Effect of unmanned aerial vehicle (drone) delivery on blood product delivery time and wastage in Rwanda: a retrospective, cross-sectional study and time series analysis

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Summary

Background The accessibility of blood and blood products remains challenging in many countries because of the complex supply chain of short lifetime products, timely access, and demand fluctuation at the hospital level. In an effort to improve availability and delivery times, Rwanda launched the use of drones to deliver blood products to remote health facilities. We evaluated the effect of this intervention on blood product delivery times and wastage.

Methods We studied data from 20 health facilities between Jan 1, 2015, and Dec 31, 2019, in Rwanda. First, we did a cross-sectional comparison of data on emergency delivery times from the drone operator collected between March 17, 2017, and Dec 31, 2019, with two sources of estimated driving times (Regional Centre for Blood Transfusion estimates and Google Maps). Second, we used interrupted time series analysis and monthly administrative data to assess changes in blood product expirations after the commencement of drone deliveries.

Findings Between March 17, 2017, and Dec 31, 2019, 12 733 blood product orders were delivered by drones. 5517 (43%) of 12 733 were emergency orders. The mean drone delivery time was 49·6 min (95% CI 49·1 to 50·2), which was 79 min faster than existing road delivery methods based on estimated driving times (p<0·0001) and 98 min faster based on Google Maps estimates (p<0·0001). The decrease in mean delivery time ranged from 3 min to 211 min depending on the distance to the facility and road quality. We also found a decrease of 7·1 blood unit expirations per month after the start of drone delivery (95% CI –11·8 to –2·4), which translated to a 67% reduction at 12 months.

Interpretation We found that drone delivery led to faster delivery times and less blood component wastage in health facilities. Future studies should investigate if these improvements are cost-effective, and whether drone delivery might be effective for other pharmaceutical and health supplies that cannot be easily stored at remote facilities.

Funding Canadian Institutes for Health Research.

Lancet Glob Health 2022; 10: e564–69

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Introduction

Blood transfusion plays a vital part in patient care worldwide. For example, blood and blood products are often used in maternal care for obstetric haemorrhages,[1] in paediatrics to treat anaemia, and in surgical procedures.[2] In low-income and middle-income countries (LMICs), 54% of blood transfusions are given to children for various conditions.[3] In sub-Saharan African nations this rate is even higher—young children with severe anaemia account for 70% of all blood transfusions,[4] followed by severe haemorrhage, which is the leading cause of maternal deaths.[5] For many sub-Saharan African countries to achieve the health-related Sustainable Development Goals related to under-5 and maternal mortality, there is a need to improve access to safe blood.[5,6]

Despite this need, the complexity of blood supply chain management remains a substantial challenge.[7] Generally, blood and blood products are perishable and have a short lifespan. Red blood cell concentrates can be stored for 42 days at 2–6°C and platelets can be stored for 5 days at 20–24°C. Additionally, unlike other pharmaceutical products, the demand for blood at hospitals fluctuates and is not easily predicted.[8] As a result, maintaining supplies at this level can also mean that blood products expire, which results in costly wastage within the system.

In Rwanda, blood product collection, storage, delivery, and transfusion are overseen by the Rwanda Biomedical Centre Blood Transfusion Services (BTS) Division, which has a Center for Blood Transfusion (CBT) in each province of Rwanda. Currently, Rwanda has 71 public and private health facilities that can transfuse patients, and all of them receive blood components that CBTs prepare.[9] On average, around 75 000 units of blood components were transfused to patients per year between 2014 and 2018 (unpublished; BTS report). Most transfusions are given to children and women as the result of malaria or obstetric complications, and to other patients because of road accidents.[10,11] As such occurrences are among the leading causes of mortality in

Research in context

Evidence before this study
The development of advanced unmanned aerial vehicles (drones) has led to their use in aerial medical product delivery. This approach has been shown to improve access to medical products in geographically challenging areas, during disasters, and in emergency cases where ground delivery would take more time. For instance, studies in higher-income and upper-middle-income countries have shown faster delivery of automated external defibrillators, and a reduction in blood product delivery time compared with ground delivery. We searched PubMed and Google Scholar, and did a review of references from previous manuscripts on this topic. Our search terms included "drone", "drone intervention", "UAV", and "blood product delivery". We reviewed studies and included data published in English up to April 1, 2021.

Added value of this study
To our knowledge, this is the first study to assess the effect of drone delivery on blood product delivery time and wastage in sub-Saharan Africa. We found that the use of drones for blood product delivery in Rwanda led to shorter delivery times and fewer product expirations, suggesting that using drones is both feasible and effective in this setting.

Implications of all the available evidence
Our study, together with other findings, suggests that drones can improve timely access to medical products, especially in remote areas, for the emergency provision of blood products. Drones can also be used to reduce product wastage in settings where product expirations are common.

Rwanda, blood products are essential for emergency departments. These blood components are obtained through two means: bulk requisitions (resupply) and nominative requests (on demand).

For bulk requisitions, hospitals with blood bank infrastructure are supplied by regional and national centres for blood transfusion. Most health facilities request red blood cell concentrates that can be stored in hospital blood banks for use as needed. The main issue with bulk requisitions has been that some health facilities have requested more blood than needed to avoid frequent travel to CBTs, resulting in product expirations and wastage. To this end, an internal Rwanda Biomedical Centre report suggested that around 6% of all blood units issued to hospitals expired before use (unpublished; BTS report). Nominative blood requests are mainly for rare blood groups, such as negative rhesus blood, or blood components with a shorter shelf life, such as platelets. Health facilities can make a nominative request once they have a patient that needs that specific blood product. The major challenge with these requests has been longer delivery times, particularly when the health facility is geographically distant from the nearest CBT. The delivery of these products is mostly done by road, which can be very slow because of remote locations and poor road conditions and sometimes affects the quality of blood and blood products.[12]

To address these concerns, in 2016, the Government of Rwanda started the use of unmanned aerial vehicles (UAVs), or drones, to deliver blood and blood products to several health facilities.[12] This was done in collaboration with Zipline, which provided an autonomous aerial delivery system designed to deliver commodities to different geographical locations in the country. The system combines an autonomous UAV system with central warehousing and fulfillment at two distribution hubs in Rwanda. These hubs can each make up to 500 deliveries per day by parachute delivery to the facility.[9,13]

To our knowledge, this was the first use of UAVs for primary health commodity delivery in Africa. Some evidence from high-income countries suggests that drones can reduce delivery times[14] and improve the quality of blood components.[15,16] However, it is unclear if these findings are generalisable to LMIC settings. Previous studies in sub-Saharan African countries have explored the feasibility of drone implementation but have not assessed the effect of drone use on medical products delivery.[9,17] Whether drones result in faster deliveries and less product wastage is important, as this distribution method is more expensive than traditional methods. Therefore, we assessed the impact of UAV use on blood delivery times and blood product expirations in Rwanda.

Methods

Study setting
Rwanda is a small and densely populated country in east Africa, where 83% of the 12 million residents live in rural areas.[18] Most of the population is covered by a community health insurance scheme that only reimburses care in public facilities. These public facilities are organised into five levels: referral hospitals, provincial hospitals, district hospitals, health centres, and health posts.[19] As in many other countries in the region, blood transfusion is used in high-risk cases, including post-partum haemorrhage, severe malaria, chronic conditions, and injuries.[10] Although district hospitals have been equipped with refrigerators to store rhesus positive packed red blood cells, issuance of negative rhesus blood, fresh plasma, and platelets is provided using emergency deliveries on an as-needed basis. Traditionally, these have been completed using ambulances that are dispatched from each health facility to the CBTs.

Intervention
In 2016, the Government of Rwanda initiated drone deliveries of blood products to 20 health facilities across

the country. The goal of this intervention was to decrease delivery times, reduce stockouts of blood components, and digitise the supply chain. Blood components were stored at two distribution hubs, and hospitals requested products when they were needed. Each hub is equipped with up to 20 UAVs and serves delivery points within an 80 km radius (22 500 km² coverage). Both hubs cover 90% of the country outside the capital. UAVs are accelerated to flight speed using an automated servo-electric launch mechanism and are recovered using an automated raised capture line. The contractual agreement with Zipline was that emergency deliveries should take no more than 1 h, and resupplies could take up to 4 h. Furthermore, the request and delivery processes were made electronic for intervention hospitals, which allowed rapid resupply of products that ran out. The government expected a reduction in product wastage from resupply requests, and it was expected that hospitals would stop overstocking blood, which in turn would reduce number of expirations.

Study design and sites

Our study used two approaches. First, we did a cross-sectional comparison of delivery times between drones and traditional road delivery. Second, we used interrupted time series analysis to assess changes in blood component expirations pre-intervention and post-intervention. We focused our study on the 20 district and provincial hospitals that were selected to receive drone delivery between Dec 21, 2016, and Dec 22, 2018. As hospitals began the intervention on different dates, we standardised their data to study time, representing the number of months before and after each facility's individual start date (appendix).

Comparison of delivery times

We used different data sources for the two parts of our analysis. For the comparison of delivery times, we obtained the electronic database containing information on drone deliveries from Zipline, the company operating the UAVs. This database contained information on all deliveries using drones during the study period, including the requesting hospital, request time, confirmation time, product type, and type of request (emergency or resupply).

Although our original study protocol included the manual collection of road delivery data from paper health facility records, collection of this data was halted by the COVID-19 lockdown in Rwanda. Therefore, we estimated road delivery times with information from two sources. First, we used driving time estimates obtained from internal BTS documentation. Second, we obtained estimated driving times from Google Maps for the closest transfusion centre to each facility.

We calculated drone delivery times by taking the difference between the order request time by a health facility and the time of order delivery at the health facility. We excluded drone order preparation and packaging time, which averages 10 min.[9] To compare drone delivery times with estimated road delivery times, we used a Wilcoxon signed-rank test to analyse the pre-intervention and post-intervention median delivery time of blood and blood components. We also did a sensitivity analysis comparing drone delivery time with a hypothetical best case road delivery system where CBTs have vehicles, so travel would only be one way as opposed to the current system that requires two-way travel from the facility.

Blood product expirations

To evaluate the effect of drone delivery, we extracted data on the monthly number of blood component expirations from Rwanda's Health Management Information System (HMIS). This system collects information on health-care services from each facility on a monthly basis and has been used in previous evaluations of this type.[20,21] From the HMIS system, we determined the monthly number of expired blood and blood component units between January, 2015, and June, 2019. To evaluate longitudinal changes in these values, we did an interrupted time

See Online for appendix

	Estimated driving time to CBT, min	Google Maps driving time to CBT, min	Drone mean delivery time post-intervention, min	Time difference (estimated driving time–drone time), min	Time difference (Google Maps driving time–drone time), min
CBT Kigali					
Kabgayi District Hospital	120	166	24	96	142
Ruhango Provincial Hospital	240	188	31	209	157
Muhororo Hospital	240	260	29	211	231
Byumba District hospital	120	168	54	66	114
Ruli District Hospital	180	168	41	139	127
CBT Ruhengeri					
Butaro District Hospital	180	178	52	128	126
Nemba District Hospital	120	84	41	79	43
Kinihira Provincial Hospital	150	156	58	92	98
Kabaya District Hospital	120	122	43	77	79
Shyira Hospital	120	84	46	74	38
CBT Butare					
Gitwe District Hospital	180	172	33	147	139
Nyanza District Hospital	90	98	33	57	65
Gikonko Health Center	120	86	40	80	46
Gakoma District Hospital	120	106	44	76	62
Kibilizi District Hospital	60	46	57	3	–11
Kigeme Hospital	90	88	40	50	48
Kaduha District Hospital	180	196	37	143	159
CBT Karongi					
Mugonero Hospital	60	66	50	10	16
Murunda District Hospital	150	116	48	102	68
Kirinda District Hospital	120	220	31	89	189
Median difference	120	139	41	79 ($p<0·0001$)	98 ($p<0·0001$)

Muhanga was the Zipline site for all hospitals. CBT=Centre for Blood Transfusion.

Table 1: **Delivery time by hospital and median difference (round trip), stratified by blood transfusion centre**

	Estimated driving time to CBT, min	Google Maps driving time to CBT, min	Drone mean delivery time post-intervention, min	Time difference (estimated driving time–drone time), min	Time difference (Google Maps driving time–drone time), min
CBT Kigali					
Kabgayi District Hospital	60	83	24	36	59
Ruhango Provincial Hospital	120	94	31	89	63
Muhororo Hospital	120	130	29	91	101
Byumba District hospital	60	84	54	6	30
Ruli District Hospital	90	84	41	49	43
CBT Ruhengeri					
Butaro District Hospital	90	89	52	38	37
Nemba District Hospital	60	42	41	19	1
Kinihira Provincial Hospital	75	78	58	17	20
Kabaya District Hospital	60	61	43	17	18
Shyira Hospital	60	42	46	14	–4
CBT Butare					
Gitwe District Hospital	90	86	33	57	53
Nyanza District Hospital	45	49	33	12	16
Gikonko Health Center	60	43	40	20	3
Gakoma District Hospital	60	53	44	16	9
Kibilizi District Hospital	30	23	57	–27	–34
Kigeme Hospital	45	44	40	5	4
Kaduha District Hospital	90	98	37	53	61
CBT Karongi					
Mugonero Hospital	30	33	50	–20	–17
Murunda District Hospital	75	58	48	27	10
Kirinda District Hospital	60	110	31	29	79
Median difference	60	69·5	41	19 (p=0·0018)	28·5 (p=0·0025)

Muhanga was the Zipline site for all hospitals. CBT=Centre for Blood Transfusion.

Table 2: **Delivery time by hospital and median difference (considering one-way trip), stratified by blood transfusion centre**

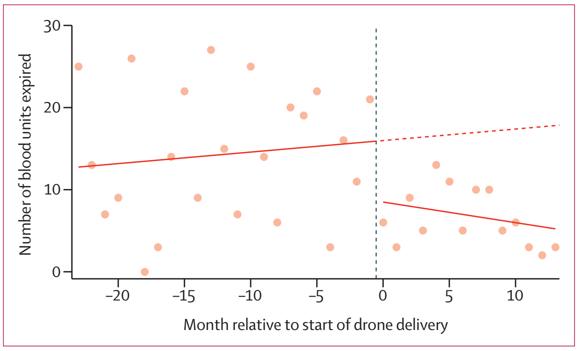

Figure: **Interrupted time series analysis of the number of blood units expired before and after the start of drone delivery in 20 health facilities in Rwanda**

series analysis using a segmented linear regression model before and after UAV deliveries began.[22] We used generalised least squares models and included a first-order autocorrelation term based on statistical tests.[22] All analyses were done with R version 3.6.2.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Between March 17, 2017, and Dec 31, 2019, 12 733 blood product orders were delivered by drones. 5517 (43%) of 12 733 were emergency orders. In these emergency orders, 14 651 blood units were delivered by drones to 20 district and provincial hospitals. Each hospital requested a mean of 276 emergency orders (SD 163) during the study period. Most emergency units delivered were of blood group O (7239 [49%] of 14 651) followed by group A (3823 [26%] of 14 651). Furthermore, most of these units were rhesus positive (13 302 [91%] of 14 651). Kabgayi (2195 [15%] of 14 651) and Butaro (1971 [13%] of 14 651) hospitals accounted for most blood units delivered, and 12 842 (88%) of 14 651 of these deliveries were for adult patients in emergency care.

Table 1 shows the standard delivery time, excluding preparation and packaging time. Overall, the mean delivery time by drone was 49·6 min (95% CI 49·1–50·2), including order preparation and packaging time. By contrast, road delivery took a driver a median time of 120 min (IQR 120–180) to deliver a blood request order back to the health facility. Based on Google Maps estimated driving times, the median road delivery time would have been 139 min (IQR 87–175), whereas drone delivery had a median time of 41 min (IQR 33–49) excluding order preparation. Based on these estimates, drone delivery was 79 min (p<0·0001) faster using estimated driving times and 98 min faster (p<0·0001) based on Google Maps estimates. Notably, the time savings from drone delivery varied widely, from 3 min to 211 min across the facilities we studied.

As hospitals use their vehicles for blood products, delivery times require a full round trip. In our sensitivity analysis, we also compared drone delivery times to the best case driving times that would be possible. Assuming that each CBT had their own ground delivery service, it would take a median time of 60 min (one-way trip) to deliver blood orders to the health facility (table 2). In this case, drone delivery would be faster by a median time of 19 min (p=0·0018). Compared with Google Maps estimates, drone delivery would be 28·5 min faster (p=0·0025) than this best case scenario.

In the pre-intervention period, 334 blood product units expired across the 20 facilities. The mean number of expired blood products per facility per month increased from an estimated 12·8 units to 15·8 units before the start of drone delivery (figure). After the start of drone deliveries, we found a level decrease (immediate change post-intervention) of 7·1 fewer blood unit expirations per facility per month in the post-intervention period (95% CI –11·8 to –2·4; p=0·0060). We also found a non-significant reduction of 0·4 fewer expirations per facility per month thereafter (–0·8 to 0·1; p=0·091). Overall, these findings represented a 67% reduction in blood product expirations at 12 months and this reduction was associated with 140 fewer expirations during our post-intervention period at these 20 facilities.

Discussion

Drone delivery has arisen as an alternative delivery mechanism for health supplies to remote areas in LMICs. Our study of the use of drones for blood and blood product delivery found that this strategy was effective, shortened delivery times, and reduced blood component wastage in Rwanda. Compared with the existing delivery system, we estimated that products arrived 79–98 min earlier than they would have by road. Additionally, we found the intervention was associated with a 67% decrease in blood and blood product expiration after the drone delivery programme was put in place.

Our findings are similar to studies that assessed the effect of similar drone delivery systems of medical supplies in high-income countries. For example, a study in the USA found that drones resulted in a median time saving of 16 min for automated external defibrillator delivery.[14] Furthermore, a study in San Francisco's Mission district (USA) found a time reduction of 83 min for prescription drug delivery.[12] Importantly, the available evidence also shows no effect of drone delivery on the quality of blood components[23] and other medical products.[15] In Rwanda, unlike road transport of blood components, drones would result in a shorter delivery duration and less exposure to poor roadways, potentially leading to less damage to delivered blood components.[9,12] Internal data provided by Zipline suggest that, of 108 170 units delivered over 3 years, only 21 (<1%) units were damaged during delivery.

To our knowledge, this is the first study to evaluate UAVs as a means of primary health commodity delivery in sub-Saharan Africa. This study supports our hypothesis that consolidating blood product distribution to two drone facilities would lead to more timely deliveries to hospitals. This consolidation and timely delivery also led to fewer stockouts of vital blood products such as Rhesus negative blood, fresh plasma, and platelets. Clinically, eliminating stockouts and expirations of less common blood products will result in more patients receiving necessary treatments with less delay, and could also have reduced the need for patient transfer or the use of second-line therapies.

In high-income countries, in addition to blood product delivery, drones have been used for delivery of other medical products. Our results suggest that drones might have other applications in sub-Saharan Africa, such as the delivery of time-sensitive medical supplies. Lastly, the large number of completed deliveries is consistent with drone delivery being feasible for use in other limited-resource settings with remote facilities.

As with all studies that use administrative data, our study had limitations that should be noted. First, we used time estimates for road delivery time rather than actual records. We had planned to collect delivery times from health facility laboratory registers. However, because of COVID-19 restrictions, we were unable to collect this information. To validate these estimates, we used two sources of driving time from CBTs to health facilities, and both data sources resulted in similar findings. Furthermore, our study did not include a control group. We did not feel that other hospitals in Rwanda would be viable controls, as they tend to be located near CBTs or referral hospitals that already have better blood bank infrastructure. As a result, our findings might not extrapolate to less remote facilities or those with differing road network connectivity. Finally, as we could not collect data from hospital records, we were unable to collect information on any changes in health outcomes that might have resulted from faster blood product delivery.

We found that drone delivery was feasible in Rwanda. In terms of reducing delivery times, this was evident both when comparing drones with current practice (round trip) and with an alternative delivery mechanism using one-way road travel. We also found a significant decrease in blood unit expirations post-intervention.

Given our findings, we believe it is important that future studies aim to quantify the health impacts of this intervention and conduct a cost-effectiveness analysis, as drone delivery is at present more expensive than road delivery in Rwanda. In the future, drones could be an option to deliver other important and time-sensitive medical supplies, such as emergency drugs or any other pharmaceutical products.

Contributors

MPN led all aspects of this study, including conceptualisation, data curation, formal analysis, investigation, methodology, software, validation, visualisation, writing of the original draft manuscript, and further review and editing of the manuscript. PN contributed to conceptualisation, data curation, investigation, methodology, project administration, validation, and review and editing of the manuscript. KS, LN, PK, VD, JPM, and CM contributed to conceptualisation, investigation, and review and editing of the manuscript. SN contributed to conceptualisation, data curation, project administration, investigation, supervision, and review and editing of the manuscript. MRL provided direct supervision, and technical support to MPN from the beginning until the completion of the manuscript. MRL contributed to conceptualisation, funding acquisition, investigation, methodology, project administration, resources, supervision, software, validation, writing of the original draft manuscript, and further review and editing of the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication. MPN, PN, and MRL accessed and verified the data.

Declaration of interests

We declare no competing interests.

Data sharing

Our ethical approval from the National Rwanda Ethics Board only permitted data access by the research team. Descriptions of the data fields are provided in the Methods section and other publicly available information (eg, driving estimates and information on intervention hospitals) is provided either in the paper or in the appendix.

Acknowledgments

This study was funded by a Foundation Scheme Grant from the Canadian Institutes for Health Research (FDN-148412, to MRL). MPN is supported by the University of British Columbia 4 Year Doctoral Fellowship. MRL received salary support through a Canada Research Chair.

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