Discussion

Drones in healthcare, are they ready to fly?

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ABSTRACT
Unmanned aerial vehicles (UAVs), commonly known as drones, have rapidly evolved from predominantly military tools into promising assets for civilian and humanitarian applications, including healthcare. In recent years, UAVs have demonstrated the potential to transform healthcare logistics by overcoming geographical, infrastructural and time-critical barriers to the delivery of medical supplies. This paper reviews current and emerging applications of UAVs in healthcare, including the transport of blood and blood products, medications and vaccines, organs and tissues, chemotherapy, and automated external defibrillators. Drawing on international case studies, particularly from sub-Saharan Africa, the UK and Europe, we highlight evidence of improved delivery times, reduced wastage, enhanced access to care and potential environmental benefits. Despite these successes, widespread implementation remains limited. We explore the key barriers to routine adoption, including regulatory complexity, safety and liability concerns, financial and infrastructural requirements, environmental trade-offs, and issues of professional and public acceptance. The paper argues that while UAV technology is increasingly mature, its integration into healthcare systems is highly context-dependent and requires coordinated, multi-stakeholder approaches. Policy reform, regulatory innovation, community engagement and further applied research will be essential to enable the safe, sustainable and scalable use of UAVs within healthcare logistics.

INTRODUCTION
For much of their existence, drones—or unmanned aerial vehicles (UAVs)—have almost exclusively seen military use.[1 2] Only within the last few decades has the paradigm shifted to explore the potential of UAVs for humanitarian purposes.[1] Their capabilities have been highlighted in disaster relief efforts and the COVID-19 pandemic,[2 3] helping to overcome transport and logistical barriers which hindered traditional transportation.[3]

Now, UAVs hold promise as a transformative force in healthcare logistics, able to circumvent challenges posed by terrain and accessibility, as well as the possibility to reduce the financial and environmental costs associated with other transport means.[4] They offer the potential to provide rapid access to critical provisions and to support healthcare organisations to adopt modern ways of working, focusing on closing health inequalities, updating logistics and developing sustainable practices.[3] However, for all their promise, few healthcare systems have operationalised drone usage within routine healthcare delivery (table 1).[1 2]

Current applications
Unmanned aerial vehicles (UAVs), commonly known as drones, have rapidly evolved from predominantly military tools into promising assets for civilian and humanitarian applications, including healthcare. In recent years, UAVs have demonstrated the potential to transform healthcare logistics by overcoming geographical, infrastructural and time-critical barriers to the delivery of medical supplies. This paper reviews current and emerging applications of UAVs in healthcare, including the transport of blood and blood products, medications and vaccines, organs and tissues, chemotherapy, and automated external defibrillators. Drawing on international

Table 1 Implemented UAV programmes or trials in different countries organised by the carried cargo

	Human tissue (including blood)	Organs	Vaccines	Cancer therapies	Other medications	Defibrillators	PPE and/or other medical equipment
Australia	✔		✔		✔		✔
Belgium	✔						
Canada	✔	✔		✔	✔	✔	✔
China	✔				✔		✔
Ethiopia	✔		✔		✔		✔
Germany	✔					✔	
Ghana	✔		✔		✔		✔
Haiti	✔				✔		
India	✔		✔		✔		✔
Japan	✔				✔		
Kenya	✔		✔		✔		✔
Malawi	✔		✔		✔		✔
Nigeria	✔		✔		✔		
Papua New Guinea	✔						
Rwanda	✔		✔		✔	✔	✔
Sweden						✔	
Switzerland	✔						
Tanzania	✔		✔		✔		
UK	✔		✔	✔	✔	✔	✔
USA	✔	✔	✔		✔	✔	✔

UAV, unmanned aerial vehicle.

case studies, particularly from sub-Saharan Africa, the UK and Europe, we highlight evidence of improved delivery times, reduced wastage, enhanced access to care and potential environmental benefits. Despite these successes, widespread implementation remains limited. We explore the key barriers to routine adoption, including regulatory complexity, safety and liability concerns, financial and infrastructural requirements, environmental trade-offs, and issues of professional and public acceptance. The paper argues that while UAV technology is increasingly mature, its integration into healthcare systems is highly context-dependent and requires coordinated, multi-stakeholder approaches. Policy reform, regulatory innovation, community engagement and further applied research will be essential to enable the safe, sustainable and scalable use of UAVs within healthcare logistics.

Blood and blood products

Although considered an essential medicine, blood is nonetheless logistically fickle due to its brief lifespan and stochastic supply and demand.[5] These complexities are amplified with significant rural populations, limited infrastructure or challenging terrains or climates.[1]

UAVs have been gaining a foothold across sub-Saharan Africa since 2016, when Rwanda—working with UAV company, Zipline—became the first to embed a UAV-based delivery network into existing health infrastructure (table 1).[2 5] The premise is straightforward: UAVs deliver requested resources from Zipline 'hubs' following a text from a medical facility.[6] The network covers 75% of the country outside Kigali, served by UAVs capable of travelling up to 150 km with a 1.5 kg payload in most weather conditions.[5] Correspondingly, health-related outcomes have shown drastic improvement, with blood arriving 79–98 min quicker than by road, 67% fewer units expiring annually and <1% of units incurring damage during delivery.[5] Zipline has subsequently expanded to also cover 50% of Ghana, while other African countries have taken similar steps (table 1).[3]

Elsewhere, UAV integration lags, despite numerous completed trials and promising results. In Northumbria, UAV-transported packed red blood cells flown over 68 km remained biochemically and haematologically viable in addition to arriving 7 min faster than by road.[4] More recently, Guy's and St Thomas' NHS Foundation Trust and Apian, a healthcare logistics company, began UAV blood deliveries between hospitals, cutting down a half-hour journey by road to 2 min as well as calculating a 99% potential reduction in CO_2 emissions (table 1).[7] The hope is for this trial to serve as the blueprint for future scaling-up of UK UAV-based systems.

Medication and vaccines

India successfully completed a 45-day, proof-of-concept UAV trial transporting 10 000 vaccine doses across 850 km in 2020.[8] Subsequently, the 'Medicine from the Sky' pilot programme was launched in Arunachal Pradesh, situated in the Himalayan belt.[8] Challenges included difficult terrain, dispersed populations and adverse weather conditions, but the UAVs ultimately succeeded in completing 700 flights spanning 15 000 km and delivering 2000 diagnostic samples, vaccines and medications (table 1).[8] Interestingly, the UAV system performed comparably with a 15-vehicle and 30-person road-based team.[8]

Again, African countries lead in UAV-centred delivery efforts. In 2019, Ghana collaborated with Zipline to create the largest vaccine UAV network, serving 12 million people across 2000 health facilities.[9] Over 6 million vaccines were delivered to UAV-supplied clinics, resulting in five fewer vaccine stockout days, 41% fewer patients being turned away and reducing missed vaccinations by 44% (table 1).[9] Zipline has also been delivering medication, including vaccines, antivenom, antirabies and epinephrine, in Kenya since 2023 (table 1).[10] The Elton John AIDS Foundation has also partnered with Zipline to deliver HIV tests, pre-exposure prophylaxis and educational materials for preventative care into Kenyan and Nigerian communities using UAVs (table 1).[11] Concurrently, Ethiopia established its first long-range UAV network with Swoop Aero, supplying six communities with 6936 vaccines in 44 flights over the course of a month-long trial (table 1).[12] Similar to the delivery network in Rwanda, the UAVs can fly up to 120 km carrying 3 kg payloads.[12]

Organs and other tissues

In 2015, US organ allocation systems were revised to prioritise immunological match-making, inadvertently increasing travel distances and, thereby, time to transplantation.[13] Crucially, organs have short shelf lives—deterioration begins from moment of harvest; thus, timeliness underpins the complex logistics of organ transportation. These contributed to a world-first in 2019 when UAV-transported kidneys were carried by over 4.5 km in under 10 min to be successfully transplanted (table 1).[13] Biopsies confirmed the mode of transportation had no impact on kidney quality.[13] Another first followed in 2021 with the first UAV-flown lungs (table 1).[14] The journey took 5 min over 1.5 km of urban landscape[14]—once again, this had no detrimental impact on the cargo.[14]

UAVs also helped shape a mid-surgery decision in India when intraoperative tissue was transported over 37 km by UAV from the operating hospital to a tertiary facility to be analysed for malignancy (table 1).[15] The UAV had completed the delivery within 15–20 min as opposed to 50–60 min by road, rendering such rapid decision-making processes feasible.[15] Similarly, laboratory samples flown from Edinburgh to Melrose by Project CAELUS in Scotland also demonstrated this advantage in Beyond Visual Line of Sight (BVLOS) flight (table 1).[16]

Chemotherapy

Like blood, chemotherapy poses logistical obstacles—namely, short shelf-life, temperature sensitivity and pre-emptive manufacture to ensure on-the-day availability per treatment regimen.[17] Yet, comparatively, very few UAV flights carrying cancer therapy payloads have been trialled.

Ongoing UK efforts seek to streamline these issues, beginning in 2021 with proof-of-concept flights carrying chemotherapy from Portsmouth to the Isle of Wight (table 1).[17] Other than reducing the sea-based 4-hour delivery time to 30 min, it helped establish standard operating procedures for visual-line-of-sight and beyond visual-line-of-sight flight and consolidated UAV safety transporting chemotherapies.[17] Progress was furthered in 2023 with stage 1 Northumbrian trials, which supported 145 NHS patients and saved approximately 176 hours travel time and 1.48 tonnes CO_2 over 4 months.[18]

Automatic External Defibrillators

Only one in 12 patients survive an out-of-hospital cardiac arrest (OHCA), with survival chances decreasing 10% every passing minute without defibrillation.[19] Early automatic external defibrillator (AED) intervention increases odds of survival by 50–70%.[20] However, 80% of OHCAs occur at home,[19] complicating AED access, particularly in isolated or less developed areas.

With time of such essence, modelling and simulation studies show UAVs delivering AEDs are generally faster compared with emergency services or bystanders.[19] Beginning in 2020, Sweden was the first country to date to pilot prospective trials of UAVs fully integrated into existing emergency service systems. Remotely-controlled UAVs were safely deployed to the incident site in 92% of OHCAs[20] and arrived prior to emergency services 64%[20] and 67%[21] of the time, at a clinically significant median of approximately 2–3 min (table 1).[20 21]

DISCUSSION

UAVs are a technology of possibility, capable of overcoming challenges such as poor infrastructure or limited healthcare provision to improve supply chain resilience and access to necessary vital healthcare. Despite considerable progress over the past few decades, UAV implementation in healthcare lags globally and faces multilevel barriers, from regulatory policies, economic and logistical considerations, to professional and public acceptance. Individual country contexts also play a key role in the uneven adoption of UAVs internationally. In developing countries, such as Rwanda and Ghana, UAVs are a necessary humanitarian intervention critical in leapfrogging immediate and pressing gaps in accessibility and health provision. On the other hand, in developed countries such as the UK and USA, UAVs do not necessarily serve the same urgent needs and may be considered more a technology of convenience. Therefore, while UAVs hold much theoretical potential, real world adoption appears far more complex and nuanced.

Legal and safety considerations

Although UAV design constantly evolves to improve operational safety, scepticism over consistent performance across different environments and conditions is warranted. However, crash data are currently scarce. While this absence points towards UAV safety and reliability, the current low level of integrated operations and the tightly-controlled nature of UAV trials may also contribute to this. UAVs remain to be stress-tested to comprehensively evaluate performance. In 2022, storms grounded UAVs in the UK,[17] outlining current operational limitations.

Additionally, translating results between UAV projects requires understanding of their variation—for example, the Rwandan UAV-grid predominantly serves rural areas[3]; consequently, lessons in risk mitigation cannot be directly extrapolated to built-up or urbanised areas. Alternatively, under-reporting of UAV crashes may contribute to the appearance of relative security of UAVs. Liability in such instances also presents a growing issue in both the legal and wider sense of public trust. Therefore, while the risks of UAV transport do not appear disproportionate, these underlying questions must be answered prior to large-scale implementation.

Furthermore, it is vital to establish the safety of UAVs in carrying medical resources, particularly sensitive or dangerous medications. Thus far, initial research is encouraging, demonstrating the effects of vibration and temperatures experienced during UAV flight minimally impact blood[4] and most medications, including insulin.[22] Nevertheless, some medical payloads being trialled (eg, cancer therapies[17 18]) may be considered 'dangerous goods', compounding fears surrounding safety risks during transportation for those on the ground.

Regulatory considerations

Dense regulatory barriers further complicate UAV adoption. The architecture underlying airspace design is old and complex—inserting modern technologies is not a simple matter. BVLOS represents the latest frontier in UAV regulations. The success in Rwanda relied on tailoring guidelines to UAV integration rather than vice-versa from a regulatory perspective, whereupon recommendations derived from the International Civil Aviation Organisation were later adapted to suit local agendas.[3] Notably, the 2018 Regulations Related to Unmanned Civil Aircraft Systems established a radically updated national framework, enabling BVLOS for commercial UAV operations in Rwanda[23] and highlighting how critical central government support is for UAV projects in navigating regulatory bottlenecks. Very few countries elsewhere have replicated Rwanda's BVLOS framework and instead opt for individual measures, such as BVLOS waivers, temporary danger areas as in the UK,[1] or corridors established in Malawi and Sierra Leone (table 1),[3] that may not be ubiquitously feasible or have limited scalability past pilot projects.

Financial considerations

Questions surround the economics of UAVs and how they may fit within pre-existing healthcare infrastructure and supply chains. All transport fleets, UAV or conventional, incur financial costs—for UAV integration, many of these are likely to be novel. Upfront investment is known to be a common early barrier. Although Rwandan and Ghanaian governments had to establish permanent budgets to pay for Zipline services, the funds were generated by the UAVs cutting upstream and downstream costs.[3] Nationally, substantial infrastructure investment will be required to facilitate UAVs as part of routine transport and delivery logistics. Likewise, regional healthcare services will need to make investments in dedicated infrastructure, such as UAV vertical take-off pads, charging stations and trained pilots, to fully benefit from UAV implementation in the supply chain. For example, operators in Sweden required 5-day pilot training to fly UAVs in pilot trials,[21] illustrating in part the time and staff investments required for UAV implementation. Longer-term costs, such as those associated with programme maintenance, must also be taken into account.

However, in the UK setting, a recent review concluded UAVs may be faster, more reliable and even cheaper than existing NHS delivery alternatives.[1] Importantly, the cost of UAVs is likely to decrease over time, as scalability and increased automation drive down initial expenses. Estimates already suggest next-day UAV delivery could be up to 80% cheaper than the current standard, largely due to these improved operational efficiencies cutting delivery costs per package.[1] Likewise, UAVs have the potential to provide substantial cost savings through reducing the need to stock excess supplies, lowering operating costs and more integrated logistics, as already seen in Rwanda and other countries.[3 8] In 2020, only long-range UAVs delivering emergency supplies made financial sense[24]; in just the 5 years since, UAVs have been successfully implemented into last-mile and middle-mile logistics globally. These demonstrate that, despite requiring upfront investment and incurring novel costs, appropriately implemented UAVs could have significant financial benefits for the health sector.

Environmental considerations

As healthcare logistics faces mounting pressure to adopt greener practices, UAVs have garnered much interest for their potential environmental benefits such as reduced global warming impact and lower energy consumption during flights compared with diesel-fuelled vehicles.[8 25] However, UAVs are not without environmental trade-offs.

Overall UAV sustainability is not only reliant on their performance during deliveries, but also during manufacturing and maintenance stages.[26] Crucially, UAVs were found to be less efficient than electric commercial vehicles in one-to-many deliveries and per kilogram of cargo.[26] Moreover, electronic waste concerns surround the use of lithium batteries, of which less than 5% are completely recycled globally.[27] Even the sustainability of electric UAVs is intrinsically tied to current methods of electricity production, which are still dominated by non-renewable resources worldwide.[25] Further relevant questions surround noise pollution during flights and the environmental costs involved in the implementation of supportive infrastructure.

Although ameliorating such concerns relies on various inputs, route optimisation will be critical for UAV implementation. Currently, UAVs demonstrate the greatest environmental benefits across one-to-one deliveries in rural areas.[25 27] Shifts in the wider context, such as technological readiness and greener policies, also have the potential to either positively or negatively impact UAV adoption.

Social considerations

UAV adoption hinges on acceptance by healthcare staff and the wider public. Easing hesitancy relies on addressing key concerns, such as safety and privacy, that can originate from unfamiliarity with UAVs. This is underlined by Wingcopter employees educating communities prior to UAV deliveries to facilitate early acceptance.[3] Some issues overlap with logistical and regulatory facets, such as flight paths over private property, data security, possible changes to the livelihoods of those employed in land-based transport services and safety of both UAVs and transported cargo. Assuaging these is not only possible but crucial for success, as evidenced by established UAV projects. For example, Zipline staff operate using locals from surrounding areas, aiming to change early apprehensions into positive engagement over time.[3] As always, clear and effective communication will be required to sensitise both professionals and the public to UAVs.

CONCLUSION

Initial UAV adoption into healthcare systems has been patchy globally, in spite of technology having matured and implementation offering clear benefits beyond merely increasing efficiency. The successful adoption of UAV technology will require a multistakeholder approach, with collaboration between governments, healthcare providers and local communities. Co-designing regulatory frameworks and addressing community concerns will be essential for overcoming barriers.[28] Policy reforms and streamlining legislation will be vital to support the sustainability and scalability of drone operations in healthcare logistics.[11] Further research is required to explore avenues of interest, including the reshuffling of roles in the healthcare sector generated by the emergence of UAVs.

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