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Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

The use of drones for the delivery of diagnostic test kits and medical supplies to remote First Nations communities during Covid-19



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Funding/support: This research is generously supported by the World Health Organization (WHO) Research and Development Blueprint—COVID-19 Infection Prevention and Control Pillar, and in part through the University of Calgary Infectious Disease Research and Development Fund for COVID-19 and the Nickle Family Foundation. Open access of this article is sponsored by the World Health Organization.

Conflicts of interest: JMC holds grants from the Canadian Institutes for Health Research on acute and primary care preparedness for COVID-19 in Alberta, Canada and was the primary Local Investigator for a Staphylococcus aureus vaccine study funded by Pfizer for which all funding was provided only to the University of Calgary. He is co-investigator on a WHO funded study using integrated human factors and ethnography approaches to identify and scale innovative IPC guidance implementation supports in primary care with a focus on low-resource settings and using drone aerial systems to deliver medical supplies and PPE to remote First Nations communities during the COVID-19 pandemic. He also received support from the Centers for Disease Control and Prevention (CDC) to attend an Infection Control Think Tank Meeting. He is a member and Chair of the WHO Infection Prevention and Control Research and Development Expert Group for COVID-19 and a member of the WHO Health Emergencies Programme (WHE) Ad-hoc COVID-19 IPC Guidance Development Group, both of which provide multidisciplinary advice to the WHO and for which no funding is received and from which no funding recommendations are made for any WHO contracts or grants. He is also a member of the Cochrane Acute Respiratory Infections Working Group. This work was partially supported by the Canadian Forces Medical Services and the Andrew W Kirkpatrick Professional

Corporation. AW Kirkpatrick has consulted for the Zoll, Acelity (3M/KCI), CSL Behring, Innovative Trauma Care and SAM Medical Corporations, and the Statesman Group of Companies, and is the PI of a randomized trial partially supported by the Acelity Corporation. No other authors have conflicts to disclose.

Author contributions: Kristin Flemons: Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration; Barry Baylis: Conceptualization, Writing - Original Draft, Writing - Review & Editing, Supervision, Funding acquisition; Aurang Zeb Khan: Conceptualization, Investigation, Supervision, Project administration, Funding acquisition; Andrew W. Kirkpatrick: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - Review & Editing, Supervision, Funding acquisition; Ken Whitehead: Investigation, Writing - Review & Editing; Shahab Moeini: Conceptualization, Methodology, Investigation, Writing - Review & Editing; Allister Schreiber: Conceptualization, Methodology, Validation, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing; Stephanie Lapointe: Conceptualization, Methodology, Validation, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing; Sara Ashoori: Conceptualization, Methodology, Writing - Review & Editing; Mishal Arif: Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing; Byron Berenger: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition; Wade Hawkins: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition.

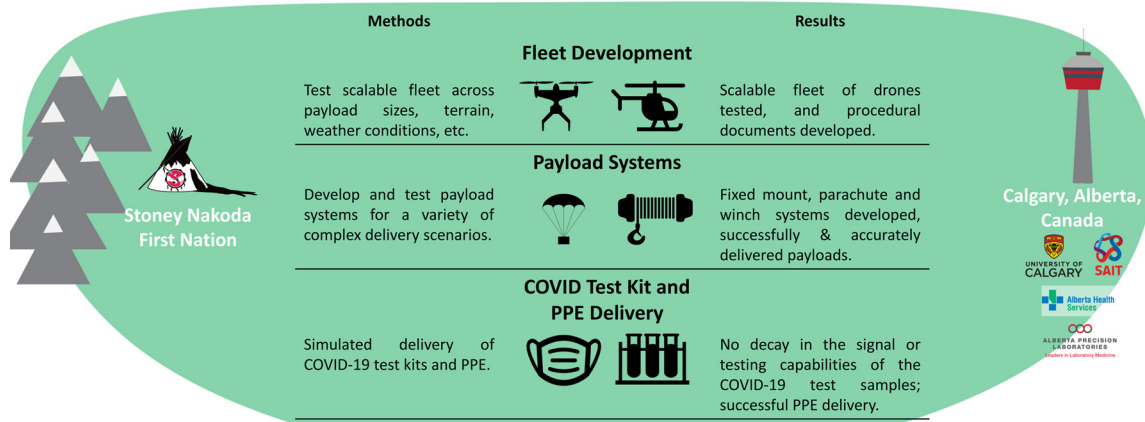
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<https://doi.org/10.1016/j.ajic.2022.03.004>

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THE USE OF DRONES FOR THE DELIVERY OF SUPPLIES, MEDICAL EQUIPMENT, DIAGNOSTIC TESTING, AND MEDICAL TREATMENTS TO REMOTE FIRST NATIONS COMMUNITIES IN ALBERTA

Background: Healthcare inequity in remote and rural Indigenous communities often includes difficulty accessing healthcare services and supplies. Drones offer a potentially cost-effective method for reducing inequity by removing geographic barriers, increasing timeliness, and improving accessibility of supplies, equipment, and remote care. Scalable solutions require robust collaborations between local communities, health services, technical operations, and academic partners.



Conclusion: Within collaborative partnerships, drone-based medical delivery models offer an innovative approach to addressing longstanding issues of healthcare access and equity and are particularly relevant in the context of COVID-19.

Key words:

Remotely piloted aircraft systems
Drones
Health care access
SARS-CoV-2
Remote ultrasound

A B S T R A C T

Background: Health care inequity in remote and rural Indigenous communities often involves difficulty accessing health care services and supplies. Remotely Piloted Aircraft Systems, or drones, offer a potentially cost-effective method for reducing inequity by removing geographic barriers, increasing timeliness, and improving accessibility of supplies, equipment, and remote care.

Methods: We assessed the feasibility of drones for delivery of supplies, medical equipment, and medical treatment across multiple platforms, including drone fleet development and testing; payload system integration (custom fixed-mount, winch, and parachute); and medical delivery simulations (COVID-19 test kit delivery and return, delivery of personal protective equipment, and remote ultrasound delivery and testing).

Results: Drone operational development has led to a finalized, scalable fleet of small to large drones with functional standard operating procedures across a range of scenarios, and custom payload systems including a fixed-mount, winch-based and parachute-based system. Simulation scenarios were successful, with COVID-19 test swabs returned to the lab with no signal degradation and a remote ultrasound successfully delivered and remotely guided in the field.

Discussion/Conclusions: Drone-based medical delivery models offer an innovative approach to addressing longstanding issues of health care access and equity and are particularly relevant in the context of SARS-CoV-2.

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The COVID-19 pandemic has highlighted multiple gaps in health care systems across the globe. Supply chain issues have caused global shortages of essential supplies, such as personal protective equipment (PPE) and testing supplies.¹ Timely access to COVID-19 testing and vaccination have likewise defined communities' ability to prevent, detect, and respond to the pandemic's spread. These issues have been exacerbated in populations already experiencing inequality in access to health care services and supplies, such as Canada's First Nations, Inuit, and Métis communities. In Canada, the rate of reported cases of COVID-19 among Indigenous people living on a reserve is currently 4.3 times higher than in the general population.² For rural and remote Indigenous communities, health care inequities often require members to travel to off-reserve locations which delays access, is burdensome and costly, and in the context of the COVID-19 pandemic, increases the risk of transmission with travel.³

Remotely Piloted Aircraft Systems (RPAS), or drones, offer a potentially cost-effective method for reducing health care inequities by removing geographic barriers, increasing timeliness, and improving accessibility of supplies, equipment, and remote care during the pandemic. In addition, the potential for drones to improve health equity and access extends beyond the boundaries of the pandemic. Reducing the need for burdensome travel, expanding the capacity of health services for both routine or emergency services, and providing access to specialists via drone-based technologies are just a few of the possibilities for remote community priorities. For remote and rural Indigenous communities, drones may also improve their ability to reach and serve members who live at greater distances from centralized communities and services. Many communities face geographic barriers such as seasonal lack of road access (eg, closures due to winter storms, or due to the need for ice roads). Likewise, for fly-in

only communities (remote and isolated communities without road access, or who rely on ice roads which are passable only in winter), drones may offer more responsive and affordable access to supplies and services.

Successful drone delivery of essential supplies, equipment, and treatment requires innovation at several levels, including the airspace regulatory environment for Beyond Visual Line of Sight (BVLOS) flight⁴; adequate safety procedures for different terrains and weather conditions; the use of appropriate drones suited to various conditions; procedures to safely land a drone in remote locations; and payload transport and delivery systems. When transporting medications or diagnostic samples, the flight itself must not interfere with the integrity of the payload contents or present a risk to the public. In addition, when providing remote diagnostics or telemedicine services, the recipient must be able to successfully retrieve the payload and operate its contents.

Given this background, and with the established expertise of the Centre for Innovation and Research in Unmanned Systems (CIRUS) at the Southern Alberta Institute of Technology (SAIT), we sought to develop a multi-pronged project with the following objectives: (1) to co-develop a governance structure to ensure that procedures and operating manuals meet the needs of the Stoney Nakoda Nation’s communities; (2) to demonstrate the potential of drone-delivered technology and supplies in diagnosis, evaluation, and treatment with a focus on COVID-19; (3) to develop and deliver a custom educational drone operation training program for Stoney Nakoda Nation members; and (4) to use this work as a scalable model for a fully operational drone-based medical delivery system. This paper focuses on progress towards the first 2 objectives; work on objectives 3 and 4 is ongoing.

METHODS






Setting: The project is a collaboration between multidisciplinary partners from the University of Calgary’s W21C Research and Innovation Centre, the Southern Alberta Institute of Technology (SAIT), Stoney Nakoda Nation (Morley, Eden Valley, and Big Horn First Nations [SNN]), Alberta Health Services (AHS), the Alberta Public Health Laboratory (ProvLab), and the TeleMentored Ultrasound Supported Medical Interventions (TMUSMI) Research Group. Project goals and operations were co-developed with SNN to ensure that community priorities and interests were served by the project, and that the proof-of-concept testing would move towards concrete benefits and eventual community ownership of drone-based services. Ongoing feedback and iterative adjustments are an integral part of the collaborative model.

The methods employed for drone operations and medical delivery simulations in the setting described included: (1) drone fleet development and testing; (2) payload system development and integration; (3) PPE delivery and COVID-19 test kit fidelity; and (4) remote ultrasound functionality.

Drone fleet development and testing

To ensure a scalable fleet capable of serving specific community and industry needs, we sought to test a variety of drone models across several application areas; multiple topographic, seasonal, and weather conditions; payload systems; and remote landing capabilities. The drone fleet was separated into 3 main categories for testing and evaluation: (1) short duration, low payload, (2) medium endurance, medium payload, and (3) high endurance, heavy/large payload (Table 1).

Table 1
Drone fleet development details

Endurance	Short Endurance (<30 min flight time)	Medium Endurance (30-45 min flight time)	High Endurance (45 min - 3 h flight time)
Payload	Low Payload (<1 kg)	Medium Payload (1-8 kg)	High Payload (8-45 kg)
RPAS examples	DJI Mavic Enterprise	DJI Matrice 300	SwissDrone SDO 50 V2
			
		DJI Matrice 600	UKRspecsystems PD-1
			
Operating Temperature	-10°C to 40°C	-20°C to 40°C	-25° to 40 °C
Operating Range	8 km	Matrice 300-15 km Matrice 600-8 km	SwissDrone – 300 km PD-1 – 800 km
VLOS/BVLOS testing completed	Flown within VLOS and EVLOS	Flown within VLOS and EVLOS	VLOS, EVLOS and BVLOS
Payload delivery systems tested	Fixed mounted payload - neoprene sleeve	Fixed mounted payload and winch system	Fixed mounted payload
Unit Cost	\$2,000	\$7,000 - \$15,000	\$200,000 - \$600,000

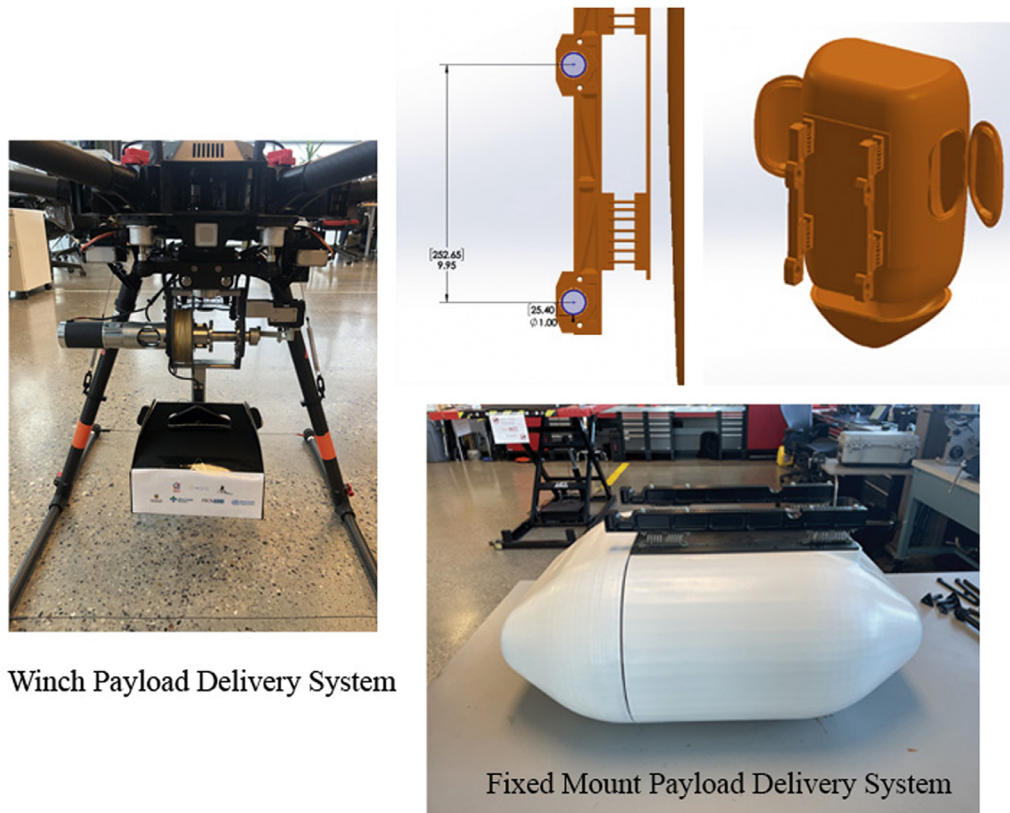


Fig 1. Winch and fixed mount payload systems.

Each drone was evaluated based on several metrics such as ease of use, flight duration (time), flight distance, payload system and capacity, flight performance in different topographic environments (ie, flat, river valleys, foothills, mountains), and a variety of weather conditions (wind speed and direction, precipitation, temperature, and humidity). Results of these tests are iteratively incorporated into Standard Operating Procedure (SOP) documents developed by the team.

Gaining permission to operate BVLOS is an ongoing core project goal, which would enable the delivery of medical supplies and equipment across larger geographic regions and thus increase the impacts of medical drone delivery for remote communities. The team has progressively built towards BVLOS flight by first planning missions using Visual Line of Sight (VLOS), and using the SOPs generated from these missions for Extended Line of Sight (EVLOS, using ground observers) and ultimately BVLOS operational procedures and protocols. Detailed discussion of drone fleet development, including procedural development and testing, flight operations development and testing, and Detect and Avoid System Testing, are provided in [Appendix A](#).

Custom payload system development and integration

Many complex scenarios may be encountered during the delivery of medical supplies and equipment, necessitating planning for multiple payload delivery systems to support all scenarios. Each system focused on the aircraft and the remote delivery location. Methodology was developed to support fixed mount, winch, and parachute delivery systems ([Fig 1](#)). Detailed methods may be found in [Appendix B](#).

PPE delivery and COVID-19 test kit fidelity

PPE delivery

A simulation was planned to develop procedures for delivery of medical supplies and identify issues with payload packing, flight, and delivery. SOPs and BVLOS procedures described in previous sections and appendices were employed for this mission. The SwissDrone SDO 50 V3 was chosen for this mission based on its high endurance and large payload capacity (>45 kg), which allowed for a larger amount of PPE supplies to be delivered.

Prior to the flight, the PPE (including gloves, gowns, face shields, and medical masks) were repackaged to reduce their space requirements within the payload container. The payload was removed, and the drone returned to the take-off zone. Factors such as ease of loading, payload capacity, ease of payload removal, and flight dynamics were evaluated and incorporated into SOPs.

COVID-19 test kit fidelity

Two simulation experiments were planned to determine whether COVID-19 diagnostic samples would suffer any degradation as a consequence of being transported via drone flight. To avoid shipping infectious material, samples were spiked with SARS-CoV-2 RNA and a MS2 bacteriophage (to mimic whole virus), which are not infectious to humans or animals ([Table 2](#)). Detailed methods are outlined in [Appendix C](#). Upon return to the lab, the samples were tested as per Pabbaraju et al.⁵

During the first test flight, a positive control vial was planned to be kept refrigerated at ProVLab Alberta, while the test vial was delivered to the drone on ice and returned to the lab on ice postflight (45-minute transit time each direction, with 2 hours total time at site). There was no additional refrigeration in the drone payload

Table 2
Results of COVID-19 test kits flown via drone versus controls

	Media	Copies/mL of E gene RNA or MS2 dilution	E gene		MS2	
			Control (no flight) Sample Ct	Drone Sample Ct	Control (no flight) Sample Ct	Drone Sample Ct
Experiment 1	Saline	3.31x10 ⁷ E gene RNA	25.14	22.26	Target not Included	
	Saline	3.31x10 ⁶ E gene RNA	27.82	26.51		
	Saline	3.31x10 ⁵ E gene RNA	30	28.94		
	UTM	10 ² MS2 phage	Target not Included		19.71	20.06
	UTM	10 ³ MS2 phage			23.44	23.38
Experiment 2	Saline in Duplicate	3.31x10 ⁶ E gene RNA + 10 ¹ MS2 phage	24.96	25	16.38	16.68
			24.98	24.92	16.63	16.3
	Saline in Duplicate	3.31x10 ⁴ E gene RNA + 10 ³ MS2 phage	33.13	33.51	23.3	23.63
			34.39	34.58	23.55	23.67

compartment. Upon return to the testing laboratory, samples were kept refrigerated until testing, which occurred within 36 hours of the flight. For the second test flight, control and test samples were picked up together and transported to the drone takeoff site without ice (45 minutes each direction). The control sample remained on the ground while the test sample was flown in the drone payload container (42 minutes flight time). The samples were then returned to the lab together without refrigeration and tested simultaneously immediately upon return.

Remote ultrasound functionality

This simulation was conducted to assess the feasibility of using a drone to deliver portable imaging equipment (Philips Lumify portable ultrasound) and a communication device (cellular phone) to facilitate the remote telementoring of an ultrasound-naïve volunteer in conducting a self-examination (University of Calgary REB14-0634). The volunteer was not a health care worker and had previously received no relevant medical training. The full methodology of this simulation is described in detail in Kirkpatrick et al.²⁹

RESULTS

Drone fleet development and testing

We successfully developed a drone fleet capable of supporting several medical-related operations at a range of capabilities and costs (Table 1).

Procedural development and testing

Procedural documents were successfully developed, tested and refined over the course of 30 missions and over 100 flights throughout southern Alberta.^{6,7} Missions were conducted across all 4 seasons. Digital and hard copy SOP documents were developed supporting each drone, payload system, and flight operation (ie, VLOS, EVLOS, BVLOS). Each SOP references the Canadian Aviation Regulations and contains checklists (ie, site survey, preflight, and postflight), and mission mapping and safety details.⁸ In addition, each SOP integrated AHS and SAIT COVID-19 safety requirements.

Special Flight Operations Certificate⁹ and Specific Operations Risk Assessment¹⁰ documents were created in support of BVLOS approval as certified by Transport Canada. These documents were submitted to Transport Canada, who approved preliminary BVLOS operation.

Flight operation development and testing

Drone operators conducted several VLOS flights where the drone stayed within visual sight (<1 km) of the pilot. At the completion of each mission, SOPs were refined with a focus on crew management. Following VLOS operation, EVLOS missions were conducted to

simulate a BVLOS mission. Leveraging spotters and continuous communication via cell phone and radio, the drone was flown up to 45 km away from the operations crew. Additional VLOS flights were conducted to verify risk along BVLOS flight routes, streamline procedures, and to train the Pilot-in-Command, Visual Observer, and operations team. At the completion of each VLOS mission, procedures were refined to support future EVLOS missions. We conducted several EVLOS flights along the Ghost Reservoir with distances ranging between 20 km and 45 km. Visual Observers with cell and radio communication were positioned along the route and communication was maintained during the entire operation. Operational procedures were refined following the completion of each mission. After completing several VLOS and EVLOS missions, we gained preliminary BVLOS certification through Transport Canada to operate at Foremost Unmanned Aircraft Systems (UAS) Test Range.

While the development and testing of the drone fleet revealed potential limitations in the ability to land the drone at locations more than 1,500 m away from the pilot using the standard command and control (C2) links, other technologies such as aerial repeaters, mobile data links, or satellite control links capable of providing continuous C2 coverage to the remote ground location alleviated this concern. The use of winch and parachute drop successfully mitigated this issue as the drone remained in radio line of sight and the C2 link remained stable.

Detect and avoid system testing and refinement

The team purchased, installed, and tested the Iris Automation Casia I, a computer vision Detect and Avoid (DAA) system—an artificial intelligence (AI)-based optical system that provides increased situation awareness to the drone crew. Several flights were operated throughout Alberta using a series of visual observers who scanned the airspace while the drone and DAA system were in operation. Airborne objects such as birds and other drones were introduced to evaluate the effectiveness of the DAA system. Testing included 15 operations around the city of Calgary; approximately 25 hours of flight tests and 3-day missions in a restricted airspace area; and a successful mission to SNN in July 2020. Test flights were conducted in VLOS, EVLOS, and BVLOS operations.

Custom payload system development and integration

Development (digital design, fabrication, airworthiness testing) of custom fixed-mount payload systems for long-range medical delivery was completed using high endurance drones, including a refrigerated unit and winch system (Fig 1). The custom payload container was mounted on the SwissDrone and successful field testing was completed, ensuring functionality and airworthiness for VLOS, EVLOS, and BVLOS operations. The container was capable of carrying supplies in individual containers with refrigeration capabilities to 4⁰ C.

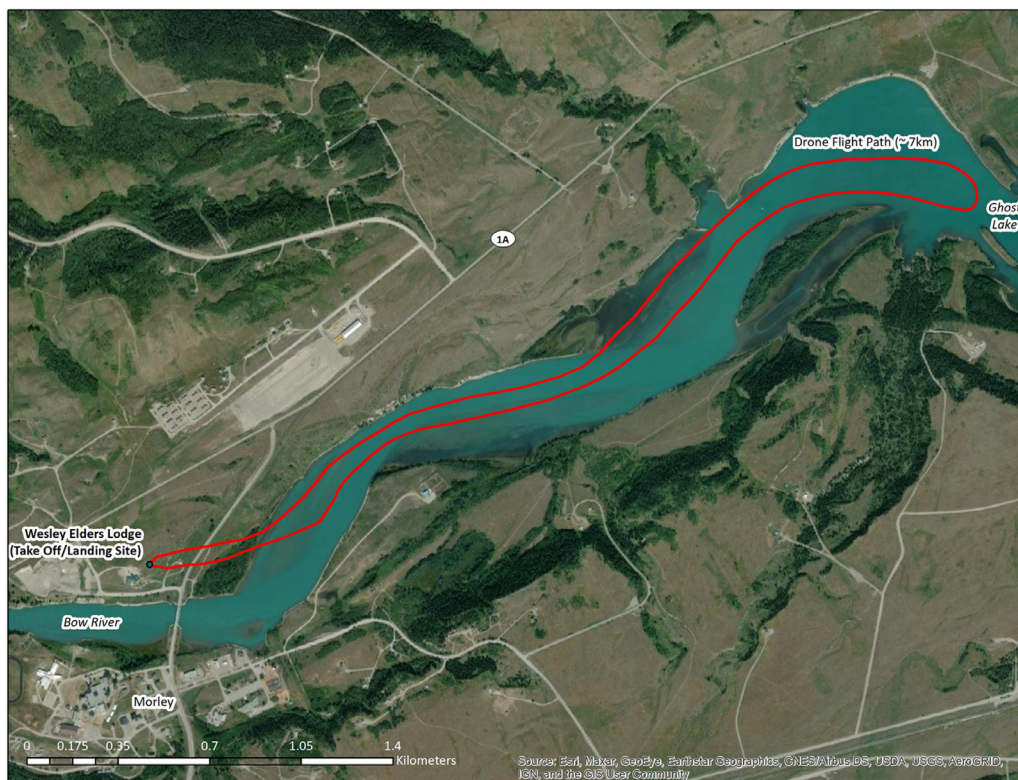


Fig 2. Map of flight path for delivery simulation mission.

Supplies were successfully delivered to a remote location. We are also working with A2Z Drone Delivery to redesign and fabricate a heavy lift winch to be mounted on our SwissDrone SDO50 V3, allowing the transport of larger payloads.

The winch system for low and medium endurance drones (Mavic Enterprise and Matrice 600) was mounted and successfully delivered medical devices (a portable ultrasound, probe, and smartphone) and PPE. The drone crew also delivered water bottles and blankets using the direct cargo delivery option; sensitive cargo such as the medical devices using the winch down cargo option; and a package containing blankets and a radio using the drop cargo option when tree cover prevented other delivery options. Deliveries were completed from altitudes between 15 and 40 m.

The custom payload container and parachute delivery system successfully and accurately dropped the payload over 10 flights in the Kananaskis Valley in the Canadian Rockies in rugged terrain.

PPE delivery and COVID-19 test kit fidelity

These simulations were conducted concurrently in July 2020, near Morley within SNN and using the SwissDrone SDO 50 V3. Mission flights progressed from safety-oriented test flights to the PPE and COVID-19 test kit delivery flight described below. The drone was operated using a BVLOS simulation (spotters were located along the flight path) from a drone operation center to the SNN Health Centre landing zone. Total flight distance was 7 km, with an average flight speed of 10 km/h (2.7 m/s) and a 42 minutes flight time (Fig 2). Air temperature was 20°C, with wind speeds of 15 km/h and clear visibility. The mission was beyond 3 nautical miles from an airport and 1 nautical mile from a heliport, however our advanced operations approvals and certification does permit operating inside controlled airspace (see Appendix A for more details on operations and pilot certification).

PPE delivery

The payload contents of PPE (including gloves [n = 200], gowns [n = 20], face shields [n = 5], and medical masks [n = 100]) and COVID-19 virus respiratory test kits were packaged in the custom, fixed-mount payload container attached to the long range, high endurance RPA as described. The payload was successfully delivered with no apparent damage.

Based on item size and weight, we estimate the following PPE items could fit in the payload container (individually): either 60 gowns (6 packages of 10); 2,000 gloves (20 boxes of 100); 2,000 face masks (40 boxes of 50); or 200 face shields.

COVID-19 test kit fidelity

Two simulations on the SwissDrone SDO 50 V3 were completed with spiked viral transport media or saline used in COVID-19 or other respiratory virus sampling kits. The drone successfully delivered COVID-19 respiratory kits and testing of samples post-flight indicated no decay in the signal or the testing capabilities of the test samples versus the controls (Table 2). Taking into consideration the conditions at the simulation site (Appendix C), there was enough data to have confidence in the proof-of-concept.

Remote ultrasound functionality

The full results of this simulation are published in Kirkpatrick et al.²⁹ The major finding was that the ultrasound-naïve volunteer successfully unpacked the payload and connected with a remote mentor over the cellular network. The mentor guided the volunteer through a successful ultrasound examination of all the relevant anatomic areas of the chest recommended to examine for patients with suspected COVID-19.^{11,12} The remote mentor was responsible for all interpretation of the images.

DISCUSSION

Drones have the potential to offer swift, on-demand access to health care for remote and rural Indigenous communities, reducing or eliminating the burden of travel to major metropolitan centers, and potentially improving patient outcomes in routine and emergency health care scenarios. This project focused on the co-development of a governance structure, procedures and operating manuals to meet the needs of the SNN's communities and demonstrating the potential of drone-delivered technology and supplies in diagnosis, evaluation, and treatment with a focus on COVID-19.

Our team has successfully developed essential procedural documents, a versatile and agile drone fleet, customized payload containers and delivery systems, achieved preliminary regulatory approvals, and completed multiple flights demonstrating proof-of-concept and successful drone-based delivery of medical supplies and services. Collectively, this work represents a foundation on which to build functional, efficient, and impactful drone delivery models in Alberta and beyond.

One of the cornerstones of this work is the modular and scalable nature of the knowledge produced. The ability to deliver and send back swabs for any number of respiratory viruses opens many opportunities for enhancing delivery to remote communities and to rapidly deploy these resources regardless of terrain and most weather challenges that may impede other modes of transportation. The use of drones to deliver tests kits and return them to the laboratory lays the foundation for an alternate delivery method for routine tests and emergency deployment during outbreaks and prepares us for the next pandemic or waves of COVID-19.

While the use of drones to deliver health care related supplies in services is currently in its infancy in North America,^{13,14} there are numerous parties interested in building and developing the sector, including health care providers; established and start-up enterprises; and remote, rural, and Indigenous communities. As a number of pilot projects and start-up companies in Sub-Saharan Africa have shown,^{15,16} the potential for drones to help “leapfrog” infrastructure limitations in remote and under-resourced settings is significant.

One of the primary challenges to the sector is the current regulatory and legal landscape in Canada, which has made it difficult to establish drone-based delivery for health care and other purposes. Developing tested and approved SOP and safety documents is a critical first ingredient in opening the sector for innovation and impact. Our team has worked with Transport Canada to obtain approval for BVLOS operations based on the robust standard operating procedures, safety and emergency procedures and DAA functions developed by the project. These documents can be exported to many other settings and provide a foundational legal and regulatory framework for establishing functional delivery models. Our partners at SNN, for example, are building on the results of the project to establish a locally owned drone service, which they have indicated will be helpful in many areas in addition to medical delivery, including resource management, forestry management, security, and search and rescue, among others.¹⁷ Other partners have highlighted potential uses in managing remote workforces, emergency medical response, and expanding the reach of specialized hospital programs beyond urban areas.

Despite its robust national health care system, health care inequality remains pervasive within Canada, and is particularly exacerbated by issues of access to services in remote and rural communities.^{18,19} Drones are an attractive alternative for the delivery of supplies and telemedicine services, ameliorating issues surrounding road quality and seasonal access, severe weather events, and lack of access to specialist services and diagnostics. The potential of offering screening services is also attractive,²⁰ as innovations in diagnostic and imaging equipment produce small, mobile technologies which

could be transported by drone—such as the portable ultrasound device employed in our simulations. These technologies are also poised to improve response in emergency situations. In this regard, delivering medical equipment is only a starting point for empowering remote point-of-care telementored diagnoses and interventions. Developing the paradigm involving appropriate guidance procedures, the phraseology, and especially understanding the human factors of remote medical guidance is in its infancy, but is an area with tremendous need and opportunity.^{21–23}

Despite the strengths of our work to date, we recognize the limitations of the current study. More work needs to be done to facilitate the process of moving what has been achieved in this project to fully functional drone-based medical delivery systems. With regard to transporting infectious substances (ie, diagnostic samples), transportation requirements (governed by Transport Canada and the UN designations for the transport of dangerous goods) will need to be updated and amended to include drones.²⁴ Further research like that reported here and by Amukele et al. will be important in this regard.^{25,26} Additional work may also be required on how extreme environmental and weather conditions might impact the flights and fidelity of human specimens along with costs. However, COVID-19 test fidelity has been tested at varying temperatures and higher altitudes, and the media employed in the specimens is routinely used to ensure fidelity of nucleic acid tests.

Further investigation is also required in building cost-effectiveness models for drone operation in different settings;^{27,28} investigating operational, logistics, and financial elements of integrating drone service into health systems AHS and local communities SNN; and increasing capacity for drone service ownership in partner communities. Toward these ends, our team will be offering drone pilot training at SNN in spring 2022.

CONCLUSION

Drone-based medical delivery models offer an innovative approach to addressing longstanding issues of health care access and equity and are particularly relevant in the context of COVID-19 and preventing pandemic spread. With proof-of-concept work yielding promising results, next steps must address regulatory, feasibility, data security, and cost-effectiveness questions in the Canadian and international contexts.

Acknowledgments

The authors would like to extend their gratitude to the Stoney Nakoda Nation Band Council for their approval to conduct missions within the Nation, and all members of Stoney Nakoda Nation for their support and engagement with the project. We also acknowledge and appreciate the assistance of Alberta Parks in granting permission to conduct missions in Kananaskis and Alberta Provincial parks, and the communications team at W21C (Alex Baron, Julia MacGregor) in designing the graphical abstract. The authors also wish to acknowledge the contributions of Dr. Jessica L McKee for her work with the TeleMentored Ultrasound Supported Medical Interventions Research Group, which was critical for the remotely mentored ultrasound simulation discussed here.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at <https://doi.org/10.1016/j.ajic.2022.03.004>.

References

- Grant K, Andruchow JE, Conly J, et al. Personal protective equipment preservation strategies in the COVID-19 era: a narrative review. *Infect Prevention in Pract*. 2021;3: 100146.
- Indigenous Services Canada. *Confirmed Cases of COVID-19*; 2020. Accessed November 15, 2021. <https://www.sac-isc.gc.ca/eng/1598625105013/1598625167707>.
- Angela Mashford-Pringle, Christine Skura, Sterling Stutz, Thilaxcy Yohathasan. *What We Heard: Indigenous Peoples and COVID-19: Public Health Agency of Canada's Companion Report*; 2021. Accessed December 20, 2021. <https://www.canada.ca/en/public-health/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/from-risk-resilience-equity-approach-covid-19/indigenous-peoples-covid-19-report.html>.
- Transport Canada. Fly your drone beyond visual line-of-sight. AARV 16908858. Published October 14, 2020. Accessed December 23, 2021. <https://tc.canada.ca/en/aviation/drone-safety/drone-pilot-licensing/fly-your-drone-beyond-visual-line-sight>.
- Pabbaraju K, Wong AA, Douesnard M, et al. Development and validation of RT-PCR assays for testing for SARS-CoV-2. *J Assoc Med Microbiol Infect Dis Canada*. 2021. Published online March 15.
- Transport Canada. *Knowledge Requirements for Pilots of Remotely Piloted Aircraft Systems 250 g up to and Including 25 Kg, Operating within Visual Line-of-Sight (VLOS)*; 2019. Accessed December 23, 2021. <https://tc.canada.ca/sites/default/files/2020-07/tp-15263E.pdf>.
- Transport Canada. Flight Operations Functional Area Checklists. In: *Commercial and Business Aviation Inspection and Audit (Checklists) Manual*. Transport Canada; 2000. Accessed December 23, 2021. <https://tc.canada.ca/en/aviation/publications/commercial-business-aviation-inspection-audit-checklists-manual-tp-13750/33-flight-operations-functional-area-checklists>.
- Transport Canada. Canadian Aviation Regulations (SOR/96-433). AARBH 14882767. Published September 29, 2021. Accessed December 23, 2021. <https://tc.canada.ca/en/corporate-services/acts-regulations/list-regulations/canadian-aviation-regulations-sor-96-433>.
- Transport Canada. Application Guidelines for a Special Flight Operations Certificate for a Remotely Piloted Aircraft System (SFOC-RPAS) Advisory Circular (AC) No. 903-002. AARV 16706421. Published July 9, 2021. Accessed December 23, 2021. <https://tc.canada.ca/en/aviation/reference-centre/advisory-circulars/advisory-circular-ac-no-903-002>.
- Transport Canada. Remotely Piloted Aircraft Systems Operational Risk Assessment Advisory Circular (AC) No. 903-001. AARV 15147375. Published July 6, 2021. Accessed December 23, 2021. <https://tc.canada.ca/en/aviation/reference-centre/advisory-circulars/advisory-circular-ac-no-903-001>.
- Ma IWY, Hussain A, Wagner M, et al. Canadian Internal Medicine Ultrasound (CIMUS) expert consensus statement on the use of lung ultrasound for the assessment of medical inpatients with known or suspected coronavirus disease 2019. *J Ultrasound Med*. 2021;40:1879–1892.
- Soldati G, Smargiassi A, Inchingolo R, et al. Proposal for international standardization of the use of lung ultrasound for patients with COVID-19: a simple, quantitative, reproducible method. *J Ultrasound Med*. 2020;39:1413–1419.
- Hiebert B, Nouvet E, Jeyabalan V, Donelle L. The application of drones in healthcare and health-related services in North America: a scoping review. *Drones*. 2020;4:30.
- Carrillo-Larco RM, Moscoso-Porras M, Taype-Rondan A, Ruiz-Alejos A, Bernabe-Ortiz A. The use of unmanned aerial vehicles for health purposes: a systematic review of experimental studies. *Glob Health Epidemiol Genom*. 2018;3:e13.
- Glauser W. Blood-delivering drones saving lives in Africa and maybe soon in Canada. *CMAJ*. 2018;190:E88–E89.
- Knoblauch AM, Rosa S de la, Sherman J, et al. Bi-directional drones to strengthen healthcare provision: experiences and lessons from Madagascar, Malawi and Senegal. *BMJ Global Health*. 2019;4: e001541.
- Clark DG, Ford JD, Tabish T. What role can unmanned aerial vehicles play in emergency response in the Arctic: a case study from Canada. *PLoS One*. 2018;13: e0205299.
- Marrone S. Understanding barriers to health care: a review of disparities in health care services among indigenous populations. *Int J Circumpolar Health*. 2007;66:188–198.
- Nguyen NH, Subhan FB, Williams K, Chan CB. Barriers and mitigating strategies to healthcare access in indigenous communities of Canada: a narrative review. *Healthcare*. 2020;8:112.
- Balasingam M. Drones in medicine—the rise of the machines. *Int J Clin Pract*. 2017;71:e12989.
- Hampton LA, Brindley P, Kirkpatrick A, et al. Strategies to improve communication in telementoring in acute care coordination: a scoping review. *Can J Surg*. 2020;63:E569–E577.
- Wachs JP, Kirkpatrick AW, Tisherman SA. Procedural telementoring in rural, underdeveloped, and austere settings: origins, present challenges, and future perspectives. *Annu Rev Biomed Eng*. 2021;23:115–139.
- Kirkpatrick AW. Point-of-care resuscitation research: from extreme to mainstream: trauma association of Canada fraser gurd lecture 2019. *J Trauma Acute Care Surg*. 2019;87:571–581.
- Transport Canada. COVID-19: requirements for safe transportation of infectious substances (Class 6.2). ASDA 16415983. Published April 7, 2020. Accessed December 3, 2021. <https://tc.canada.ca/en/dangerous-goods/covid-19-requirements-safe-transportation-infectious-substances-class-62>.
- Amukele T. Current state of drones in healthcare: challenges and opportunities. *J Appl Lab Med*. 2019;4:296–298.
- Amukele TK, Street J, Carroll K, Miller H, Zhang SX. Drone transport of microbes in blood and Sputum Laboratory specimens. *J Clin Microbiol*. 2016;54:2622–2625.
- Butterworth-Hayes P. Comparing the cost-effectiveness of drones v ground vehicles for medical, food and parcel deliveries. Unmanned airspace. Published November 13, 2019. Accessed November 12, 2021. <https://www.unmannedair.space/info/commentary/comparing-the-cost-effectiveness-of-drones-v-ground-vehicles-for-medical-food-and-parcel-deliveries/>.
- Haidari LA, Brown ST, Ferguson M, et al. The economic and operational value of using drones to transport vaccines. *Vaccine*. 2016;34:4062–4067.
- Kirkpatrick AW, McKee JL, Moeini S, et al. Pioneering remotely piloted aerial systems (Drone) delivery of a remotely telementored ultrasound capability for self diagnosis and assessment of vulnerable populations—the sky is the limit. *J Digit Imaging*. 2021;34:841–845.