AUTONOMOUS VEHICLES

Testing the delivery of human organ transportation with drones in the real world

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Last-mile transportation of human donor lungs in a densely populated urban environment has been made possible with drones.

For patients in need of a life-saving transplant, organs are in short supply. The moment an organ is removed from the human body, it begins to rapidly deteriorate. Failure to deliver and transplant an organ in a timely manner can result in a missed opportunity to save a life. Historically, organ transport has relied on standard ground and air transportation. Although these methods are satisfactory, they are risky, inefficient, and expensive (*1*). Significant delays persist and are exacerbated by road traffic and transportation availability in metropolitan areas. In an effort to improve and innovate organ delivery (*2*–*3*), we validated the process of donor lung transportation via remote piloted aircraft system (RPAS) in controlled airspace over the densely populated urban environment of downtown Toronto, Canada in September 2021.

THE DRONE

The base RPAS technology used for this flight was the M600 Pro drone by DJI (Shenzhen, China). Transplant-specific modifications to the drone were completed by Unither Bioelectronics (Quebec, Canada) and included the removal of the landing gear and payload rack to accommodate the installation of a specially designed lung transport box (Fig. 1). Additional modifications to the electronic systems were performed to enhance digital communication and connectivity of the drone in the downtown environment and avoid the many interfering signals. Several additional safety features were incorporated into the drone, including an ASTM-qualified parachute recovery system and multiple cameras, lights, and GPS trackers. The entire system, including the lung transport box and organ, was designed to weigh no more than 25 kg at takeoff.

THE LUNG TRANSPORT BOX

Although light in weight, lungs are large, fragile organs that require tremendous care during transportation (*4*–*5*). Given a maximum takeoff weight allowance and the fixed weight of the RPAS base, we designed and constructed a lightweight carbon fiber transport box. It could accommodate human lungs of any size and weight—a key feature given that the exact weight of the organ to be used for transplant could not be known at the time of design. In addition, the transport box maintained an internal temperature of about 4°C with appropriate cooling materials, had a burst strength ≥200 pound-force, and minimized vibration. Importantly, we performed extensive testing with the transport box in both flight and laboratory settings to confirm the performance features before proceeding with the organ flight.

With the successful delivery of kidneys (*6*–*7*) and now lungs, the development of a universal transport system for all organs is within reach. A transport box that adapts to the temperature, size, and weight constraints of each organ is critical to realize RPAS potential. Moreover, simultaneous transport of multiple organs will further enhance the adoption of RPAS technology in transplant medicine. Given that lungs are the most challenging donor organs to transport, the transport box described here may serve as a template for future technical developments.

FLIGHT OPERATIONS AND ROUTE

Flight testing began in 2019, and more than 400 test flights and 50 flight hours were performed. RPAS takeoff was from the Toronto Western Hospital (TWH) rooftop (43.653°N/79.405°W), and landing occurred at the Toronto General Hospital (TGH) rooftop (43.658°N/79.389°W). Neither hospital was equipped for aircraft, so we constructed customized 3.66 m–by–3.66 m RPAS pads that provided consistent digital positioning during takeoff and landing and elevated the drone above any physical or electronic rooftop disturbances. The total flight time took about 5 min to cover the 1.5 km through downtown Toronto. The drone was remotely piloted using customized FlytNow software (FlytBase Inc., USA) co-developed between FlytBase and Unither Bioelectronics that included manual backup systems. There were copilots stationed at the takeoff and landing sites and a pilot in command at a waypoint with direct visibility over the entire operation.

ENVIRONMENTAL CONDITIONS AND SAFETY PROTOCOLS

The proof-of-concept flight was constrained to ideal environmental conditions that included no precipitation, ≥5-km visibility and ≥1000-m ceiling, and a maximum flight altitude of 120 m. Temperature (between −10° and 40°C) and wind (≤4 m/s) conditions were also restricted.

The flight was performed within visual line of sight as per Transport Canada regulations. Additional emergency landing

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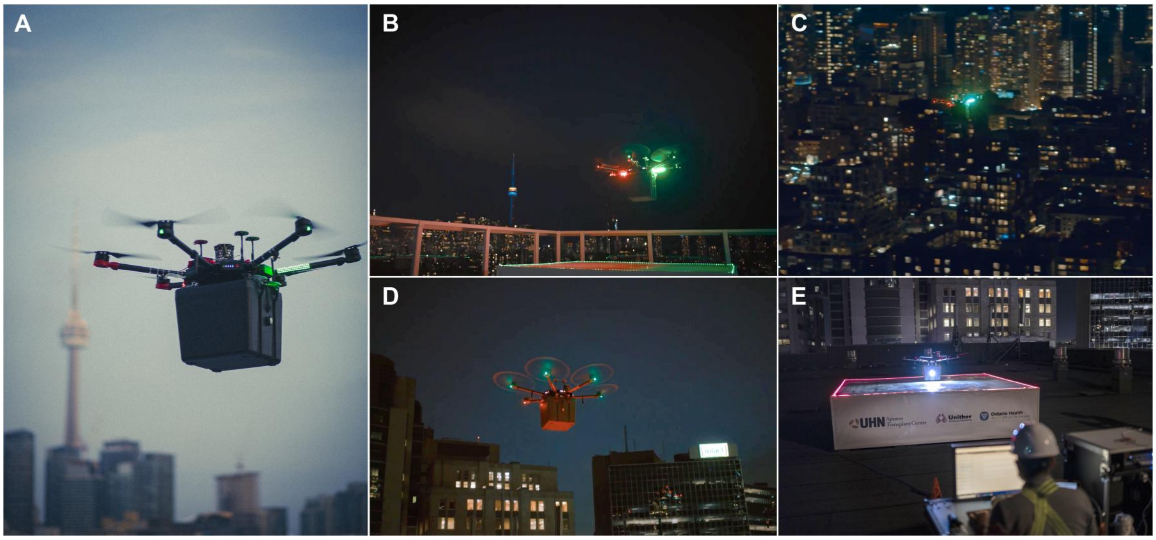

Fig. 1. Delivery of donor lungs via drone. Images of the drone used to deliver human lungs for transplant during (**A**) test flight, (**B**) takeoff from TWH, (**C**) mid-flight over Toronto, (**D**) landing approach, and (**E**) landing at TGH.

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points were established along the predefined flight path, and the pilot in command had the ability to intervene and control the aircraft at any point in time. Visual observers were present along the route, and a ground safety vehicle was placed on standby in case of emergency. In the event of a catastrophic failure, an emergency stop that enabled the deployment of a parachute system was in place and previously tested.

FLIGHT AUTHORIZATIONS

Coordination among the various stakeholders was pivotal to this project's success. The necessary ethics approvals were obtained from our institution (University Health Network, Toronto, Canada). Collaboration with TGLN (Trillium Gift of Life Network; responsible for the management of all organ donors in Ontario) was instrumental in the planning and execution of the organ procurement logistics. The flight took place in controlled Class C airspace, and thus, all RPAS activities were under the auspices of Transport Canada Civil Aviation Regulations and required air traffic services approval by NAV CANADA. Given the proximity (0.2 km) of a nearby helipad, a notification mechanism was established to ensure that all airspace users were aware of RPAS activity.

TRANSPLANTATION AND FOLLOW-UP

The recipient was a 63-year-old patient with idiopathic pulmonary fibrosis. At the takeoff and landing sites, donor lungs were inspected by a thoracic surgeon. The operating room (OR) team was placed on standby waiting for the arrival of the lungs. Surgery immediately followed RPAS landing and organ transfer to the TGH OR. Drone delivery of the organ had no impact on the surgical procedures performed in the OR. After lung transplantation, the patient had a routine postoperative course. They were extubated 1 day after transplant and discharged from intensive care 2 days after the surgery.

CONCLUSIONS AND FUTURE PROSPECTS

The use of drones to transport donor organs is safe and effective (*6*–*7*). This flight demonstrates a successful approach to last-mile delivery logistics over a densely populated urban area and, together with reports of drone delivery of medical supplies in other settings, including rural areas (*8*), enables RPAS-based organ transport anywhere.

Concurrent with the development of centralized, high-volume organ repair centers (*2*), the demand for an efficient organ transportation network is high. Thus, RPAS technology is likely to see early adoption in these locations (i.e., American Northeast, Southeast, and Ontario, Canada). Permanent installation of drone-specific aerial routes requires further collaboration and authorization with aviation authorities and is the near-term goal of the field. As organ procurement geographies expand, transcontinental delivery routes should be established with the goal of achieving a global supply network for organs using RPAS technology.

The challenges related to multimodal transportation of organs can be overcome using drones. The ability to fly, uninterrupted, from donor to recipient hospital is an attractive alternative to a combination of planes and busy airports with automobiles and city traffic. Even for short trips between nearby hospitals, drones offer a reliable transportation method that overcomes typical city congestion. Thus, it is likely that all donor organs will be delivered by drone in the future, irrespective of distance from the transplant hospital.

Automated aircraft represents the future of travel: The ability for vertical takeoff and landing enables flight to and from almost any building, and autonomous control negates the need for highly specialized pilots (*9*). RPAS systems will continue to evolve and exceed current weight and distance limitations. With the support of regulatory agencies, larger RPAS aircrafts flying outside visual line of sight will soon be possible (*9*). Drone flight represents a faster, more economical, more controlled, environmentally friendly, and safer alternative to traditional transportation methods—a transformative approach to organ transplantation, a medical speciality where minutes matter.

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Competing interests: S.K., M. Cypel, and M. Cardinal have filed patents related to the transport box and fully adhere to policies in place at University Health Network that ensure academic integrity and management of potential conflicts of interest between authors and industry partners. All other authors declare that they have no competing interests.

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