SUBJECT REVIEW

Use of Unmanned Aerial Vehicles for Medical Product Transport

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Abstract

Advances in technology and decreasing costs have led to an increased use of unmanned aerial vehicles (UAVs) by the military and civilian sectors. The use of UAVs in commerce is restricted by US Federal Aviation Administration (FAA) regulations, but the FAA is drafting new regulations that are expected to expand commercial applications. Currently, the transportation of medical goods in times of critical need is limited to wheeled motor vehicles and manned aircraft, options that can be costly and slow. This article explores the demand for, feasibility of, and risks associated with the use of UAVs to deliver medical products, including blood derivatives and pharmaceuticals, to hospitals, mass casualty scenes, and offshore vessels in times of critical demand.

Introduction

Earlier this year, a brewery in Wisconsin employed drones to deliver beer to ice fishermen on Lake Waconia.[1] This short-lived experiment was curtailed by the US FAA before the efficacy of the delivery method was proved, but the initiative shows a possible alternative to common delivery options for small packages.[2] However, as the FAA re-evaluates the current regulations and restrictions, larger companies, including Amazon, are actively researching the potential feasibility of UAVs for the transport of goods.[3] UAVs may soon be used to transport goods quickly, safely, and inexpensively across both accessible and inaccessible terrain such as to stranded mountain climbers or boats adrift. This presents medical providers with intriguing new possibilities for transportation in times of critical need and in routine circumstances. The possibility of using UAVs for commercial transport, medical transport, and disaster relief has been suggested, but no literature exists on the feasibility and potential applications of UAVs in the medical field.[4-8] Currently, medical supplies in the United States are delivered by ground transport as well as aircraft, both fixed and rotor wing. During emergencies, the availability of blood products and pharmaceuticals is often limited at critical access hospitals, and conventional channels of supply may become disrupted. This article aims to outline the demand, feasibility, and risks regarding the use of small UAVs (Fig. 1) to transport blood and pharmaceutical products to critical access hospitals, mass casualty scenes, and offshore vessels in times of critical demand.

Potential Applications

The prompt use of blood products, including packed red blood cells (PRBCs), plasma, and platelets, has been shown to save lives in bleeding trauma patients.[9-14] Although many critical access hospitals have blood products available, inventory is limited, and supplies of platelets and plasma are typically even more restricted than red cell products. A critical access hospital is defined as a hospital with 25 or fewer beds located at least 35 miles from another hospital via a primary road or 15 miles via a secondary road.[15] Level III trauma centers, although not synonymous with critical access hospitals, are often also located in rural areas and provide critical access to trauma patients in these regions. Since the early 1990s, the number of level III trauma centers in the United States has increased, but they have limited resources, especially centers in rural areas.[16] In addition, 46.7 million Americans still have no access to a level I or II trauma center within an hour from their homes, and an additional 81.4 million Americans would not, without helicopter services, have access to a trauma center within an hour from home.[17] Thus, even with the expansion of trauma centers in the past 2 decades, many Americans still have limited access and could potentially benefit from a higher level of local care.

Although a trauma center must have blood products immediately available, this supply is not unlimited, and large reserves typically are not on hand. Current standards of care recommend transporting patients who require transfusions to larger hospitals when resources, including blood products, are unavailable or limited. This is often a costly process and may delay appropriate initial care. Attempts have been made to alleviate this issue by transporting PRBCs and plasma with advance transport teams. Although innovative, the change does not overcome the significant operating cost of manned aircraft or the risks to flight crews traveling in remote areas. Furthermore, natural disasters and mass casualty incidents may occur in remote locations that require temporary blood

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Figure 1. Artist's rendering of a medical transport drone. (Reprinted with permission from the Mayo Foundation for Medical Education and Research.)

banks, and transportation can be a significant barrier to establishing these forward operating stations.

The ability of critical access hospitals to maintain an inventory of blood products is complicated by numerous factors, including shelf life and cost. Hospitals may have various types of PRBC products and 3 different types of plasma available to prevent delays in emergent transfusions. Although the shelf lives of PRBCs (42 days) and plasma (1 year) are relatively long, other products, such as platelets (5 days) and thawed plasma (5 days), may be wasted when the demand is low.[18] Critical access hospitals stock a restricted supply of blood products compared with large tertiary care hospitals (Table 1). In a patient with severe bleeding, a massive transfusion ($>$ 10 units in 24 hours or 5 units in 60 minutes) may be needed, which can often rapidly deplete a hospital's blood supply.[19] The average trauma patient undergoing massive transfusion requires an average of 22 units of PRBCs and 14 units of platelets, which is more PRBCs than most critical access hospitals stock.[20] Initial massive transfusion resuscitation also includes plasma, and critical access hospitals typically have a limited supply of this product.

Regional blood banks that supply critical access hospitals keep enough frozen blood on hand to meet regular demand. During times of high demand or possibly for only 1 patient with massive bleeding, the blood supply of a critical access hospital may become depleted and require intensive support from the regional blood center.[21,22] An example of this was during an earthquake in Bam, Iran. This event highlighted the inefficiency of the current process by which blood is distributed. Although 108,985 blood units were donated, only 23% of these units were actually distributed to hospitals. Interestingly, only 1.3% of the units were delivered to the disaster site within 4 days.[23] Although many factors can complicate a disaster response, it is clear that distribution, not supply, remains a critical problem.

Studies of similar events in the United States reinforce that a lack of blood products in times of natural disaster or mass casualty is often not the issue; rather, the logistics of distribution are the challenge. One study found that in only 4 cases in the past 25 years have more than 100 units of blood been used in the first 24 to 30 hours after a disaster in the United States.[21,23] In a review of recent disasters in the United States in which mass appeals often resulted in increased blood donations, significant delays were found in the distribution of these time-sensitive donations.[24] It is important to note that, because of screening and laboratory testing, blood is typically not usable on the date donated. Nevertheless, the ability to expeditiously shift blood products between centers to resolve shortages, without involving humans in the transport process, would improve patient care and reduce expenses.

Blood banks have safeguards and backup systems in place to prevent shortages in times of disaster or increased demand. One commonly used method is to keep a small supply of blood products on hand and then request blood, as needed, from regional blood banks or regional hospitals. Although this system helps decrease blood product wastage, reported wastage rates still range from 1% to 26%.[25] When increased demand occurs, blood products are then sent by courier, taxi, ambulance, or police vehicle.[26] The military uses more advanced methods, including refrigerated trucks, helicopters fitted underneath with sling loads, and parachutes, to deploy blood during combat situations. Ground transport is relatively inexpensive, but risks to personnel remain, and transport can be hindered by weather, road conditions, or the austerity of the environment. Conventional air transport by fixed or rotary wing aircraft is expensive and also puts the crew at risk. Although several trauma networks routinely send blood products with helicopter transport crews, this still requires the patient to then be transported to the regional center, putting both the crew and patient at additional risk.

Table 1. Example Inventory of Blood Products by Hospital Type

Minimum Inventory	Critical Access Hospital	Regional Hospital	Tertiary Hospital
PRBCs			
Type O positive	4-6	29	410
Type O negative[a]	2-4	12	115
Type A positive	4-6	29	351
Type A negative	2-4	8	83
Type B positive	2-4	10	69
Type B negative	0-2	4	83
Type AB positive	0-2	6	16
Type AB negative	0	2	4
Total	14-30	100	1,131
Plasma			
Type O	2	10	531
Type A	2	10	739
Type B	2	10	181
Type AB[a]	2	20	96
Total	8	50	1,547
Platelets	0	4	30
Cryoprecipitate			
Type O	0	2	84
Type A	0	2	82
Type B	0	2	20
Type AB[a]	0	4	13
Total	0	10	199

PRBCs = packed red blood cells.
[a]Type of blood used in an emergency (uncrossmatched) situation.

Because they are cost prohibitive, aircraft are not routinely used to transport blood products alone to the patient.

Therefore, the use of UAVs may have applications in the field of medicine. It is not uncommon for a critical access hospital to have a limited stock of medications and to have less varied medications compared with a regional hospital. Antivenom, for example, is rarely used, has a limited shelf life, and is expensive; thus, it is not practical to stock it in many hospitals. As a result, either the patient must be transferred to the product or the product must be shipped to the patient, which could cause significant delays in care. UAVs might fulfill the shipper role without risk to transport crews and without requiring the patient to be transferred. Similarly, medical devices such as external fixator devices, automatic defibrillators, combat gauze, and tourniquets may also be sent by UAV if a need were to arise (Table 2). The use of UAVs in natural disasters has been proposed by disaster relief organizations. However, this use also could be expanded to multicasualty events domestically. In these circumstances, UAVs could potentially be used to transport emergency medical supplies to local hospitals and even directly to the injured patients at the scene.

Our Experience

The current system in the United States for delivering blood products relies on a combination of regional suppliers and hospitals. The smallest critical access hospitals in our region, typically 4 to 12 beds, routinely stock 2 to 6 units of red cells in their inventory and no fresh frozen plasma or platelets. Larger critical access hospitals typically carry 14 to 30 units of red cells, 8 units of plasma, and no platelets or cryoprecipitate. These facilities do not use blood products as frequently, so it is not uncommon for hospitals to send blood that is nearing expiration (within 7-10 days of expiration) back to a larger hospital to prevent waste. Medium-sized hospitals (20-50 beds) in our region carry minimal plasma and no platelets. This results in a very limited supply that may not be enough to support significant hemorrhage or massive transfusion protocols. Typically, only regional facilities possessing 50 or more beds have extensive supplies of PRBCs, plasma, platelets, and cryoprecipitate (Table 1). Recognizing that rural America is served by these smaller medical establishments, it is apparent that the quality of care is affected by the cost and timeliness of blood product deliveries, and even the larger hospitals can run low on selected blood types.

Large regional hospitals typically receive shipments of blood daily, whereas smaller regional hospitals receive blood weekly at most. The regional hospitals rely on other larger hospitals or regional blood banks to restock their blood supply if they reach minimum levels between shipments. During regular business hours, blood is often delivered via courier services. For trauma or massive bleeding events, hospitals sometimes rely on the highway patrol to transport blood products from other centers. If a patient needs additional

Table 2. Availability of Selected Products Amenable to Delivery by UAV

Product	Mass Casualty Scene or Offshore Vessel	Critical Access Hospital	Regional Hospital	Tertiary Hospital
PRBCs	None	Minimal supply availability	Available	Routinely stocked
Plasma and platelets	None	Rare/none	Available	Routinely stocked
Prothrombin complex concentrate	None	Rare/none	Rarely stocked	Routinely stocked
Defibrillator	Occasionally	Routinely available	Routinely available	Routinely available
TXA	None	None	Rarely stocked	Routinely stocked
Trauma gauze and tourniquets	Rare	Minimal supply availability	Routinely available	Routinely available

PRBCs = packed red blood cells; TXA = tranexamic acid; UAV = unmanned aerial vehicle.

transfusions and blood is not available or the hospital is expected to use more than they have on hand, the patient will typically be transferred to a larger center. Some advanced transport teams, including air and some ground transport crews, have started to carry blood products. Our critical care transport team flies with 3 units of O-negative red cells and 3 units of type A–positive thawed plasma. They also stock medications such as tranexamic acid. Our advanced transport team makes about 2,000 flights per year and, in 2013, delivered more than 200 units of PRBCs and 200 units of plasma. Thus, the demand for prehospital access to blood products is clear.

Feasibility

Military drones can cost up to $60 million and require aviation experience to pilot.[27] In recent years, however, small rotary wing aircraft have been developed that are more affordable and require minimal training to operate. Commercial versions are available for $10,000. These vehicles may be manually controlled or programmed to fly specific routes or patterns. The functional capabilities of UAVs vary substantially depending on the model. Military fixed wing drones can fly at speeds over 100 miles per hour, but smaller rotary wing UAVs are typically limited to 40 to 60 miles per hour. Flight times and payload also vary considerably depending on the size of the UAV. Small commercial UAVs can typically carry a payload of approximately 5 lb for 30 to 60 minutes of flight time. The geographic range, depending on payload and fuel source, is thus limited to 20 to 60 miles for small commercial UAVs, although military UAVs have ranges up to 1,000 miles. Weather is also an important limiting factor in the utility of small UAVs, but larger UAVs have limitations similar to conventional aircraft. Because of their capabilities, UAVs are under consideration for use in a plethora of industries, including farming and package delivery, and are already being used for film production and police surveillance.

Traditional medical transport aircraft require either a runway or a helipad to land on, which are expensive to maintain and also require a significant amount of space. Cruise ships and other offshore structures such as oil platforms or remote islands, which have limited space for such aircraft to land, also typically have little to no availability of blood products. Thus, the delivery of blood products to such remote locations is typically limited to rotary wing aircraft, which still require a moderate amount of space to land. However, UAVs, depending on their size, require very little space to land, can (depending on the size of the UAV) be landed with little to no specialized facilities, and can even deploy packages from a low hover. Thus, they are ideally suited for this type of application. The use of UAVs to deliver blood products and medications to cruise ships, military vessels, and oil platforms merits further exploration.

Risk

Currently, the FAA prohibits commercial use of drones. This rule, however, is under review, and parameters of use are expected to be designated by 2015. By definition, UAVs do not have a pilot on board. Accordingly, they present fewer hazards to human life than manned aircraft. Although the risk of a crash injuring people on the ground persists, the size, light weight, and alternative fuel sources of these vehicles reduce impact-related perils. With respect to the existing medical product distribution system, fatal events resulting from rotary and fixed wing aircraft in medical transport are relatively rare.[28] However, 40 deaths per year still occur during medical transport in the United States, and most of these occur during ideal transport conditions.[29] In the United States, emergency medical services personnel have a fatality rate of 12.7 per 100,000 workers, more than twice the rate of the nation's average workforce, making this a very risky occupation.[30] Manned transport services perform an important role in the delivery of patient care, and these services will not be replaced in the near future. Their efforts may, however, be supplemented with unmanned deliveries to critical access facilities, thus reducing patient transfers and transportation costs while minimizing hazards to human life.

Before UAVs are deployed to transport medical products, some risks need to be carefully assessed, including aviation concerns from the crowding effect of proliferating UAVs. In addition, blood products must be packaged in a manner that ensures minimal risks of exposure and tampering during transit, and protections must be implemented to prevent unauthorized interception of controlled substances. Patient privacy and Health Insurance Portability and Accountability Act regulations also must be considered.

Conclusion

When new FAA regulations are issued, it is reasonable to expect that American entrepreneurialism will fully exploit the limits of UAVs. We anticipate that unmanned airborne package delivery systems will be a financially and technically feasible mode of transport for the civilian sector in the near future. Disaster relief and commercial transport may be the best circumstances for early trials to assess the feasibility of UAVs for medical product transport.

In the resource-intensive environment of a disaster, speed is valued, and the special capabilities of UAVs, including the capacity to travel over closed roads and terrain without risk to a flight crew, are particularly valuable. Our preliminary conclusions suggest that the use of UAVs could be a viable mode for the transport of medical products in times of critical shortage. The full potential, effects, and usefulness of UAVs regarding medical transport are still unknown but have promise. Although the exact cost of a commercial UAV program is still largely unknown, it most likely would be significantly lower than that of conventional medical transport. The role of UAVs for medical transport is promising, but further research to assess the feasibility, demand, and safety of UAVs is warranted.

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