for systematic synthesis. Overall, after two rounds of search, three studies were included in our study, as summarized in Table 2. Figure 1 depicts the process of our search from initial identification, screening, eligibility and inclusion (Figure 1: Systematic Flow Diagram of relevant article search for qualitative synthesis).

Discussion

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 (Amukele et al., 2017) and one on the delivery of haematology specimens (Amukele et al., 2015).

The latest, reported in 2019 was a study in the Republic of Rwanda, a small country in Central East Africa (Evan et al., 2019) 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 (Carillo-Larco et al., 2018).

There was also concern with regards to the climate issue in which drones can be used in reality. No study has been carried 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 (Ranquist et al., 2017).

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 health providers in improving the efficiency of healthcare delivery and survival rates among patients (Taylor et al., 2018). 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.

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 introduction of drones, this advent technology was expensive and not popular. Usage was limited and the perception was negative. They were primarily used in active combat and military target killing. This perception affected our societal values and belief, and consequently our behavior towards the drone (Rao et al., 2016).

Nowadays, drones are used widely in more than fifty different applications; for example goods and food delivery services, agriculture, security systems, recording and aerial photography, archeological surveys, and meteorology analysis (Aydin, 2019).

For a medical drone, this changing paradigm from a life damaging to a life saving perception certainly required a lot more than simply an innovation; widespread public awareness was in order. 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 (Aydin, 2019). 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.

Stumbling Blocks in Maternal Healthcare-Specific Drone Application

The three arms of healthcare drone application are transport and delivery, search and rescue, and remote medical care. Until this systematic review was completed, there are 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.

Nevertheless, maternal healthcare specific drone application remains a scarcity. This may be attributable to a few obstacles. For instance, blood products such as red blood cells and platelets are labile and need to be handled in a specific environment. Unlike goods and meals, red blood cells need to be stored and maintained at temperatures between 2-4°C, and platelets at 22-24°C with constant agitation (Bardyn et al., 2017). This primarily translates into a massive challenge for drones adaptation in maternal healthcare. Thermologger, special storage, ice packs, and the flight distance of drones are challenges to contend with, in addition to maintaining optimum specific temperature in blood product transport, to ensure successful use of drones in obstetric emergencies in different geographical region. A drop in temperature may affect the biochemical components of blood products and leads to ineffective transport.

Other than environmental factors, the capability of drones to deliver blood products depend 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 2-4 units of red blood cells are needed to save a patient's life. Future drone use in such life scenarios requires the ability to carry a payload of at least 1.5-2.5 kilograms.

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 as well expand the potential use of drone beyond maternal healthcare-specific usage, including other modalities of medical intervention such as imaging and robotic arms.

Limitations

Several limitations were encountered during this systematic review. First, the instruments for extracting the information from the identified relevant sources are not validated. We extracted as much information as possible from the reports and summarised the finding, as in table 1.

Secondly, we did not search using the specialised 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, we did not record the reason for exclusion while screening through the titles and abstracts. However, we overcame the possible bias with our very specific inclusion criteria. We specified the use of drones for maternal health related purposes only, either a direct relationship such as Maternal Mortality Ratio, or indirect such as blood and haematology laboratory specimens.

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 our review to be comprehensive and deductive.

Conclusion

In our systematic review on the utilization of drones for medical products transportation in obstetric emergencies, three studies were identified and none dwelt on a direct outcome on maternal health. This shows reveals a wide knowledge gap in studying the relationship between drones or UAVs usage with achieving maternal healthcare benefit. Recent advancements in drone technology imply a significant potential for drones to be an alternative solution to healthcare accessibility, hence in saving lives worldwide.

Future drone research framework is suggested to focus more on maternal healthcare-specific drone applications. This includes the effect of drones on maternal mortality and morbidity, the study of cost effectiveness of drones over ambulances in saving maternal lives, and maternal healthcare providers' acceptance in applying drones technology.

Abbreviations

CEMD	Confidential Enquiry into Maternal Deaths
CV	Coefficients of Variation

FP24	Frozen plasma within 24 hours of collection
KAP	Knowledge Attitude Practice
MDG	Millennium Development Goal
MedART	Medical product Aerial Transportation
MedGRT	Medical product 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

Declarations

Ethics approval and consent to participate:

Not applicable. This is a systematic review of published literature. No human subjects participated in this study.

Consent for publication:

Not applicable

Availability of data and materials:

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Competing interests:

Mahdy ZA is an Associate Editor of the journal. Other authors have disclosed no competing interest.

Funding:

This systematic review was supported by Universiti Kebangsaan Malaysia via a research grant (DCP-2018-004/1).

Authors' contributions:

MAHZ led the review, was responsible for managing the synthesis, data extraction and drafted the report. RZARS provided expert clinical advice (pathology) and reviewed the final report. RAR provided expert clinical advice (obstetric & gynaecology) and reviewed the final report. IMS provided expert clinical advice (emergency medicine) and reviewed the final report. AI provided advice for the systematic review and methodology, and reviewed the final report. ZAM provided advice on the methodology and systematic review, made critical comments that helped in the interpretation of the results, helped in writing sections of the report and reviewed the final report. All authors read and commented on draft versions of the report.

Acknowledgements:

We thank our colleagues from Ministry of Health (MOH), Malaysia who provided insight and expertise that greatly assisted the research. We would also like to show our gratitude to our team members from Faculty of Engineering and Built Environment (FKAB) and Faculty of Information Science and Technology (FTSM), Universiti Kebangsaan Malaysia for sharing their pearls of wisdom with us during the course of this research.

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Tables

Table 1 **Search terms used for this systematic review**

Categories	Search Terms
Drone-related	Drones
	Unmanned Aerial Vehicles (AUV)
	Unmanned Aerial System (UAS)
Obstetric/maternity-related	Obstetric emergency
	Obstetric case
	Maternal Mortality Ratio
	Postpartum Hemorrhage
	Blood supply
	Blood delivery
	Blood products delivery

Table 2 Summary of studies included in this systematic review.

	Author	Journal	Year Published	Title	Location of experiment	Samples	Study Design	Finding Summary	Comments
1.	Amukele et al.	Transfusion	2016	Drone transportation of blood products	Baltimore, Maryland USA	6 leukoreduced red blood cell (RBC) units, 6 apheresis platelet (PLT) units, 6 unthawed plasma units frozen within 24 hours of collection (FP24)	Case-control study	The stability of blood products is well maintained by using drone transportation of 26.5 minutes flight, including products lysis, temperature, pH, platelet count and Mean Platelet Volume (MPV). 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. Other limitations of the study include not flying the drone in warmer temperatures (maximum ambient temperature studied is 29-30 °C without flying the products.)
2.	Amukele et al.	PLoS ONE	2015	Can Unmanned aerial systems (drones) be used for the routine transport of chemistry, hematology, and coagulation laboratory specimens?	Baltimore, Maryland USA	336 tubes of blood samples (168 samples were flown, and 168 samples were held stationary on the field)	Case-control study	33 most common chemistry, hematology, and coagulation clinical laboratory tests were done and shows no systematic differences in results from flown versus 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 (CV). 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	IEEE Spectrum	2019	The blood is here: Ziplines medical delivery drones are changing the game in Rwanda	Rwanda	Two units of RBCs, with total payload of 1.3 kg	Cross-sectional design with descriptive analysis.	Able to achieve a distance of 80km (45-minutes flight) and served 25 hospitals and clinics daily. Average duration of 10 minutes was required to launch a blood order from the facility. Able to eliminate the blood expiry from seven to zero in year 2018.	There were random errors in the study that resulted in a slightly poorer precision in the experimental sample, compared to analytics' Coefficients of Variation (CV). The study was unable to conclusively determine the cause of the random errors (either due to UAS transport, or protracted time from initial phlebotomy to the analyte measurement)

Figures

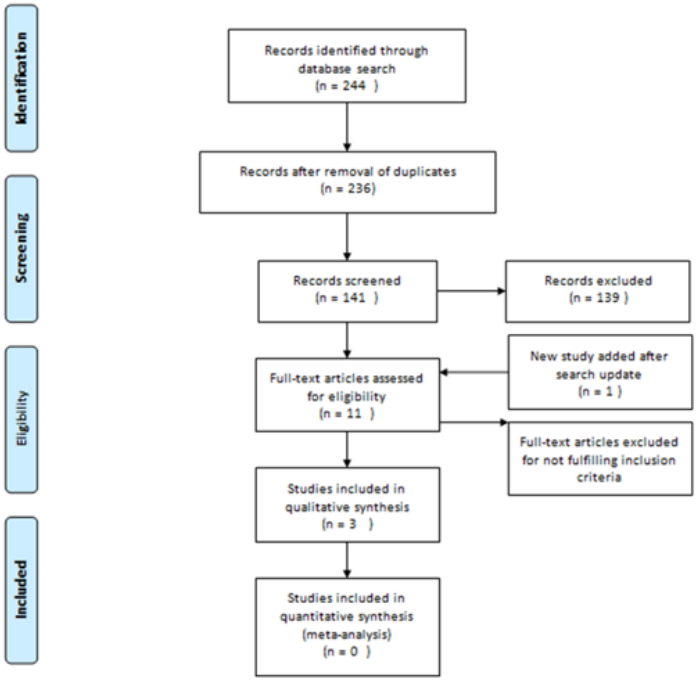

Figure 1

Systematic Flow Diagram of relevant article search for qualitative synthesis.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.pdf
- PRISMAflowdiagram.pdf