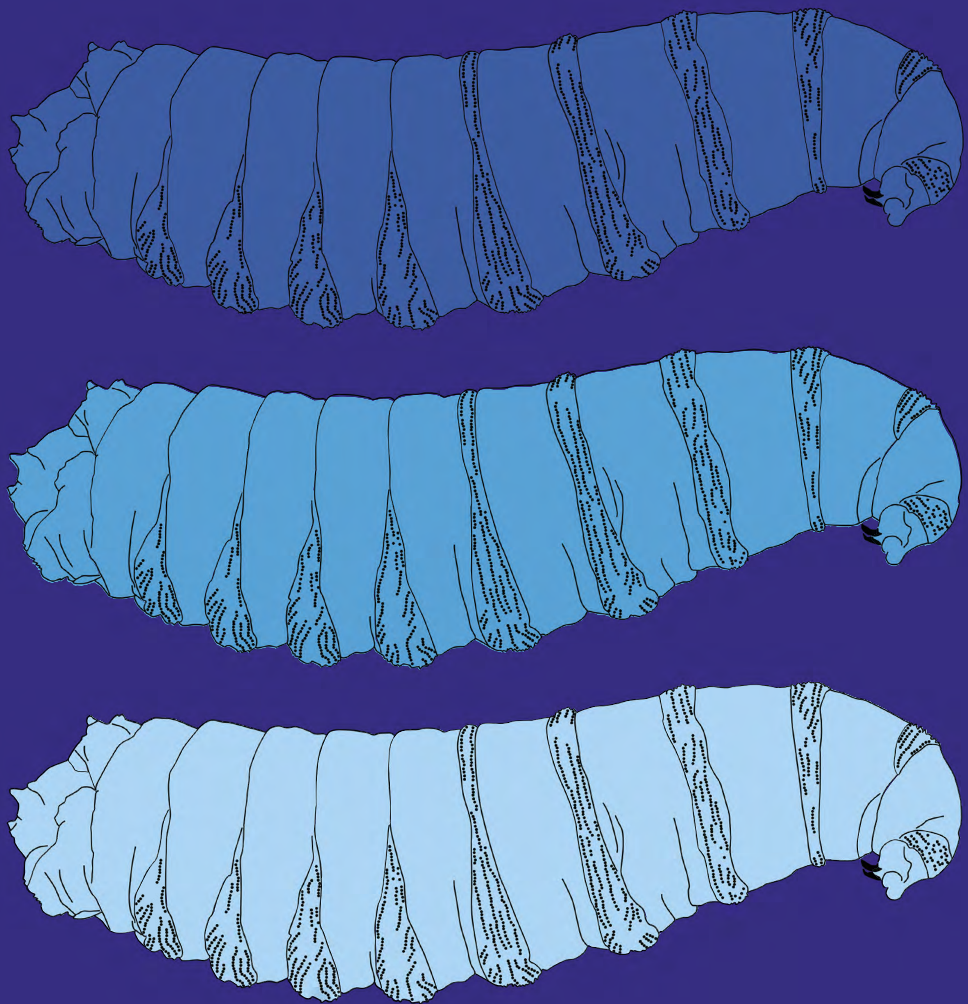
A COMPLETE GUIDE TO MAGGOT THERAPY

Clinical Practice, Therapeutic Principles, Production, Distribution, and Ethics



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18. Drone-assisted Medicinal Maggot Distribution in Compromised Healthcare Settings

Frank Stadler and Peter Tatham

Timely delivery of medicinal maggots is challenging when logistics infrastructure is poor due to underinvestment or disaster-related destruction of roads, bridges and railway lines. Unmanned Aerial Vehicles, commonly known as 'drones', are much cheaper to procure and operate than planes and helicopters and can overfly the areas where roads or railway lines are impassable. This chapter provides a brief profile of current drone technology, and explores drone service design considerations in relation to medicinal maggot distribution. It also presents case examples of drone technologies that could be used for medicinal maggot distribution, and provides guidance for the implementation of drone-assisted medicinal maggot distribution.

Introduction

There is a particular logistic challenge in the administration of maggot therapy because medicinal maggots need to be transferred from the laboratory in which they are produced to the patient within 24–48 hours. In addition, they need to be kept at a temperature of between 6 and 25°C to maintain their health and vigour and, therefore, their therapeutic efficacy [1]. With these constraints in mind, Chapter 17 discusses

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various options that exist for the distribution of medicinal maggots in compromised healthcare settings [2]. The concept of drone-assisted transport was briefly mentioned but it warrants greater attention in this dedicated chapter in light of the ever-increasing application of drone technology in the humanitarian setting.

In low- and middle-income countries or in the aftermath of a disaster, distribution of perishable medical goods can present a significant challenge when fast distribution of goods is hindered by poor infrastructure due to underinvestment or disaster-related destruction of roads, bridges and railway lines, and associated communication systems. Although these distribution challenges can often be overcome with aerial transport using helicopters or aeroplanes, these are expensive to procure and operate, especially if they were to be employed to distribute only medicinal maggots. Furthermore, during disasters there are multiple competing demands for helicopters and planes and it is therefore unlikely that the transport of medicinal maggots will be considered a high priority. By contrast, 'drones'—also known as Remotely Piloted Aircraft Systems (RPAS) or Unmanned Aerial Vehicles (UAVs)—are much cheaper to procure and operate and, like planes and helicopters, can overfly the areas where roads or railway lines are impassable. Drones are frequently used by military forces for both surveillance or attack but are increasingly employed in non-military contexts including: the structural evaluation of buildings [3], the provision of aerial surveillance and mapping [4], and fire detection [5]. There is also a growing realisation in the military and civilian context that drones can deliver rapid pre-hospital medical care and medical supplies from a distance whether that be in war, in times of disaster, or to provide development aid [6, 7]. Pre-hospital applications of drone technology are being developed for i) search and rescue, ii) resuscitation and telemedicine, iii) damage assessment and response coordination, iv) medical evacuation, and v) medical supplies delivery [6, 8, 9]. Thus, although there is great potential for the use of drones to transport medicinal maggots to inaccessible healthcare settings, to date this mode of transport has not been utilised. This chapter therefore aims to encourage maggot therapy supply chain managers to consider drone-assisted distribution of medicinal maggots. In doing so it offers:

1. a brief profile of current drone technology,

2. an exploration of drone service design considerations and how they apply to medicinal maggot distribution,
3. case examples of drone technologies that could be used for medicinal maggot distribution, and
4. points to bear in mind when considering implementation of drone-assisted medicinal maggot distribution.

Please note that the information provided in this chapter may well be out of date by the time it is published. Such is the speed of development in this field of transport logistics. However, the main aim of this introduction to drone-assisted medicinal maggot distribution is to convey an appreciation for the opportunities of drone transport and to sensitise supply chain partners to the issues that need to be considered.

Drones and Their Capabilities

According to the United Nations Office for the Coordination of Humanitarian Affairs [10] (UNOCHA) drones are becoming relatively commonplace, with 270 companies in 57 countries reported as manufacturing such aircraft in 2014 [10], figures that have undoubtedly increased since then. Furthermore, it has been estimated that annual sales of drones will surpass US$12 billion in 2021, which reflects a compound annual growth rate of 7.6% from the US$8.5 billion recorded in 2016 [11]. Having said this, it must be appreciated that there are significant capability differences between various classes of drones—in particular in respect of their endurance, speed, payload and normal operating altitude.

In essence, drones range from small rotary-wing platforms that cost around USD4,000 [12] to high-end aeroplanes such as the USAF Global Hawk, which is the size of a small executive jet and has a unit cost of USD130M [13]. However, their generic features include the ability to be flown by an operator who remains on the ground at a distance from the aircraft itself, together with a payload that can include video or still cameras, or items such as equipment or medicines (for example, medicinal maggots). Such drones can use either fixed or rotary wings and are powered by battery or fuel-driven engines—as a result their endurance varies from minutes to hours.

Short Range

The most prevalent type of drones (both in terms of numbers sold and the quantity of different platforms available) is the relatively short-range aircraft that is battery-powered and utilises four rotor blades to provide the vertical and horizontal movement. Such quadcopters are perceived to have particular promise in the context of providing a transport medium for medicinal maggots as they are extremely easily moved to the desired operational location and can carry a respectable payload given (as will be discussed further below) the relatively light weight of maggots and their associated packaging. They are able to fly Beyond Visual Line of Sight (BVLOS), and also represent an area where significant research and development is being undertaken. For example, between them, Amazon and Walmart have registered 153 new drone patents in the period July 2018–June 2019, whilst over 9,000 patents exist across the world as of June 2019. Examples of such drones are to be found in Table 18.1.

Table 18.1 Examples of the payload/endurance of short-range drones [14, 15].

Model	Maximum Payload	Endurance
DJI MATRICE 100	3.6 kg	40 min
DJI MATRICE 600	6.0 kg	16 min
DJI S1000	6.8 kg	15 min
Tarot-T18	8.0 kg	20 min
DJI S900	8.2 kg	18 min
FREEFLY ALTA 8	9.0 kg	16 min
DJI Agras MG-1	10.0 kg	24 min
ONYXSTAR HYDRA-12	12.0 kg	30 min
AZ 4K UHD	20.0 kg	20 min

Short-range drones for humanitarian missions. The Humanitarian UAV Network (UAViators, www.uaviators.org) is a community of practitioners with the mission to promote the safe, coordinated and effective use of drones for data collection and cargo delivery in humanitarian and development settings. They have collated information on drone trials for humanitarian missions which mainly used short range aircraft to provide commodities to either remote communities or those impacted by disasters [16]. What is particularly beneficial to humanitarian operations is the ability of these drones to fly in the aftermath of floods (for example those which devastated Mozambique in 2019) or earthquakes (as was the case in the 2015 disaster in Nepal), directly from their base to the location of need. However, the relatively short range of these small, low-cost aircraft is a challenge, albeit one that is slowly being overcome by a general increase in endurance found in the most recent drones emerging on the market.

Medium-/long-range drones. In contrast to the short-range drones described above, some longer-range platforms are also available. These carry a similar payload to the short-range variants but have a considerably longer endurance. This can be utilised either by flying significantly greater distances or by 'loitering' in an area until it is appropriate to transfer their payload. Some examples of such drones are offered in Table 18.2, and it will be noted that these can launch/land either in a similar way to a regular aircraft (fixed-wing models) or vertically (hybrid fixed-wing/rotary mimicking a helicopter). The former requires the drone to be launched either by a mechanical catapult or from the roof of a specially modified moving vehicle, and to land either on a relatively flat surface of several hundred metres in length or be caught by a net or line-and-hook system as employed by Zipline (www.flyzipline.com). Thus, both the land and launch systems needed for such drones require pre-positioning of the necessary equipment.

Zipline drones are launched by a catapult system which reduces the drain on the drone's battery in the initial phase and results in an operational radius of some 80 km with a payload of up to 1.8 kg. On reaching the destination, the payload is despatched to the ground by means of a parachute. On return from a delivery, the drones are snagged by a wire stretched between two masts and physically land on a large inflatable mattress or come to rest suspended on the wire system. This is a unidirectional distribution strategy which results in a hub-and-spokes transport network structure where drone distribution centres (launch and landing facilities) are co-located with medical warehouses.

It does not permit bi-directional transport of cargo. Nevertheless, at its maximum capacity, a 30-drone system as has been deployed in Ghana is capable of moving up to 1,000 kg/day [17].

By contrast, drones that operate using vertical take-off and landing mechanisms typically have a reduced flying speed (and, hence, range) but are less constrained in terms of their operations as they require only a launch/land zone of 5 m in diameter. The Wingcopter (www.wingcopter.com) and Swoop Aero (www.swoop.aero) drone models have been developed for medical supply-chain applications among other uses [18, 19, 20]. Both have rotor systems that allow the drones to launch vertically and fly in forward motion. For delivery purposes, the Wingcopter 198 can deliver three separate packages with a total weight of 5 kg to different locations within a range of 75 km per flight [19]. The latest Swoop Aero platform Kite™ (Figure 18.1) can transport 3 kg of supplies over a distance of 175 km, or 5 kgs over a distance of 130 km, all at a speed of up to 200 km per hour [21].

Figure 18.1 The Kite™ drone from Swoop Aero for medium-range deliveries. Photo: © Swoop Aero.

Table 18.2 Exemplar Medium-/Long Range Drone Key Performance Data [19, 22–24].

	Wingcopter	Latitude HQ 160B	Aerosonde Mk 4.7	Boeing Insitu Scaneagle
Endurance	2.5 hrs	15 hrs	14+ hrs	24+ hours
Cruising Speed	40 km/h	65 km/h	90–110 km/h	90–110 km/h
Ceiling	5,000 m	6,200 m	4,570 m	4,500 m
Wingspan	1.78 m	3.81 m	3.6 m	3.11 m
Overall Length	1.32 m	2.44 m	1.7 m	1.7 m
Max. Gross Take-Off Weight	17 kg	53 kg	36.4 kg	22 kg
Max. Payload Weight	6.0 kg	9.97 kg	9.1 kg	3.4 kg

Longer-range drones would appear to be particularly suited to deployment in the aftermath of disasters such as the two major cyclones that struck Vanuatu in 2015 and Fiji in 2016. For example, they can capture video or photographs of the impacted regions, fly geo-stationary and mimic the action of a cell phone tower, and survey resupply routes to see if these have been compromised by fallen trees, broken bridges, etc. In addition, they can deliver cargo payloads to the disaster-affected area [25].

In summary, drones are highly-suited to the delivery of medical supplies because of their ability to fly directly to the point of care such as a remote healthcare clinic or a field hospital, and because of their relative cheapness when compared to helicopters/fixed-wing aircraft. In addition, as unmanned modes of transport, they do not endanger logistic workers if isolated communities affected by unrest and armed conflict require medical supplies.

However, if it is envisaged that drones will be employed to transport materiel to those in in need, a key decision that needs to be addressed is whether to operate with a short-range drone that costs in the order of US$4,000 versus a long-range drone such as the Aerosonde Mk4.7 (see Table 18.2) which in 2014 cost some US$100,000 [26]. Applied to the delivery of medicinal maggots for maggot therapy, the response to this question will depend on the locations of the medical facilities and the presence/absence of alternatives that would allow the timely and cost-effective provision of medical supplies [27].

In practice, however, the use of drones in a medical delivery role has, to date, been largely limited to short-range micro or mini variants. Whilst such micro/mini drones can provide significant benefit to the responding agencies (and, hence, the affected populations), their endurance is typically less than 30–40 minutes with a payload, in most cases, of less than 10 kg (see Table 18.1). Thus, such systems have a limited capability when required to transit significant distances from their base to the patient. Consequently, consideration should be given to the potential benefits in terms of reach and cost savings of long-endurance drones. In particular, it should be noted that whilst the payload of such drones is similar to their smaller counterparts, their range is in excess of 1,000 km thus allowing them to cover significant distances from their base station without refuelling.

Drone Service Design Considerations Specifically for Medicinal Maggot Distribution

Although drone technology has enormous potential to ease the medicinal maggot distribution challenge, it will be important to select the particular combination of aircraft and service infrastructure with the appropriate capabilities to meet the circumstances in which the supply chain is operating. To illustrate this challenge, it follows a brief discussion of drone service design considerations [28] and how they might apply to drone-assisted medicinal maggot distribution.

What Level of Autonomy and Automation is Required? It is unrealistic to expect that drone operators and technicians can be located at every remote healthcare facility that requires medicinal maggots for wound care and other medicines. Likewise, a comprehensive rollout of training programmes for lay operators in these facilities may also be hard to implement. Therefore, it is desirable that drone technology is as autonomous and automated as possible. Ideally it should require no, or very little, intervention from staff at the receiving end.

What Are the Ground- and Flight-support Requirements Regarding Technology, Staffing, and Training Needs? Drone service operation and monitoring of the drone fleet in transit is not trivial and requires adequate financial investment, access to technical support, and staff that are appropriately skilled. While it is unlikely that medicinal maggot producers will run drone delivery services themselves, they will want to be assured that their consignments of highly perishable medicinal maggots will be reliably delivered in good condition, to the right place, at the right time, and all this at a low cost. Therefore, they and other customers will have a vested interest in the drone systems established and their overall operational requirements. Ideally, these customers should be consulted and have a say in the process of identifying the drone technology that best suits their needs.

What Is the Regulatory Environment for the Operation of Drone Services? Drone service providers must operate within the laws and regulations given by the air safety regulators of the relevant country. These regulators have been caught off-guard by the fast pace of research and development in the aerial robotics field but are now beginning to regulate for the wide-spread use of drones. However, there will be a transition period where the global regulatory landscape for drone operations will be in flux and drone service providers must therefore work closely with these agencies when establishing operations in a new jurisdiction. Regulatory matters are further discussed under 'Ethical and Regulatory Considerations'.

How Much Space Is Available to Launch and Land the Drone? Different drone technologies require different launch and landing or drop-off infrastructure. Short-range helicopter-style drones can land and take off vertically, as do some fixed-wing drones with a vertical take-off and landing capability. Other fixed-wing drones require small runways for landing, whilst Zipline drones (discussed in more detail below) do not land to deliver their cargo but drop it by parachute above the destination healthcare facility. For healthcare facilities receiving medicinal maggots it would be most convenient if the drone landing and launch pad i) had a small footprint, ii) was physically close to the receiving department such as the hospital pharmacy, and iii) was cheap to construct and maintain.

What Is the Desired Range for the Drone? Are Stopovers for Delivery or Refuelling/Battery Change Intended or Possible? It is foreseeable that there is a constant but dispersed need for maggot therapy in hard-to-reach areas, meaning that medicinal maggots for only one or two patients will need to be delivered to several healthcare facilities in a given geographic area. Therefore, it would be convenient for the drone to visit more than one facility on a single trip to fully utilise its cargo capacity. For battery-powered drones with a limited flight range this might make recharging or a battery change necessary. Likewise, hybrid vertical take-off and landing drones such as the Latitude HQ160B use battery power to run the rotors that enable them to land and take-off vertically, which imposes a limit on how many times this can be done before recharging or battery changes become necessary [23]. If drones were required to regularly operate beyond their battery range, then infrastructure at designated stop-over points would need to be in place.

What Delivery Network Structure Is Possible or Desirable? The primary concern to a medicinal maggot producer and the customer healthcare facilities is the reliability of delivery and the condition in which the highly perishable medicinal maggots arrive at the point of care. From this perspective, the producer is likely to be only interested in a hub-and-spoke distribution network where the hub is the producer location and the spokes are the trips to the remote healthcare centres. Whether the drone operator chooses to fly the drone back to the producer location or sends it on to another location is of no consequence to the medicinal maggot producer.

What Is the Nature of the Payload? What Is Its Relative Density (Mass-to-Volume Ratio)? Is the Primary Packaging Rigid or Plastic? Does It Require Temperature Control? Is It Fragile, or Hazardous? Medicinal maggots prepared for maggot therapy are minute and have negligible weight and so are normally packaged in light but rigid small plastic containers (primary packaging). The perishability of the product also demands temperature-controlled parcel packaging. It follows that a key concern when sending medicinal maggots via drone is the consignment volume and the need to maintain the acceptable temperature range of 6–25°C [1]. Producers wanting to utilise drone transport will have to work with drone service providers to develop packaging and payload compartment solutions that ensure efficient use of payload capacity and maintain temperature control. Recently developed short-range drones and the medium-range Wingcopter and Swoop Aero drones have been developed with a focus on the transport of general medicines and blood products [18, 19]. They are likely to meet the general requirements for medicinal maggots, but it appears that the use of long-endurance drones for cargo transport (including medicinal maggots) may still require some more research and development.

Case Examples of Drone Technology that Could Meet Medicinal Maggot Distribution Needs

Short-range Quadcopter Drones

Matternet (https://www.mttr.net/) is a drone technology company focussing on the development of drone logistics networks for the transport of goods. For example, Swiss Post is using Matternet quadcopter technology for the delivery of blood and other pathology specimens in the Swiss cities of Lugano, Bern and Zurich [29], whilst the feasibility of their short-range drone systems has also been demonstrated in several LMIC settings. For example, in Bhutan Matternet collaborated with the World Health Organization (WHO) to trial the transport of medical supplies across difficult Himalayan terrain to provide hard-to-reach communities with access to healthcare [30].

The effectiveness of this form of quadcopter technology has also been demonstrated in a collaboration with Médecins Sans Frontières (MSF) who, in 2014, trialled the use of a battery-operated drone to transport tuberculosis samples from a remote health clinic to a main hospital laboratory in Papua New Guinea [31]. Whilst the clinic was 43 km by air from the hospital, by road the distance was 63 km. Under normal conditions the road trip took four hours but in bad weather the road was impassable. The US$5,000 drone employed had a range of 28km, and so had to stop over at a village for a battery change. Even so, the transit time with a 0.5 kg payload was under one hour compared with the (at least) four-hour regular journey by road [31].

Medium-range Fixed-wing Drones

The challenge of limited endurance of drones has been overcome by a number of drone developers with varying technological approaches. For example, Zipline has been providing a core transport service for medical supplies initially from two locations in Rwanda, and more recently (2019) in Ghana, where 30 drones have been operated from four distribution centres [17].

In 2016 WeRobotics conducted test flights with various fixed-wing drone systems in the Peruvian Amazon, where poor infrastructure and remoteness prevents timely distribution of life-saving medicine [32]. Drones were used to transport snake bite anti-venom, blood samples and various other essential medical and non-medical items between a local health hub and remote villages. For one such village, drone delivery took only 35 minutes compared to the six-hour river-boat trip that would normally be necessary to access the remote community.

Wingcopter medical delivery drones have been successfully tested in Tanzania and Malawi. In Tanzania the drone was used to deliver medicines over a 60 km distance to the 400,000 residents of Ukerewe Island, Lake Victoria. Over the six-month pilot project, the drone performed more than 180 take-offs and landings and spent a total of 2,000 minutes flying 2,200 km to and from the island [33].

Implementation of Drone-assisted Medicinal Maggot Distribution

Packaging requirements. Medicinal maggots are a highly perishable commodity which must be protected from extreme heat, cold and mechanical stress. The rotary drone systems developed for transport of medical and other goods are designed to carry their payload in generous payload compartments that may be part of the fuselage or a separate payload pod. The long-endurance drones typically carry cargo within the fuselage which imposes limitations on the volume of the payload as well as its shape which must align with that of the fuselage. However, it appears there has been less focus on the design and development of long-endurance cargo drones to maximise payload capacity and convenient loading and unloading of cargo, and so this is likely to be an area that will benefit from further investigation. Medical goods such as blood products, vaccines, and medicinal maggots also require protection from adverse temperature conditions, especially when flying for many hours in all kinds of weather. Given that medicinal maggots have not, as yet, been distributed by drone, it is clear that trials would need to be conducted under different climatic conditions to test whether medicinal maggots can be safely delivered without suffering loss of vigour.

Training. There would need to be a robust training programme that ensures the safe and ethical operation of drone services. Depending on the mode of drone technology employed, staff at healthcare facilities receiving medicinal maggots would need to be able to safely oversee the landing of the drone, or the retrieval of a parachuted parcel as in the case of Zipline services. Regarding the former, staff will almost certainly need to be able to report to the controlling agency that the landing area is clear and that it is safe to land the drone. They would then need to remove the medicinal maggot consignment and re-launch the craft safely. For fully autonomous drones this would simply involve securing the launch area and giving remote operators permission to launch. For less sophisticated drone models, it might involve catapulting the drone by hand. However, the emerging generation of cargo drone services are moving towards complete automation, with customers requiring no training whatsoever to dispatch or receive deliveries [34, 35].

Ethical and regulatory considerations. Drones were originally developed as weapons of war. It is therefore important to consider the ethics of using drones to transport medical supplies such as medicinal maggots. Fortunately, recent studies on the perception and application of drones in medical and humanitarian contexts [27, 36] suggest that most stakeholders endorse drone technology because it can strengthen humanitarian responses, enable rapid needs assessment, and fast delivery of vital medical goods. Nevertheless, a sizeable minority still have doubts and view the deployment of drones in humanitarian work unfavourably. The prevalent attitude toward drones will differ from community to community and depend on the humanitarian situation. For example, it can be expected that conflict-affected communities who have experienced military drone attacks would be apprehensive about humanitarian drone use, while hard-to reach and natural disaster-affected communities are more likely to embrace the use of drones. In this regard it would be important to ensure that all stakeholders involved in the operation of drones are comfortable with this technology ahead of its implementation. This could, for example, involve community and business consultations explaining the benefits of drone technology and discussing any potential downsides, actual or perceived.

Irrespective of community buy-in, drone services cannot be implemented without regulatory approval. The key issue is the development of a suitable regime that ensures the safety of those involved in the use of drones as well as those with whom they may interact, such as regular commercial aircraft flights or ad hoc operations by fixed or rotary aircraft. Multiple national and transnational aviation agencies across the globe are actively engaged in developing regulations that provide an appropriate balance between safety and privacy concerns and the potential benefits of drone operations [37]. Unsurprisingly, rapid progress in drone technology and a push by industry to operationalise civil drone services in both high- and low-income countries is resulting in a complex mix of regulatory responses depending on geographic location and jurisdiction. Given this fluid regulatory landscape, a detailed discussion in the context of maggot therapy supply-chain management is best postponed because it would be quickly out of date. Nevertheless, three key areas will need to be considered as part of the overall approach adopted.

- ***Airspace management***. Drone operations occur under the International Civil Aviation Organisation (ICAO) rules which state that the lower ceiling for commercial aircraft operations is 500 feet (or 1,000 feet over buildings, towns or cities). Under this ceiling, countries set their own rules and these would generally apply to drone operations. This division is aimed at de-conflicting the airspace and thereby allowing room for industry to work with local civil aviation authorities to develop a suitable regulatory regime to oversee what is sometimes described as Unmanned Traffic Management (UTM). As an example, in the aftermath of Typhoon Haiyan (locally known as Yolanda), which struck the Philippines in 2013, the mayor of the affected region banned the operation of all aircraft (including rescue helicopters) for a period in order to allow the use of drones to provide maps of the region for subsequent use by the responding agencies and non-government organisations (NGOs) [38]. It follows, therefore, that this aspect should be considered as part of the distribution network design, selection of drone capabilities, and actual operations.

- ***Privacy issues.*** Each country sets its own rules around the issues of privacy. For example, in some countries a drone operator should obtain express permission from all individuals and landowners within the proposed flight path, and this also applies to members of the public overflown in public spaces such as parks, etc. Such laws are routinely flouted by amateur operators, but compliance with local regulations such as this would be a major consideration for any medicinal maggot drone operators—although the local authorities may be able to provide specific authority for drone flights in the event of a disaster or an emergency response.
- ***Licencing of operators.*** In most countries the operation of drones requires the individual 'pilot' to possess an appropriate licence. Obtaining such licences and maintaining the required continuation training has the potential to create further challenges as there is no guarantee that a pilot who is certified in Country A will be permitted to operate in Country B. Thus, it will be important to ensure that the drone operators do, indeed, hold the required operating licences. Given the areas of challenge summarised above, it is relevant to note that the previously mentioned UAViators Network has led the development of a Humanitarian UAV Code of Conduct (https://www.uavcode.org/code-of-conduct/) and accompanying guidelines which were developed via an extensive process of expert consultations including a UAV Experts Meeting in 2015, co-organised with the UNOCHA, the World Humanitarian Summit (WHS) and Massachusetts Institute of Technology (MIT) [39].
- ***Outsourcing to third-party service providers.*** The proliferation of drone systems and services to provide transport for medical

supplies provides ample opportunity to collaborate with other organisations wanting to distribute medical commodities such as vaccines, blood products, and pathology samples. For instance, a medicinal maggot production laboratory might sensibly share drone services with a pathology laboratory. In such a scenario (that is similar to the case study in PNG described earlier) medicinal maggots would be flown one way to remote communities, and instead of returning empty, the drone could deliver pathology specimens from those communities to the local pathology lab for analysis. This would lead to better utilisation and fewer empty trips, and thus more cost-effective operations. From this it could be argued that drone-services are best provided by a third-party service provider who coordinates and operates transport services for a host of customers and commodities. This would ensure better utilisation of drone capacity by more customers, which is essential for the financial sustainability of the service [40].

Summary

Medicinal maggots are highly perishable and need to be delivered within 24–48 hours to the point of care. In most instances this can be achieved with third-party transport providers using regular air- and land-based transport networks. However, where such transport infrastructure does not exist, or where it is interrupted due to war or disaster, it will become necessary to utilise alternative technologies such as cargo drones. Rapid improvements in endurance, range, payload capacity and automation are already making drones a viable alternative to traditional high-speed courier services in cities as well as in compromised healthcare settings. Consequently, maggot therapy supply-chain managers are encouraged to consider drone-assisted distribution of medicinal maggots and related consumables where other forms of transport would not guarantee timely delivery.

Medicinal maggot transport with drones has not been tested yet. Particularly long-duration flight may expose medicinal maggot payloads to detrimental environmental conditions, e.g. high or sub-zero temperatures, or excessive vibration. Therefore, implementation research and development trials are required to test the capacity of various drone technologies to safely deliver medicinal maggots, and to make improvements to drone design and medicinal maggot packaging if necessary.

It is unlikely that medicinal maggot producers will have the volume of deliveries required to make the operation of a drone fleet financially viable. Rather, with the growing uptake of drone technology in the development and humanitarian sector, it makes more sense to take advantage of commercially operating drone service providers.

To conclude, cargo drone technology has the potential to bring maggot therapy to patients in healthcare settings previously considered unsuitable for this therapy because effective, efficient and timely supply chains were impossible to maintain.

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