LETTER TO THE EDITOR

The final frontier? Exploring organ transportation by drone

To the Editor:

1 | ROOM FOR IMPROVEMENT

Technical, immunologic, and patient care advancements have improved transplant outcomes, but geography and organ transportation remain impediments to access to transplantation. Organs are moved using a complex network of couriers, commercial aircraft, and transplant personnel. Reliance on commercial aircraft schedules and couriers add cold ischemia time (CIT) and may prohibit transplantation altogether.¹ Private charters can be used; however, this comes at great expense. If transplantable organs were moved by unmanned aircraft systems (UAS), or drones, ill-timed commercial flights or expensive charters could be avoided, improving access to transplantation.²,³

A discussion of transportation innovation is timely. Recent kidney allocation system (KAS) changes allowing for greater organ sharing (Table 1) have increased access to transplantation, particularly for sensitized patients.¹,⁴ However, with increased sharing, the average distance traveled by a kidney has increased significantly. For some kidneys (eg, high calculated panel reactive antibody kidneys) the distance has increased 60% to 706 miles.¹ CITs have also increased and more than 22% of kidneys are now transplanted after 24 hours. As a result, delayed graft function (DGF) rates increased from 25% to 31%.¹ More efficient transportation might allow for the benefits of the new KAS without sacrificing CIT or increasing DGF rates.

2 | INNOVATIONS

To begin exploring organ drones, we partnered with the University of Maryland UAS test site. Furthermore, we developed several novel technologies (eg, HOMAL, Human Organ Monitoring and Quality Apparatus for Long-Distance Travel, patent pending) to monitor organ status (temperature, pressure, and vibration) and location during UAS flight. Following consent and Institutional Review Board approval, we obtained a 57-year-old deceased donor kidney. The total CIT at allocation was 19.0 hours, the creatinine was 0.5 mg/dL, and the Kidney Donor Profile Index was 70%. The organ was loaded onto a DJIM600 drone (Figure 1A, B). These data were then pushed to a ground-based server, and thereafter to the users’ smartphones in real-time.

3 | DRONE FLIGHTS

We performed a series of HOMAL validation studies during which the organ drone was slowly and/or rapidly accelerated. Thereafter, we tested the stability of the organ drone in hover at altitudes of 100 and 200 feet (Figure 1C; see supplementary video file online). Next, a total of 14 distance organ drone missions were flown at speeds ranging from 30 to 42 miles per hour over distances of 1.5-3.0 miles. Kidney biopsies taken before and after drone flight were read by a senior kidney transplant pathologist and failed to show damage related to extrinsic forces.

Organ drone findings were then compared with fixed-wing flight (Figure 1D). During fixed-wing flight, the organ experienced more vibration (>2.0g) than during drone travel (<0.5g, \( P < .01 \); Figure 1E). These differences were most prominent during takeoff and during landing. A full report of these findings will be published in the engineering literature.

4 | HOW MIGHT DRONE FLIGHT AFFECT THE FUTURE OF TRANSPLANTATION?

It is unclear how many additional deceased donor kidneys could be transplanted if organ drones were implemented. However, approximately 20% of kidneys in the United States are discarded. While data are unavailable, it is likely that a portion of these would be accepted

<table>
<thead>
<tr>
<th>Before KAS</th>
<th>After KAS</th>
<th>% Change</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>8569</td>
<td>78.6</td>
<td>7805</td>
</tr>
<tr>
<td>Regional</td>
<td>961</td>
<td>8.8</td>
<td>1450</td>
</tr>
<tr>
<td>National</td>
<td>1371</td>
<td>12.6</td>
<td>2141</td>
</tr>
</tbody>
</table>

Changes in organ sharing observed with the new KAS. There is significantly more regional and national kidney sharing. Fewer kidneys are transplanted locally. Data taken from www.unos.org.

TABLE 1 Geographic sharing of organs based on changes to the kidney allocation system (KAS) in the United States
A, Deceased donor organ loaded onto MDJI600 drone. B, Graphical User Interface for HOMAL component showing real-time organ-level data. These data were also pushed to users’ smartphones. C, Image of packaged organ and fixed-wing aircraft used to test differences between drone and standard flight. D, Telemetry data from the environmental monitoring and location-tracking sensors embedded in the OTMS transport box. A, B, and C represent plots of vibration, travel distance, and altitude, throughout the UAV flights, respectively. Periods 1-4 (highlighted in gray) represent high vibration periods occurring in various flight pattern tests: (1) vertical takeoff and rapid descent, (2) vertical takeoff and rapid ascent/descent cycles, (3-4) vertical takeoff and long-distance (3 km) transport test. E, Vibration recordings from the organ sensor module during transport on a fixed-wing aircraft. Periods of distinct vibration patterns can indicate flight phases.
if faster travel (and thus shorter CITs) was available. Beyond kidneys, similar extrapolations could be calculated for liver, pancreas, and thoracic transplants.

There are several additional major hurdles to overcome ahead of organ drone transportation. The first is speed. Drones can be engineered to fly from hospital-to-hospital, unlike an airplane. Thus, if a civilian drone were capable of traveling 350 miles per hour (similar to fixed-wing), an organ could move from Miami to Baltimore (1098 miles) in 3.1 hours. Drones that travel >100 mph have been developed, but they cannot support an organ payload. Secondly, federal regulations do not yet allow for civilian drone use beyond line-of-sight; however, there is significant discussion this will soon change.

In this exploratory study, our drones traveled too slowly to move an organ long distances. However, these data are proof-of-principle that organs can be safely moved by drone. We modeled the shipment of an organ between 2 nearby centers. Such transport may be beneficial in cities where couriers, traffic, and organ loading add precious unnecessary CIT. Indeed, small trips such as these may be an important first step for organ drone transportation.

With ongoing investigation, organ transportation innovation has the potential to revolutionize transplantation through significant CIT reduction. A coordinated effort by transplant stakeholders including entrepreneurs and policymakers will be needed to make this a reality.

DISCLOSURE

The authors of this manuscript have conflicts of interest to disclose as described by the American Journal of Transplantation. Dr. Scalea is the recipient of 2 patents and a seed grant through the office of technology transfer at the University of Maryland, Baltimore, and he is the recipient of a Maryland Innovation Initiative Grant through TEDCO. The other authors have no conflicts of interest to disclose.

Keywords

organ transplantation in general, translational research/science

Joseph R. Scalea 1
Stephen Restaino 2
Matthew Scassero 3
Stephen T. Bartlett 1
Norman Wereley 4

1 Division of Transplantation, Department of Surgery, University of Maryland, Baltimore, MD, USA
2 Maryland Development Center, Baltimore, MD, USA
3 University of Maryland UAS Test Site, California, MD, USA
4 Department of Aerospace Engineering, University of Maryland, College Park, MD, USA

Correspondence

Joseph R. Scalea, Division of Transplantation, Department of Surgery, University of Maryland, Baltimore, MD.
Email: jscalea@som.umaryland.edu

REFERENCES


SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.