Introduction

Since the dawn of human spaceflight with Yuri Gagarin's 1961 expedition into space, 612 individuals have travelled to space to date.[1] Space travel poses significant risks to human health and performance, with the extreme conditions of the space environment inducing a myriad of physiological reactions and adaptations. Acceleration forces, weightlessness, and radiation are just some of the stressors imposed on humans in the space environment, and act as key mechanisms for the physiological changes experienced by humans during spaceflight.[2] One such example can be seen in weightlessness. Microgravity-induced weightlessness experienced by space travellers fuels physiological change across the cardiovascular system, where hydrostatic forces exerted on the heart and blood vessels are alleviated, leading to structural changes to the heart, potential changes to the pumping action, and fluid redistribution of the blood and interstitial fluid centrally as opposed to the wider extremities of the body.[3]

Extending beyond the cardiovascular system, in the absence of countermeasures, the musculoskeletal system, including bone and muscle, exhibits atrophy at a rate of 1%-1.5% and 1% per month respectively, and the neurological system is hindered by space motion sickness, estimated to impact around 70% of astronauts.[4] In addition to the negative effects of radiation exposure, these examples demonstrate some of the unique variables for the space sector to have considered for the sustained health of humans in space.[3] Not all health concerns regarding the space environment are physiological. An incident during Skylab 4 in 1973, for example, where the crewmembers ended communications for a break from work-related duties causing significant concerns in terrestrial control, demonstrates the importance of crew mental health for the successful completion of spaceflight missions.[5]

With the extensive impact of the space environment on human health in spaceflight, medication has been a key feature for promoting and maintaining astronaut health since the conceptualisation of human spaceflight. There is much fragmentation in the use of descriptors for the different disciplines that make up the pharmacy and pharmacology sector, and different laws and regulations for these disciplines in every country. With respect to this paper, the term Pharmacological Countermeasures (PCMs) will be employed to refer to any drug, medication, or non-food nutritional supplement used to improve health. Early PCM examples can be seen in the early Apollo programme, where marezine tablets was originally used for the treatment of space motion sickness for astronauts, though this was later replaced on Apollo 11, 13 and 17 by a combination of dextroamphetamine and scopolamine capsules due to greater efficacy of the combination in reducing the sedation side effect,[6] with intramuscular promethazine also demonstrating efficacy as well.[7] Medication has also been used across other health systems, with bisphosphonates like alendronic acid combined with resistance exercise being successful in the reduction of all bone physiology indices.[8] Further reports from astronauts on the International Space Station indicate zolpidem and zaleplon use for improved sleep, and the administration of ibuprofen, paracetamol and aspirin for the pain-related treatment of joint, back and muscle pains and headaches, among others.[9] Across the space continuum, pharmacotherapy acts as the first line of treatment for the adverse events encountered in the space environment.

Given the direction for future spaceflight focusing on long-term exploration and humans becoming an inter-planetary species, pharmacotherapy will be a necessary consideration for risk management to enable the sustained presence of humans in space. With the National Aeronautics and Space Administration (NASA) launching the Artemis Programme to return humans to the moon by 2024,[10] and aspirations to develop a lunar gateway facilitating human exploration to Mars and beyond,[11] medication will be vital in managing human health in space. This will be particularly important given the rise of commercial and civilian space travel (including tourism) and the current lack of medically binding criteria for a commercial spaceflight participant's suitability to fly. These existing practices will enable humans with pre-existing health conditions to venture into space safely for the first time.[12] However, the current lack of knowledge regarding drug stability, altered pharmacokinetics and pharmacodynamics, and pharmaceutical usage and efficacy acts as a significant barrier to the successful treatment and prevention of medical events and the chemical safety and robustness of any pharmacotherapy onboard.[13] For example, studies have shown that drug absorption, metabolism and excretion are significantly different in spaceflight. Previous spaceflight experiments demonstrated that the rate of absorption for paracetamol is doubled during spaceflight, with crewmembers also demonstrating faster peak concentration and drug clearance levels compared to ground-based comparisons. However, crewmembers' salivary concentrations demonstrated lower levels of absorption and peak concentration later in flight.[13-15] While such findings may be a consequence of the inherent limitations associated with spaceflight research, including the use of saliva sampling as opposed to blood testing and the small sample size available at the time, the potential for drug-related physiological changes is a necessary consideration for spaceflight safety. For drugs with a narrow therapeutic index (digoxin, theophylline, warfarin, etc.), significant changes in blood concentration can be fatal, and a more comprehensive understanding of pharmacokinetics and pharmacodynamics is therefore essential for space travel.

The current discussion surrounding medicines has become an important consideration for future spaceflight, but there is a lack of ongoing discourse on pharmacists and medication. As a flexible healthcare profession with expertise in medicines, pharmacists are ideally placed to consider PCMs in space, but are minimally involved in current space operations. Although the role of the space medicine doctor has been discussed in the literature,[16] there is significantly less dialogue surrounding the role of the pharmacist with regards to the health of space participants. While a small proportion of pharmacists are actively involved with space participant health in the space sector, their role has much more potential, being primarily centred around the preparation of medication kits and medication utilisation reviews for astronauts at the International Space Station.[17] Contemporary pharmacists contribute to a number of key areas within healthcare, including the rational, cost-effective use of medicines, the direct involvement with patient care and the ability to collaborate with many healthcare professionals.[18] They also contribute towards drug procurement,[19] pharmaceutical compounding, and conduct these roles across a range of settings beyond day-to-day healthcare contexts, like disaster response zones.[20] The present-day pharmacist has a broad skill set, yet they currently play a limited role in the space sector despite the pharmacist potentially being able to support a range of medication and general healthcare-related duties. As a consequence, this study aimed to investigate the pharmacist's role in the space sector across various pharmacy and space sector stakeholders.

Methods

Study Design

A blend of semi-structured interviews (n = 34; pharmacy n = 15, space sector n = 19) and focus groups (n = 7; pharmacy n = 5, space sector n = 2) were used across pharmacy and space sector stakeholders, including in-person and online formats. Online interviews and focus groups were conducted on Microsoft Teams, while in-person interviews and focus groups were conducted in University seminar rooms. While interviews were conducted in one-to-one scenarios, focus groups sizes varied between 2-4 participants across both stakeholder groups (n = 22; pharmacy n = 15, space sector n = 7). All interviews and focus groups were digitally recorded and subsequently transcribed verbatim. Research participants and members of the research team were present for all interviews and focus groups. Ethical approval was obtained from the School of Pharmacy ethical committee (Ref-014-2019).

Sample and Recruitment

The Consolidated Criteria for Reporting Qualitative Research (COREQ) was used to guide the study methods.[21] A combination of purposive and snowball sampling was used to recruit pharmacy and space sector stakeholders (total n = 56; pharmacy n = 30, space sector n = 26). The pharmacy stakeholders represented various pharmacy domains, including hospital, community, general practice, industry, academia, policy makers and future pharmacists. The human health-related space sector stakeholders included the following participant backgrounds: commercial space industry, international space agency sector lead, private astronaut, future space tourist, space law, space journalism, future space doctor, space academia, policy makers and aerospace doctor. The sample included international representation from Africa, Asia, Australia, Europe and North America. Purposive sampling provided the power to approach participants with the backgrounds to represent the various sectors.[22] Snowball sampling is frequently applied where samples with target characteristics are not easy to access.[23] Inductive thematic saturation was used to guide data collection, with the absence of novel themes or codes indicating the continuation or conclusion of data collection respectively.[24]

Procedure

Recruitment email invitations were disseminated to potential participants of interest, who were identified iteratively through personal and professional networks, conferences and relevant online platforms. For instances where participants were known to a researcher, another member of the research team conducted the relevant interview/focus group to reduce potential instances of bias. Participants who expressed an interest in participating were provided with a participant information sheet and written consent was obtained. Once initial consent was obtained, a member of the research team liaised with the participant to determine an appropriate time to conduct the interview. A semi-structured topic guide was used during the interviews/focus groups. Participants were made aware that the focus of the research was to explore the potential role of pharmacists in space travel. The interview/focus group schedule (Appendix 1) explored a series of introductory space questions to set the tone of the interview, and followed this by asking participants to outline what they believe the pharmacist's role could be in the space sector. This was followed by questions regarding the associated barriers and facilitators to participant-described roles, and concluded with the interviewer(s)/facilitator(s) asking participants about future recommendations for the incorporated roles. These topics formed the main body of the questions asked. Additional non-scheduled questions were used to elicit further information on the topics mentioned. Field notes were made during and after interviews/focus groups to aid data transcription, analysis and management processes. This paper focused on information pertaining to the pharmacist's role, rather than the barriers, facilitators and recommendations, for data management purposes.

Data Analysis

The verbatim transcripts were analysed using Braun and Clarke's six-step process for thematic analysis,[25] identifying themes across both stakeholder groups which represented pharmacist roles conducted within the space sector. The six steps to thematic analysis were: Become familiar with the data; generate initial codes; search for themes; review themes; define themes; and conduct write-up. An inductive, data-driven approach was used for the analysis to generate themes,[26] rather than a pre-determined framework or theory. An inductive thematic analysis was used, meaning the themes were derived directly from the data.[27] The investigation followed a phenomenological orientation. Due to the exploratory nature of the study, our research focused on the description of the potential pharmacist's role in the space sector from the personal and subjective lens of the participants' experiences.[28]

The primary purpose of thematic analysis was to identify emergent patterns that interpret and make sense of the data, which can subsequently be used to address the research purpose.[29] NVivo 12 (QSR International, a computer-assisted qualitative data analysis software, was used to manage and analyse the data collected. The data analysis was conducted by two researchers; one experienced qualitative pharmacy researcher (L.S.T) and one trained qualitative health psychology researcher (L.S). Both interviews and focus groups were transcribed and uploaded to NVivo 12 where thematic analysis was conducted. The codes for interviews and focus groups were then combined to create a series of overarching themes. This was conducted independently and discrepancies were presented to a third experienced qualitative pharmacy researcher (C.A) to reach a consensus.

Results Thematic Analysis

Thematic analysis led to the generation of three overarching themes (Table 1). Inductive thematic saturation occurred at approximately 50 participants, with the continuation of recruitment >50 participants acting primarily to expand the geographical representativeness of stakeholders. To aid with clarity of interpretation, we define spaceflight participants as those who are actively participating as astronauts, deep space exploration members, or space tourists. Two acronyms were used to identify Pharmacy (PH) and Space Sector (SS) participants.

Table 1: Themes and Sub-themes Generated

Themes	Sub-themes
Medication management	Medication optimisation
	Medication distribution
	Manufacturing
Medication-related research	Drug properties
	Human health, practice and clinical research
	Analogue research

Medication Information	Improving space health and medication literacy
	Medication consultations
	Space medication information hub
	Telepharmacy

Medication Management

The most consistent definition of medication management encompassed the system of processes, cost effectiveness and behaviours which aims to ensure medications are used safe and effectively, based on the definition proposed by the United Kingdom National Prescribing Centre.[30] Activities which promote safe and effective medicines management occur at each stage of the medicines journey and aim to improve outcomes for the patient. The stages of the medication journey include manufacturing, procurement, prescribing, dispensing, supply, storage, patient use and disposal present in contemporary society.[18] Within the theme medication management, sub-themes of medication optimisation, medication distribution and manufacturing were generated.

> *"You can have medical doctors over there (space) and it's definitely appropriate to have a pharmacist over there to at least help to safeguard the medication."* (Interview; PH2).

Medication Optimisation

The UK Royal Pharmaceutical Society's defines medication optimisation as focusing on outcomes and patients relative to medication, supporting them to attain the correct medicines at the appropriate time. The definition examines how patients may stop or start their medicines, how they use them over time and how lifestyle changes or non-medical therapies may reduce the need for medicines.[31] Across both groups, medicine reconciliation and reviewing spaceflight participant medicine regimens before, during and after flight was considered an important component of the role, to optimise medication use. For the purposes of this study, we interpreted medication optimisation to sit within the broader scope of medicines management.

> "*You've got an individual that might be taking a medication regimen ... preferably it's by a pharmacist who's the expert in medicines and therefore can understanding from a pharmacodynamic and pharmacokinetic perspective how the medicines (work) … because really what we're talking about is do their current medications need to change in the context of being in space."* (Interview; PH11).

Space sector participants highlights that the pharmacist role can address the gap for patient-centred care in spaceflight participants, by addressing patient's concerns such as minor ailments and not only focus on fatal health issues.

> *"I think a pharmacist could really think about the comfort of participants in ways that I know a lot of the other researchers are not… An experienced pharmacist could sit down and say "ok I've worked with 12 astronauts, I know that many of them felt discomfort during this part of the transition… this percentage of them felt like they had a head cold until they chose to medicate, you know here are the things you can do prophylactically in advance, here's the fast-acting solution for you know when you find yourself in trouble, and then here's something for maintenance " (Interview; SS19).*

In reference to the timeline for medication reviews and documentation, a combination of pre-flight and post-flight were most frequently recommended by both groups.

> *" … You would also need a record of what medicines the person's taking on Earth before, what they would need in space and if they would need any medicines on return to Earth as well."* (Focus Group; SS6).

The benefits of having a pharmacist to optimise medication for spaceflight related to the alleviation of adverse health effects, supporting spaceflight participant health by ensuring medication used are effective, managing and troubleshooting potential unknown side effects associated with space travel. This was particularly prevalent in space sector stakeholders.

> *"So pharmacists may play a big role as we said earlier in order to 'control' the … with the right … medicines … they could (help maintain)… astronauts' health … (at a) standard, say little (side effect) problems, little or big (emergency) problems that might happen during their stay in space."* (Interview; SS12).

Personalised medication regimens was a notable inclusion across both groups.

> *"I think again it comes down to individualisation where a pharmacist plays a big role, how to individualise a drug or a regimen or a treatment… because… the bodily factors are changing, the dynamics are changing, you would want an expert to make sure that, you know, this particular treatment is perfect for this kind of, changes, this kind of person"* (Interview; PH9).

Pharmacists optimising treatment regimens for spaceflight remained constant across both groups, with further reference to the need for updating space-related clinical guidelines in line with contemporary healthcare. Participants inferred that pharmacist input could modernise and progress the antiquated medication practices within the space sector, suggesting the inclusion of pharmacists in developing space-related clinical guidelines.

"So pharmacists are going to be sitting there thinking you're giving this drug that you gave in the 1950s but because it works we're still sticking with it … yeah and they don't have that feedback within the medical team." (Focus Group; SS4).

Medication Distribution

Both groups suggested the distribution of medications as an area needing more pharmacist involvement. Medication transportation was the most frequently discussed role in the area.

" … And one major area I would say is transporting medications… whether they transport it as a tablet form or a liquid or, or they go from there and compound it and what kind of diseases are more prevalent there." (Interview; PH9).

Pharmacists were suggested to have more insight in the supply, packaging and storage of medication to be transported, determining the most appropriate formulations for spaceflight medication transportation and storage.

"We had fights in fancy boardrooms about, err, refrigeration, it's like why can't I have a refrigerator? And the engineers were like "oh no you can't, like we don't have the power, we don't have the room, we don't, no you can't have a refrigerator." And the engineers would say "well can't you put the medicine in the corner of the food fridge?" I was like no, the food fridge gets opened a bunch of times a day, that's not sensible, and then we have issues with contamination and microbial growth and like, no that's not the way to go either, so yeah." (Interview; SS13).

Although the space sector stakeholders agreed with the pharmacist's role in the supply and storage of medication, they believed a pharmacist could develop novel transportation modes to ensure continuous supply for longer space exploration and space tourism.

" … I think people will have to come up with novel ways of actually … transporting these new medicines as well." (Interview; SS2).

Manufacturing

Manufacturing emerged as a common role across both stakeholder groups. In particular, drug development and manufacturing were identified as suitable roles for pharmacists, suggesting pharmacist involvement in creating pharmaceuticals for use in space.

" … There's no special space-made medications that exist yet, and I think that the role of the … pharmacist then is to think about whether it is useful to make special space-made

> *medications for astronauts, with different dosages, different routes of administration, so different characteristics and perhaps different materials."* (SS-17).

Pharmacy stakeholders indicated quality assurance and regulatory opportunities for pharmacists to undertake.

"One… of the roles, because when it comes to QC [Quality Control], QA [Quality Assurance]… from a completely regulatory point of view, you still need a pharmacist to, to (do) all these things." (Interview; PH1).

Although stakeholders cited and supported the manufacturing of in-situ three-dimensional (3D) printing of medication in space, several participants did not feel the pharmacist's role would be able to optimise the technology due to the lack of technical training. Participants did, however, identify the need to involve a pharmacist to ensure medication is appropriately licensed and regulated for treatment.

> *"Anything that is going to be consumed to treat any… disease, it is considered a medication and so it has (to have) full licensing and it has to go under a pharmacist"* (Focus Group; PH2).

Medication-related Research

The second theme identified considered pharmacists in a research-related capacity, with three research areas comprising the sub-themes: drug properties research, human health and clinical research and drug-analogue research.

Drug Properties Research

Participants perceived that a pharmacist could help research drug profiles in reference to the space environment, with pharmacokinetics and pharmacodynamics being the key properties to consider.

> *" … Definitely looking at pharmacokinetics and pharmacodynamics … I think that's a really important aspect because … there is some evidence to show that these change in space."* (Focus Group; SS6).

Participants supported a collaborative approach to drug properties research, with one suggesting a pharmacist could work with a pharmacologist to strengthen the research.

> *"I think the other aspect though is to understand, I think pharmacists and pharmacologists have a role to play in understanding the difference in the pharmacodynamics of any drugs in space."* (SS16).

Drug efficacy was a research area to consider as well, with a focus towards understanding whether drugs work in a space environment compared with a terrestrial environment and whether they have a similar side effect profile.

> *" … Then there's the 'well how do we know (if it's providing the intended therapeutic effect)?', well then there comes in the research part… it's everything from, again just thinking very basically, is an aspirin … how, do you, does an aspirin work the same way in space as it does here?"* (SS7).

Drug stability was also considered by participants as an important concept to investigate, with drug storage identified as important in the context of medication degradation.

> *" … Storage is obviously a huge concern on spaceflight, you can't bring your medication like this up and even if you did they'd probably degrade. So for something like flying to Mars, when they've flown medication before they degrade quicker than they should on their shelf-life, I mean that was only one study but we definitely need to do more research into that."* (Focus Group; SS6).

In response to being asked whether any particular areas of research would need to involve a pharmacist, some participants mentioned the concept of drug stability in light of different dosage forms for medication, indicating the pharmacist could play a role in better understanding dosage forms in the context of drug stability in space.

> *"The pill form or the capsule form - Is there a difference? Maybe there is, maybe there isn't, and then you're talking about … injectables and inhalers, all these other dosage forms that then you kind of have to just say … does it, does it just stay stable?"* (Interview; SS7).

Human Health and Clinical Research

Pharmacy and space sector stakeholders suggested pharmacists could play a role in furthering knowledge around the human body in space more broadly.

> *"… And so what happens when we're in this position, and so I do think there's an important role for pharmacists, for pharmacy, and the understanding of how the body responds and how the health of the body alters in space."* (Interview; SS9).

The pharmacist's role in the context of human health research shifted towards human health and medication, with space sector stakeholders suggesting the research role could support drug protocol development and medication management research promoting the safe use of medications for humans in space.

> *" … I think the role of the pharmacist is going to be a lot of research and experimental at first because we're going to have to design whole new (medication) protocols, and decide on methods of drug delivery, what works and what doesn't because of the fluid shifts, you can't use like gas and air and stuff, and what drugs you can take and some of the side effects aren't ones that you're gonna (expect).*" (Focus Group; SS4).

Regarding the conduct of research, pharmacy and space stakeholders preferred humans as active participants under study would be important, with some space sector stakeholders recommending research participants with prior spaceflight experience.

> *"Well … I think that you … can get the data out of the people that have already flown."* (Interview; SS19).

Participants highlight the concept of a large-scale voluntary participation programme for human space research, with less focus on actual spaceflight experience. However, they highlight that cost would be a limitation to medication research.

> *"I think it would bring them to cost considerations, so probably which country and how much cost would be a major factor deciding where exactly to do the research. There has to be testing centres, there has to be research centres… I think again human volunteers have to test themselves and produce research."* (Interview; PH9).

Analogue Research

A subset of pharmacy and space sector stakeholders considered analogue research important, with a pharmacist using terrestrial research methods to extrapolate findings to the space context.

> *"You know an adverse event had never been considered of what was going to happen in space. But how do you, how do you research that? You can research it based on the data that you have from folk in high altitudes, and extrapolate from there if that is possible"* (Interview; PH7).

Medication and Health Communication

The final theme referred to the pharmacist in a pedagogically-focused role, supporting health and medication information communication and dissemination within the space sector. The four sub-themes generated were: improving space health and medication literacy, medication consultations, space medication information hub and telepharmacy.

Improving Space Health and Medication Literacy

The education role was primarily identified by pharmacy stakeholders, and related to medication use education for spaceflight. The education role involved pharmacists explaining a spaceflight participant's, and particularly a space tourist's, health status to them, providing them with information pertaining to medication use and management in space.

> *"They need to be explained about the health condition and about how they manage the medication or even if like the dose is changed of how the medication is being used in … space."* (Interview; PH4).

Suggestions were made for pharmacists to educate spaceflight participants on the impact of the space environment on their health. Space sector participants pointed to the lack of regulation responsibilities surrounding the health of spaceflight participants as adding value to such a role.

> *"… But from a health side it [health risk] is not covered because there are no regulatory requirements for the health of a spaceflight participant. But I do think health literacy is important, yes."* (Interview; SS1).

In terms of the timeframe and structure, participants perceived the education role to function at pre-flight and during-flight, providing medication and holistic health education.

> *" … The astronauts that we have now are largely interested in taking care of themselves well, but they might not know everything they need to know, and I think that an Astropharmacist, if you had an additional member of the medical team that could give good advice on diet, on supplements, on medication, that would be really helpful having another potential medical educator on the team, I think that could be really useful."* (Interview; SS13).

Medication Consultations

While pharmacy stakeholders perceived medication consultations as important, more space sector stakeholders viewed medication consultations as an important role for pharmacists in the space sector.

> *"Somebody helping me map out what pharmacological agents I would take with me in a personal preference kit wouldn't need to be with me every day of my training … but it would be somebody who would be brought in as a consultant, you know, and said '… let me sit down with you and interview you and talk to you about … what things do we think you might be sensitive to, what you wouldn't be, let me look at your … personal history with medicines and how you react to various medicines and let me develop a plan for putting to the kit'."* (Interview; SS19).

Some space sector stakeholders referenced medication consultations as guiding medication plans and providing general support for spaceflight participants, with others highlighting pharmacists as able to consult about the production of medication as well.

> *"… So actually making the medications and providing expertise and consultation is where they (pharmacists) can play a role."* (Interview; SS17).

Pharmacists could also support the extraction and utilisation of appropriate constituents for drug development on an extra-terrestrial level, according to space sector stakeholders.

> *"So if, if say a scientist or a geologist says we have this much silicon on the moon, a pharmacist is going to know better than anybody whether we could use that as an excipient to, to bulk up that drug that we're meant to be making."* (Interview; SS17).

Additionally, pharmacy stakeholders perceived medication consultations to focus on clinical health, as opposed to medication manufacturing outlined by the space sector stakeholders.

> *" … If people are feeling unwell ... they can contact the pharmacist, and then the pharmacist can tell them … give them some advice … tell them what medication to take, and … lifestyle advice, maybe … something like how to relieve some symptoms inside of, in space."* (Focus Group; PH-1).

Space Medication Information Hub

Stakeholders believed centralising space medicine information globally would be useful, drawing a parallel to drug information centres in hospitals on Earth.

> *"… Especially when you say the drug could fluctuate very much in space. So yes, getting all the data, centralising is definitely a very good idea and it's also effective, it's just like your drug centre, your drug information centre over here. So it serves the same purpose."* (Interview; PH2).

Other stakeholders perceived a pharmacist as developing an information database, rather than an in-person hub.

> *"I think it's a bit weird for a space man on the moon to call me in here to ask me about paracetamol. I think most likely it would be a database."* (Interview; PH1).

The British National Formulary (BNF) was described to be a proposed database structure, with a space-specific formulary being more beneficial than a drug information centre.

> *"A space BNF. Yea I think most likely it will be some kind of space BNF."* (Interview; PH1).

Telepharmacy

Several pharmacy stakeholders proposed telepharmacy as a useful mode for consultations.

> *"I think the role of a pharmacist … like telepharmacy, I think that's probably a very good start to say that once I have the knowledge, I am available for consultation."* (Focus Group; PH2).

Other pharmacy stakeholders suggested the use of mobile phone applications as a suitable mode of administration, with space sector stakeholders also highlighting that recent technological advancements could improve the provision of remote digital/telepharmacy services.

> *" … And you know in telemedicine the doctor will say 'I want you to go to the chest and get medication number 10 and take 2 of those tablets for me', it's that kind of thing … but it would be interesting to know If there are ways to improve provision of pharmacy services remotely in that way, in these days of virtual reality, augmented reality, AI and so on."* (Interview; SS16).

Space sector stakeholders later demonstrated how novel technology could be applied to improve remote telepharmacy services.

> *"For example using augmented reality to be able to choose medications or something … because we're looking at that in terms of diagnostics of course, in terms of being able to assist a non-medically trained person to provide a diagnosis and treatment of somebody in the field from a remote centre somewhere, but to be able to do that for medication provision would be useful as well."* (Interview; SS16).

Discussion

Exploring the pharmacist's potential role in the health of space participants yielded an expansive array of opportunities for pharmacist involvement, with medication management, medication-related research and medication and health communication identified as key roles for the pharmacist.

Pharmacist Medication Management in the Space Sector

The frequent discussion of the pharmacist as a medication management professional from both groups reflects the contemporary pharmacist's current role. Pharmacists provide leadership and support for medicines management, with evidence demonstrating that the presence of pharmacists increases the prevention, detection of medication errors and the ability to resolve medication issues that arise.[32] However, studies in medication management for space exploration have been weak in terms of subject numbers, duration and required detail for the evaluation of proper dosing, therapeutic effect, medication use behaviour, adverse events or possible drug interactions.[9, 33-35] Although personal health information cannot be put at risk, such data should be made available to experts for evaluation.[9, 34, 35] The training and education of individuals taking medication in space should be developed through evidence-based research and evaluated in a systematic manner to increase the efficacy and safety of all treatments and to develop human skills, systems and databases in pharmacovigilance and therapeutics.[9, 34, 35] The minimal current space pharmacy workforce may be sufficient to provide medical kits for International Space Station (ISS) supply and medication review for a small number of trained space explorers today. However, this will change substantially when the inevitable expansion towards long-term deep space exploration and commercial, civilian spaceflight comes to fruition. Considerations must now be made to prioritise research with the inclusion of not only basic science and quantitative research but clinical and social sciences to develop health systems interventions to propel space medication management to be at least equivalent to terrestrial systems. There is a need to develop interventions/systems to mitigate medication errors, monitor medication use, evaluate medication reviews, and understand medication use behaviours, with the aim to ensure the safe and effective use of medication with the rapid expansion of commercial, civilian space flight and the complexities of long-duration space flight.

A prevalent concern regarding the commercialisation and advancement of space travel is health risk, which typically revolves around the future trajectory of commercial space tourism as an industry and humans becoming a sustainable inter-planetary species.[36] One of the key health-related concerns for commercial space travel rests within the presence of civilian astronauts like tourists and workers, who may not be as rigorously trained and vetted as federal astronauts. Instead, these civilians are lay members of society with multiple patient-oriented characteristics to consider, potentially requiring more medication optimisation considerations than traditional astronauts. Given the aim to increase accessibility of space yielding a new population of spaceflight participants, such participants may have a variety of health conditions and complex medication needs. Healthcare concerns surrounding commercial ventures will subsequently be heightened, particularly given the currently limited understanding of PCMs in the space environment. These concerns can be addressed by moving from a unidimensional, technology-centred space travel to a multidimensional, technology and patient-centred healthcare-driven space travel, as this approach enables the sector to tackle the complex health profiles of future spaceflight participants while enabling appropriate mitigation strategies for health-related risk to be considered, in additional to the complex technological needs of space. Pharmacists are ideally placed to act as a key profession in the subsequent transition towards a patient-centred spaceflight approach, not only in the context of emergency care but for more general patient-centred care as well, as in their contemporary role.[37] Given the growth of spaceflight technology in recent years, considering patient-centred spaceflight may be important for enabling the space sector to engage more openly, not only with pharmacists, but with other allied healthcare professionals as well. This would enable healthcare professionals to potentially draw upon terrestrial experiences or develop novel means to sustain human space travel, particularly in the context of tourism and deep space exploration, including the colonisation of Mars.

Storage, supply, packaging and transportation of medication is linked to the stability of medications. Various factors such has radiation has been thought to affect the degradation of medication but there are no convincing studies.[13] A current study on the ISS (with specimens inside and outside) has investigated the impact of cosmic rays on ibuprofen test specimens, formulated by direct compaction as tablets with entirely inorganic ('lunar-analogue') excipients. Several tests are being conducted, including space-specific ray protection concepts high atomic number-metal coating and targeted excipient matrix-drug complexation, in addition to the conventional shielding of the drug in the excipient matrix. Further testing of aluminium blister shielding, similar to respective commercial tablet packing, is also being conducted,[38] however the study findings have not yet been published, and understanding in this area is currently limited and requires further investigation.

When considering medication management from a distribution and manufacturing standpoint both stakeholders suggested a need for novel approaches. On demand, on site medication manufacturing is an emerging field[39] with both stakeholder groups citing the potential of 3D-printing medication in-situ. Much hope to individualise and provide flexible medication (i.e. personalised medication) was nourished by the introduction of continuous processing in pharmaceutical formulation design in the last decade. In particular, this was triggered by the anticipated facilitation of continuous processing by flow chemistry[40] and the campaign flexibility of modular manufacturing in containerised factories.[41, 42] While this trend has not yet been completed, flow chemistry is unanimously seen as the ideal (on-board) space manufacturing technology, as well as microfluidic chips being ideal for disease studies with tissue materials.[43, 44] A relevant development for on-board space medicinal manufacturing came from the Massachusetts Institute of Technology and Novartis, who have integrated miniaturised process modules to "shrink" a whole drug manufacturing and formulation fabrication line into two refrigerator-sized process units.[45, 46] Downgrading such advanced technology in terms of increasing robustness and decreasing complexity could increase access of medication and ease transportation cause to other extreme environments on Earth.

In consideration of sustainability, these innovations are recommended to promote the international harmonisation of an appropriate drug licensing, regulation and quality assurance structure appropriate for the space sector. Given the existing drug quality control role which pharmacists currently undertake,[47] with checks relating to air quality and both microbiological and chemical contaminations, amongst others,[48] pharmacists are ideally positioned to support medication licensing and manufacturing quality assurance within the space sector.

Pharmacists as Space Medication Researchers

Regarding the medication-related research role proposed by both stakeholder groups, a wide variety of pharmacist academics exist with a plethora of skills to support a space medication research role. Whether considering drug properties, human, clinical, social/pharmacy practice research or analogue research, a pharmacist can support the conceptualisation, design and conduct of medication-related research in these areas. Pharmacists are frequently involved in many research areas, including medication management, clinical, social pharmacy, public health and epidemiology, service implementation and laboratory investigations, and adapting to a space-related medication research role could be a natural transition for research-oriented pharmacists. Given the identification of pharmacokinetic and pharmacodynamic research from stakeholders, this may be a particularly beneficial area to bolster pharmacist involvement, particularly given the highly limited understanding of these properties in a space environment.[13] Another novel area which pharmacist space medication researchers may want to consider is personalised medication and pharmacogenetics. Personalised medication was intensively investigated in the last decade, with many advances on the analytical determination of the patient's needs from a biomolecular (pharmacogenomics) perspective[49] and using evidence-based medicine[40, 50], but with less advances in supporting the fast, flexible provision of personalised medicines and personalised formulations. Pharmacogenetics testing may be a potential solution to the problems encountered with PCMs in spaceflight, as such testing could be used as a guiding diagnostic instrument to reduce adverse drug reactions or instances of therapeutic failure. Given the recommendation that ~30% of medications available on the ISS may benefit from personalised dosage adjustments or therapeutic changes in poor or ultrarapid metaboliser groups,[51] pharmacists are well situated to research the applications and implications of personalised medication in reference to pharmacogenomics in the space sector.

Throughout the interviews, participants referred to the team-based nature of the space sector. This is particularly important for the conduct of space medication research, and the importance of the pharmacist working in conjunction with a variety of healthcare professionals cannot be overstated. Pharmacists working as part of the research team would need the support of psychologists, nurses, paramedics, disaster scientists, engineers and many more disciplines to appropriately tackle the unknowns surrounding space medication within research. The wider range of resources and multiple areas of expertise provided by multidisciplinary teams typically benefit complex research questions, and the pooling together of multiple resources may also result in substantial cost-savings compared to an individual or single organisation conducting research.[52] With space medication being a pertinent example of a complex research question, the pharmacist's involvement as not only part of the research team but also the healthcare team should be considered in that of a multidisciplinary capacity. Supporting pharmacists to consider a multidisciplinary academic career in reference to space medicine may subsequently be a valuable route for expanding the pharmacist's role into the space sector.

Pharmacists as Medication Information Providers

From an educational standpoint, the pedagogically-driven medication and health communication role primarily identified by the pharmacy stakeholders incorporates key components of the pharmacist's current duties. Whether in a clinical, academic or industry profession, pharmacists frequently communicate medication and health information to patients, colleagues, or lay audiences. Moreover, pharmacists are able to support other healthcare professionals on appropriate medication use,[53] and the general increase in patient-facing duties for clinical pharmacists[54] suggests the pharmacist's current skill and experience-based profile complements a medication and health information role for the space sector. Providing general medication education to spaceflight participants and conducting medication consultations appear to be natural roles for a pharmacist to undertake, which was supported by both pharmacist and space sector stakeholders. As highlighted during the COVID-19 pandemic, the integration of virtual medical pharmacy consultations places the profession in a strong position to adapt to the telepharmacy role identified by stakeholders.[55] In reference to the final role, supporting the provision of a space medication information hub, the rigorous scientific training curriculum provides pharmacists with the background needed to understand, comprehend and synthesise scientific communications which would comprise a centralised space medicine database.

Recommendations for Astropharmacist Roles Coming to Fruition

Astropharmacy is defined as an area of pharmacy addressing the question of how pioneers and explorers are to receive effective medical and pharmaceutical care in the context of space.[56] The European Space Agency's most recent policy paper titled Science in Space Environment PCM Roadmap,[57] which used data from this study, identified four key areas with respect to PCMs: Effects of space-altered physiology; mitigating medication-related problems; coping with emerging hazards; and the optimisation of existing PCMs. Pharmacists were named as one of several professions to collaborate with to investigate the target areas to advance medical practice for spaceflight, supporting the notion that pharmacists should investigate the pharmacological risks associated with spaceflight, which indirectly highlights the pharmacist's potential in medication management within the space sector. Guided by the current ESA PCM roadmap[57] and key stakeholder perspectives across the pharmacy and human health-related space sector fields, building a quantitative and qualitative knowledge base within these PCM areas could provide the foundations to support the development of an Astropharmacist workforce in the future.

From a medication management and research standpoint, reflecting upon and investigating the potential risks of medication use for planned long-term, commercial spaceflight missions, with the intention to become an interplanetary species, our findings recommend reinforcing the evidence-base for pharmacist involvement with PCMs. Identifying and providing solutions to medication-related space sector problems provides risk mitigation and cost-effectiveness for the space sector to support the development of an Astropharmacist workforce, which in-turn could support the implementation of structured pharmacy training curriculums with Astropharmacy accreditation. The development of the role of pharmacists to work collaboratively in space is timely to mitigate health risks, potentially saving billions of dollars and the reputation of space travel. Due to the novelty of Astropharmacy, building a quantitative and qualitative evidence-base and relating evidence to the pharmacist's potential role in improving PCMs use in space is a necessary second step to determine the true value of each role uncovered in our investigation.

Research Limitations

These findings intend to act as a form of hypothesis generation, determining the potential roles a pharmacist could take on within the health of space participants in the space sector, and therefore provide utility as a guideline for potential pharmacist involvement, and not a determination of the feasibility and overall efficacy of such roles. Although the study focuses on potential roles for pharmacists, vast gaps in knowledge regarding medication use in space were identified, with further research requiring a multidisciplinary workforce to attain the ideal standard for space exploration. It is also important to note that some space sector participants required clarification of the pharmacist's terrestrial role before being able to contribute to the discussions. While participant response bias may develop across focus groups and interviews, particularly given that participants agreeing to participate may naturally be more inclined to seeing the pharmacist's role expand compared to non-respondents, the interviewers attempted to explore all perspectives from a neutral standpoint. The interviewers intended to create a neutral discussion on the pharmacist's role in the space sector, however the presence of social desirability bias may naturally surface during interviews and focus groups due to participants being given prior notice of the focus and purpose of the research. To reduce this, pharmacist roles were discussed relative to the advantages, disadvantages, and associated barriers to offset potential biases arising from the study design.

Nevertheless, this investigation provides the first true qualitative assessment of stakeholder perspectives surrounding the pharmacist's role in the space sector, providing the initial evidence base to disseminate and subsequently act as a catalyst for discourse on the pharmacist's role in a frequently overlooked health-related sector. The sample represents an international overview of two key sector perspectives across multiple pharmacy and space health domains, both of which are important in the development of the pharmacist's role in the space sector. While our research did not intend to provide transferable findings or provide generalisable perspectives on the topic, we were able to generate a range of potential pharmacist roles in the space sector through the perspective of key stakeholders relevant to the area. Given that the data analysis was conducted by two qualitative researchers independently (L.S, L.S.T), and primarily by a health psychology researcher, this reduced the potential bias arising from a sole pharmacist researcher coding the pharmacist role in the space sector. A pharmacist may be more likely to selectively code to promote the pharmacist's role, whereas a health psychology researcher would not benefit directly from an expansion to the pharmacist's role and subsequently take a less biased perspective on the subject matter, while maintaining the knowledge necessary to undertake the analysis appropriately. The data analysis was checked by two experienced qualitative researchers (L.S.T, C.A), while interviews were further examined by an experienced qualitative researcher (L.S.T) to ensure correct research practices were followed. While determining the trustworthiness of qualitative research is not objective by nature, incorporating multiple professionals provides greater neutrality and subsequent credibility for the study findings. This approach consequently added to the methodological rigour for the analysis undertaken and subsequent findings retrieved as they relate to the pharmacist's role.

Conclusion

Overall, this study provides the first qualitative exploration of the roles a pharmacist could adopt in contributing to healthcare in the space sector. Stakeholders suggested a plethora of potential Astropharmacist roles, with medication management, medication-related research, and medical and health communication identified as the key themes comprising a pharmacist's involvement. While pharmacists currently work at NASA and are involved with medication use in space, the existing workforce is minimal. With the space sector heading towards humans as an inter-planetary species, expanding the workforce to account for the emergence of these areas remains an important consideration moving forward. The data presented here provides a novel lens regarding how pharmacists can contribute to the space sector beyond their current roles, and indicates that the amalgamation of two previously distinct workplace domains may be a conceivable reality for the future pharmacy and space workforces moving forward.

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Appendices

Appendix 1:

Interview and Focus Group Guide

Briefing

The purpose of the focus group/interview is to discuss the possible role of the pharmacists in space travel. We would like to understand the potential role of the pharmacists, barriers, facilitators and recommendations for the pharmacists role in space travel.

The focus group/ interview will take approximately 1-2 hours. I may stop you briefly to give others a chance to speak.

Note: Confirm that all participants have read and understood the participant information sheet and signed the consent form.

Since the interviews/focus groups will take a semi-structured approach, the discussion will focus on any topics the participants feel to be important.

Overall view

For the interview/focus group, mention: I think it would be great for you/all of you to briefly introduce yourselves, your background, and a bit about what you do.

- Tell me what do you think about space and space for us in the future?
- Are you aware of topics related to health in space?
- What do you think might be the role of pharmacists in space travel?
- Do any other possible roles come to mind?
- What do you think are the possible benefits of Astropharmacists?
- What do you think are the possible disadvantages of Astropharmacists?
- Do you foresee any barriers to developing the roles of Astropharmacists?
- What skills/facilitators do pharmacists already have that might be useful for these Astropharmacist roles?
- What new skills will pharmacists need to develop to undertake these Astropharmacist roles?

Recommendation

Do you have any recommendations on how to develop the Astropharmacist's role?

Highlighting key issues

- Of all the things discussed, what is the most important to you?

Closing

- Summarise the discussion.
- Ask whether anyone would anyone like to add anything.
- Thank all participants for their contributions and close.