Evaluation of the effectiveness of medical kits for extra-terrestrial environments through analog missions

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Abstract

The present paper analyses the effectiveness of medical kits in analogue missions. Considering the effects of space on multiple systems of the human organism, it is crucial to ensure that the necessary medical supplies are provided to the astronauts. Following ESA's roadmap, Pharmacological Countermeasures (PCMs) are of major importance for lunar and planetary missions. The medical kits need to be of minimum weight and well organized for immediate access in case of an emergency. During this study, medical kits were created following the World Health Organization (WHO) guidance and were used in two analogue missions, one in Switzerland (Asclepios) and one in Scotland. The analogue astronauts had to use the kits across variety of six medical scenarios which are anticipated in a planetary mission.

Post-mission semi-structured interviews took place with the crew, discussing their experiences as well as the pros and the cons of the medical kit and recommendations. The analysis was thematic and the software NVivo was used to record the data. As a result, the case study provided information on the effectiveness of the medical kits, in terms of quantity of medicines, variety and organization; providing an insight into the different types of medical kits after evaluation.

I) Introduction

Considering the effects of space on human health, it is important to ensure that astronauts have access to medical resources in terms of quality and quantity. Astronauts cannot have access to the majority of healthcare due to either size constraints or due to safety concerns such as expiry date, or temperature and radiation sensitivity of the products.

The Medical Kits (MK) are of utmost importance to ensure that all of the potential cases may be covered and in such quantities for the whole crew, as resupply in long-term missions may be challenging. If it is in the ISS, in case of an emergency, the time for resupply will be much longer than the one needed. Taking into account, that future or lunar planetary missions will be long-term, resupply is nearly impossible.

This research – case study, aims to evaluate the performance of Medical Kits through analogue space missions and extend the findings to space exploration.

Since the inception of spaceflight in 1961, over 600 individuals have flown to space (4). Space exploration poses a significant threat to human health due to the extreme nature of the extra-terrestrial environment eliciting a multitude of pathophysiological changes (1). Astronauts, however, do not have access to the vast array of healthcare services or supplies available on Earth due to feasibility. Therefore, it is crucial that the medical kit (MK) taken on space missions is optimal to ensure the good health of astronauts and, ultimately, a successful mission (2).

Missions to space have provided valuable insight into the pathophysiological changes occurring in the human body as a result of extreme environmental stressors such as radiation and microgravity (5). Physiological adaptations are experienced particularly in the cardiovascular, musculoskeletal, neurological, and immunological systems (6, 7). For example, microgravity significantly alters the cardiovascular system of space travellers, as it alleviates hydrostatic forces exerted on the heart and blood vessels by the blood, leading to potential changes in the structure and action of the heart. Consequently, this causes a change in

the individual's physical appearance due to fluid shift, where the blood and interstitial fluid are redistributed. The musculoskeletal system is also largely affected by the effects of microgravity. The lack of gravitational forces causes bone and muscle atrophy at rates of 1-1.5% per month (7). One illustration of physiological changes due to spaceflight can be seen during the National Aeronautics and Space Administration (NASA) Twins Study (8). A 340-day investigation was conducted, where two identical twins were studied to understand the effect of long-duration spaceflight on the human body. The study concluded that certain biological mechanisms and functions were vulnerable to spaceflight, including attenuated cognitive function, body weight and appearance changes, and altered immune responses. This study provided a unique insight into the effects of long-duration spaceflight by allowing direct comparisons to be made between two individuals sharing the same genetic makeup in both terrestrial and extra-terrestrial environments.

Psychological health is also significantly impacted by the space environment. Research suggests that spaceflight-induced stress (SIS) is one of the main barriers to long-duration missions (9). An example of SIS occurred during Skylab 4 in 1973. After spending 84 days in space and experiencing increasing disputes with terrestrial control, the crew suddenly ceased all communications and work-related activities for a day to rest (10). Another illustration of SIS occurred during the Salyut 7 mission, where cosmonaut Valentin Lebedev expressed his deteriorating mental state, describing increased irritation with fellow crew members and a loss of motivation (11). These missions exhibited the effect of microgravity and isolation on human behaviour and highlight the significance of mental well-being alongside physical well-being for the safety of the crew and the success of missions.

The term Pharmacological Countermeasures (PCMs) will be utilised in this paper to refer to any medication, supplement, or drug used to support health (12). Throughout history, human beings have resorted to the use of PCMs to manage various health challenges. This practice has also been extended to spaceflight, where the extreme conditions present medical challenges for space travellers. Various PCMs have been used during space travel thus far. For example, bisphosphonates such as alendronate sodium combined with exercise have shown to be successful in preventing bone changes, such as bone mass decline in the microgravity environment (13, 14). Crew members aboard the International Space Station (ISS) reported using pharmacological treatments to aid sleep, alertness, and pain management. Medications such as zolpidem and zaleplon were used to induce sleep. Paracetamol and non-steroidal anti-inflammatory drugs (NSAIDs), such as ibuprofen, were reportedly used to control various types of pain. Pharmacological interventions were used by a large percentage of crew members on the ISS, indicating it is a highly effective strategy which is crucial to space travel (15).

Analogue space missions are used as a medium to undertake research in conditions simulating the extra-terrestrial environment. They are conducted on Earth, which is host to an extensive array of environments which resemble certain characteristics of spaceflight (16). This enables research to be conducted in a more efficient, economical, and safe manner, compared to actual space missions, without compromising the credibility of the research (17). Many analogue missions have been conducted over the past years to simulate and address the various challenges of spaceflight. However, at present, evidence is minimal on the use of MKs in analogue space environments. A study by Binsted et al.(20) addressed the impact of human factors in analogue studies. This research was particularly significant as it provided an understanding of human performance in analogue space missions, which is crucial to the accurate development and testing of countermeasures, such as MKs.

The remote, rudimentary environment of space provides limited access to healthcare services, compelling astronauts to rely solely on MKs for countermeasures. This highlights the importance of an optimised, well-equipped MK to adequately support the safety and well-being of the crew during missions. Space travel is increasingly advancing from Low Earth Orbit (LEO) missions to long-term, deep space exploration missions, with NASA's plans to return humans to the lunar surface by 2024 and extend human exploration to Mars (3). This

further substantiates the necessity for developing an efficient and effective MK to contribute towards the sustainability of these missions. Research conducted by Wotring (15) provided a review of medications use during long-duration spaceflight. This study provided insight into the selection and frequency of medications used aboard the International Space Station (ISS) by crew members. Medication records of 24 crew members on 20 missions in a 10-year period were analysed to identify various trends. This type of study is significant as it can inform the development of MKs for the space environment. This study can be beneficial in informing a MK, as data is gathered directly from an extra-terrestrial environment. Therefore, unlike analogue missions, there is no risk of participant "disbelief", as suggested by Binsted et al.(20). The data is collected over a 10-year period which improves the accuracy of results as it can negate anomalies. However, personal medication use was not included in the data set, suggesting that the study does not fully represent the medication usage rates, and so would inaccurately inform the development of a MK, if used. As the data was collected from medical reports, no information is provided on crew perspectives of medications use, such as reasoning behind usage rates and efficacy of medicines. Therefore, there is a knowledge gap, so this study cannot promote the optimisation of a potential MK.

The MK used aboard the International Space Station (ISS) was developed using NASA's "Integrated Medical Model" (IMM) (19). This model conducts a probabilistic risk assessment by using Monte Carlo simulations to forecast crew health risks based on the characteristics and requirements of the mission and crew. The MK was developed based on risk factors, mass and volume constraints, and a pre-set resource list, which is a limiting element of the model as it does not consider various qualitative factors. This method uses a quantitative approach, which can be useful for the management of space and resources in the MK. However, this type of approach does not review the efficacy or usability of the MK, due to the absence of user feedback integration during the development phase. Furthermore, this development approach does not provide guidance for MK design, which introduces ambiguity and can consequently lead to confusion and error.

Fimbault et al.(18) conducted a study to develop a MK proposal for offshore yacht races. The offshore yacht racing environment can be comparable to that of spaceflight in terms of remoteness. Therefore, the findings of this study can provide a valuable insight into the considerations made during the development of the MK. Methods used in this study included a critical review of the literature and recommendations from 19 medical experts of the maritime environment. The selection of medications included were based on medical challenges experienced in prior races. The quantity of medications and other items in the kit were significantly decreased to avoid confusion, and medications with severe side effects were eliminated. This method of development is similar to that of NASA's IMM (19), as previous health challenges were considered. However, unlike NASA's IMM, certain qualitative aspects, such as kit design, were also considered, which implements a user-focussed approach and can enhance the efficacy of the MK. Although the methods used in this study can provide valuable insights, it is subject to bias and does not incorporate various stakeholder perspectives, reducing the credibility of results.

Medical kits are crucial to the health and performance of individuals in remote environments such as space (2). Multiple studies have investigated the development and use of medical kits in various environments (15, 18, 19). However, these studies have conventionally relied upon quantitative methodologies or existing literature to underpin their findings. This body of literature does not provide a comprehensive understanding of the efficacy of current medical kits, as it lacks a qualitative perspective. Therefore, the existing literature is inadequate to inform the development of an optimal medical kit, as it does not consider its functionality, which is crucial to effective patient care. This study aims to explore medicine and space sector stakeholder perspectives regarding the medical kit used in analogue space missions to extend these findings to space exploration.

. Methods

1.1 Study setting

This study was conducted during two analogue space missions, one of which took place in Scotland, the other in Switzerland - Asclepios. The Scotland mission was conducted in May of 2022 on an uninhabited island, focussing on remoteness in an extreme environment. The Asclepios mission focussed on the Lunar South Pole environment and took place at Sasso San Gottardo in Switzerland. Ethical approval was obtained for the Scotland analogue mission. Ethical approval was not required for the Asclepios analogue mission as it was considered a case study.

1.2 Study design

Two types of MKs and several case studies were developed to undertake this study during both analogue missions.

Focus groups were conducted both in-person and online. Asclepios mission pre- and post-focus groups were conducted online via Microsoft Teams. The Scotland pre-mission focus group was conducted entirely in-person on the morning of day one before the mission started.

1.1.1 Development of medication kits

Two versions of the MK were developed for use during the analogue space missions: a simulation MK and a genuine MK. The simulation kit was created to assess how countermeasures are used in a case scenario. On the other hand, the genuine kit was developed to address true medical requirements which could arise during the missions.

The simulation MK was developed by a pharmacist and health psychologist. Initially, the World Health Organisation (WHO) Model List of Essential Medicines (21) was used to generate the framework of the simulation MK; it was then modified to suit the demands of the specific mission locations. An extensive literature review was then conducted to inform the further modification of the MK, coupled with a thorough comparison with the MK list provided by NASA (22). The finalised simulation MK was then critically reviewed by an expert group of researchers before being approved for use. The simulation MK was predominantly intended for pharmaceutical use.

The genuine MK was developed by a research team at University College London (UCL). This MK was more comprehensive in comparison to the simulation MK, including a greater variety of medical supplies.

1.1.2 Case studies

Six case studies were developed prior to the missions, reflecting various health problems that may be encountered while exploring an unknown extreme environment, such as space, with some requiring the use of a MK. Scenarios were developed by healthcare professionals and academics. The patient case scenarios were conducted over two full days (total n = 6; n = 4 daytime, n = 2 night-time).

Patient	Health concern	Intervention
A	Pelvic fracture	Use of SAM splint and stretcher.
B	Homesickness and anxiety	Support and reassurance.
C	Gastroenteritis	Fluid and nutritional management.
D	Abdominal bleeding	None, end of life care.
E	Fractured or sprained ankle	Analgesia for pain relief.
F	Tension pneumothorax	Chest decompression requiring the use of a decompression needle.

Table 1 Patient case scenarios and interventions.

1.2 Sampling and recruitment

The methods underlying the study were guided by the Consolidated Criteria for

Reporting Qualitative Research (COREQ) (23). Purposive sampling was used to employ various medicine and space stakeholders (total n = 10; medicine n = 6; space sector n = 4). Contrary to random sampling, which intentionally recruits participants with varying demographic backgrounds, purposive sampling is a non-random technique where participants are chosen based on the relevance and contribution of their qualities to the research, which facilitates the optimal allocation of resources (24). The medicine stakeholders' backgrounds included: acute and emergency medicine consultants, junior doctor, and family medicine doctor. Space sector stakeholder backgrounds included: a planetary scientist, an emergency rescue diver and engineers.

1.3 Data collection

Data from both missions were collected in the form of focus groups (total n = 4; prior to Asclepios mission n = 1; post Asclepios mission n = 1; prior to Scotland mission n = 1; post Scotland mission n = 1) conducted with medicine and space sector stakeholders. This study exclusively relied on the use of focus groups to enable the exploration of group dynamics, whilst also having increased practicality compared to interviews. Group dynamics enable participants to share individual experiences and move from a self-doubting perspective to one of innovation and problem-solving. Research suggests that effective group dynamics can facilitate the generation of more critical and comprehensive comments compared to interviews (25, 26). Focus groups allow researchers to have an increased understanding and better evaluate the research findings (27).

Participants' current opinions on the medication kit and medication management were discussed in addition to their anticipations for the mission. One month following the Scotland mission, the post-focus group was conducted at a research evaluation workshop in London, with a hybrid of face-to-face and Microsoft Teams participation. The post-mission focus group followed similar themes to the pre-mission focus group, emphasising reflection on the mission and any differences in opinion since the pre-mission focus group. The focus group size ranged from 2 to 5 participants across both missions and lasted between 32 to 52 minutes each. All focus groups were recorded digitally and transcribed verbatim by a research student at the University of Nottingham. Transcripts were refined by four MPharm research students and subsequently corroborated by one other MPharm research student to ensure the credibility of the data collected (28).

Focus groups were conducted by a health psychology researcher and experienced qualitative pharmacy researcher.

1.4 Data analysis

1.4.1 Thematic analysis

Braun and Clarke's six-step approach was used to analyse the verbatim transcripts, facilitating the identification of prevalent themes regarding the medication kit across both missions. The six steps followed in conducting the thematic analysis were as follows: familiarisation with data; generation of initial codes; search for themes; reviewal of themes; definition and naming of themes; and creation of a report (29). Based on Braun and Clarke's approach, the following steps were conducted to thematically analyse the data in this study: familiarisation with data; Generation of initial codes; search for themes; reviewal of themes; defining and naming of themes.

An inductive approach was employed instead of a deductive approach to generate themes in this thematic analysis (30). An inductive approach was taken as it uses the entire data set to construct codes and subsequently deduce themes, which consequently provides a more comprehensive illustration of the data set.(31).

NVivo 12 (qualitative data analysis software) was utilised to coordinate and

analyse the collected data (32). The cross-checked transcripts from all four focus groups were uploaded into NVivo 12, where thematic analysis was conducted. Codes were initially created separately for the pre, and post-mission focus groups, they were then combined to form a set of overarching themes and sub-themes. In vivo coding utilises participants' exact statements by using direct quotes from focus groups, which can facilitate the understanding of various nuanced meanings as opposed to other methods of coding. The use of direct quotes avoids incorrect meanings being inferred from the data and prevents researcher interpretation errors (33).

Results

Thematic analysis findings

Thematic analysis of the data set revealed three overarching themes (Table 2). Acronyms were used to identify medicine stakeholders (MS) and space sector stakeholders (SS).

Table 2. Table of themes and sub-themes identified.

Themes	Sub-themes
Beneficial aspects of the medical kit	Record-keeping materials Reusability
Challenges of the medical kit	Supply challenges Medication packaging Medical kit design
Recommendations for medical kit improvement	Preparation prior to mission Enhanced design and organisation Optimisation of medication in the kit Documentation

Beneficial aspects of the medical kit

The first theme expressed positive aspects of the MK from participants' experiences with regards to both analogue missions. This theme compromised of two sub-themes: record-keeping materials, and reusability.

Record keeping materials

Across both missions, participants agreed that the presence of record-keeping items in the MK enabled the crew to keep good track of stock and supply.

"We had a list ... so, we knew how much medication is left in the medical bag, and we knew how much they [crew members] have taken 17 already. We had sort of a diary... so, we had a real good control of what was delivered to who at what point." (Post- focus group; MS 004).

Reusability

In the context of this sub-theme, the term "reusability" refers to the ability of the MK to be used multiple times without requiring total replacement after each mission.

Participants stated that items in the MK with extended shelf-life were not discarded after each mission and were able to be reused for future missions.

"We still have the medication that we didn't use, we will reuse it because… the medication is new. So, it's still lasting, I think at least two or three years for most of the medication... So, the non-medicationmedication kit is in a bunker in Asclepios so, we have all the material reusable for the next mission." (Post- focus group; MS 004).

Challenges of the medical kit

The second theme generated, expressed the negative aspects of the MK from participant perspectives. The three sub-themes: supply challenges, medication packaging, and medical kit design, were generated from this theme.

Supply challenges

Multiple challenges were identified regarding supply in the MK. Participants shared their experience of a shortage in supply of certain items due to a lack of proper preparation prior to the mission.

"We used a lot of pain medication, which I thought was running a little bit lower at the end… I think the pain was way more than we anticipated had to be treated." (Post-focus group; SS 002)

When asked about the challenges of the MK, participants expressed concern regarding the excessive supply of non-essential items in the MK, contributing to the overall weight of the medical bag.

"So, I would have wished for… less of doubles or triple things that we were not needing. But I think that would be because we had to carry it a long way and therefore it was quite heavy. So, taking only the necessities and I think there were a lot of things that we actually never used." (Post-focus group; SS 002)

Medication packaging

Medication packaging challenges were of high prevalence across both missions.

Participants discussed issues surrounding the practicality of the medication packaging used, explaining that it made medication access difficult, consequently deterring crew from using the medication.

"I think it was all about practicality… I think that was the number one thing… because if I'm fumbling to get into some pots when my hands are cold, I just might not even use that drug. It will put me off even using it." (Post-focus group; MS 001)

Participants also expressed that the large amounts of packaging present made them less efficient when treating patients, especially in emergency situations.

"The way it was packaged… wasn't the best, because you have to open like a lot of things, and in an emergency, I was opening many boxes to get one thing out… Especially if you have to stop with the patient down, get into backpack by taking medication and then give it to them, then carry on again. That takes a lot of time." (Post-focus group; MS 002)

One participant also mentioned that the process of opening various aspects of the MK was very noisy and disturbed other crew members.

"At night-time when I was delivering patient care, I was opening these things… it was just making a lot of noise and I was thinking is there a better way to package the item, so it doesn't make a lot of noise when you try to open [it]. I noticed that during night we were trying to deliver care in the tent without disturbing everyone else, but [there] was a lot more package." (Post-focus group; MS 002)

Similarity between the outer packages of many medications was mentioned to be a challenge for crew members, making medications difficult to distinguish from one another.

"I think when it comes to the pills, the fact that they all look the same, they're in the same type of pots and they are labelled in the same way, it makes it very counterintuitive in the sense that it makes it very difficult to distinguish." (Post-focus group; SS 003)

When asked for opinions on the different types of medication packaging used, the absence of dosage information on packaging was highlighted, with participants expressing that this led to confusion.

"Indicating the amount or the dose that each pill has [on the packaging] would be useful. Because we had that on paper so, we had the pot, we had the name, then we had to go to the paper to check. Ok, one pill corresponds to this, in this case, but then for the other one, even though the pill looks exactly the same, it's a different dose, so yeah, it made our heads a bit confused." (Post-focus group; SS 003)

In comparison to blister packaging, 'pot' packaging was regarded to be more dangerous and contributed to a lack of control of the medications, according to participants.

"Kind of dangerous…because like the pots are open so, you can just take pills out. You don't really have control of how much you have… It's like they have those really big pots with hundreds of pills, and you can take 50 and nobody recognizes it. So, if you can take it out and then see that one is missing, it kind of has more structure and more safety you know…I mean a system that you really see okay one is taken out because, you know,

the medication is stored in the analogue mission centre, in the base, so you don't really have control [over] who is getting there. It always can be that someone goes there and takes medication on [their] own. So, [with blister packs] you would see if something's missing instead of the pots, like, you don't really see it." (Post- focus group; MS 004).

Weather conditions negatively impacted the components of the MK, due to the inadequate packaging, according to participants.

"It's difficult if you're in a wet, wild Scottish place because then they [adhesive bandages] lose their stickiness when they get wet and they get soaked. The plaster actually gets damaged or dirty." (Post-focus group; MS 001)

Medical kit design

Various aspects of the design and structure of the MK contributed to challenges faced by crew members.

Participants expressed that the number of medical bags supplied for the missions were not only excessive, but also too large and too heavy.

"I think we had way too many medical bags for the medical team. [They] were way too heavy and too big for a couple of days." (Post focus group; SS 001)

According to participants the shape and style of the medical bag caused it to be impractical, for a few reasons. Firstly, the characteristics of the bag made it difficult to carry multiple items alongside it, whilst also maintaining easy access. Secondly, the backpack structure required opening of the entire bag for any type of access, which introduced the possibility of external contaminants entering the bag.

"It's hard to do anything else with it [medical bag], you can't carry a backpack on top of it or something." (Post-focus group; SS 002)

"I'm not sure backpacks are the best way to carry medicines. They're not the most user friendly because that means you have to stop what you're doing, take your backpack out that open, I'm not sure that's the best thing…I had to open the whole bag… to just open up a section. I [could] see a tick trying to get into it, and I'm thinking…I have a whole 22 bag open, and things are going to get into it. Then if you bring that back to your tents, you're going to contaminate them." (Post-focus group; MS 002)

The organisation of the MK was viewed as unsatisfactory, with participants explaining that it led to a time-consuming process of understanding.

"We had to first sort out the whole thing, and we felt that it was very unorganised, [it took] at least an hour of understanding." (Post-focus group; SS 002)

Participants reported poor familiarity with the MK, due to its large size. Lack of familiarity with the MK reduced the crew's efficiency in providing medical treatment to patients.

"We had a bigger medical kit to go through…I think for me we could have used it better, or I could have used it better by being more familiar with what we actually had in there [medical kit]. Because we had so much information to keep on top of about the whole rest of the medical kit, I didn't really know what we had available until we needed to use it and therefore, I couldn't make decisions very quickly because we didn't know…what was at our fingertips." (Post-focus group; MS 001)

One participant reported difficulty when attempting to find multiple different items required for a single procedure, which negatively impacted the quality of patient care.

"I was trying to do the needle decompression…I was opening up every single thing to try and find this one thing. And this patient was like, dying in front of me… in an emergency, you just want to find things easily without faffing about." (Post-focus group; MS 002)

Recommendations for medical kit improvement

The final theme exhibited recommendations for MK improvement based on participants' experiences. This theme was identified across all four focus groups and generated the sub-themes: preparation prior to mission, enhanced design and organisation, optimisation of medication in the kit, and documentation

Preparation prior to mission

Across both missions, during pre- and post- focus groups, participants agreed that adequate planning was crucial when developing the MK. The importance of good protocols, risk analyses, and training was highlighted in this sub-theme.

Participants collectively expressed the requirement for thorough risk analyses prior to the mission, to ensure the MK is adequately suited for the various health challenges which may arise during the mission.

"So, it's really important… that you [complete] a good risk analysis beforehand, so that you… have taken into account any risk that could occur during a mission and have any medication you may need on site." (Pre-focus group; MS 005)

When asked about completing the pre-mission risk analyses with the wider healthcare team, participants expressed that this would be beneficial.

"This [inclusion of the wider healthcare team] can always bring some new perspective, which is really important for us." (Pre-focus group; MS 005)

Participants specified the importance of ensuring that the medications themselves can withstand the various demands of the environment.

"Particularly in a remote environment… making sure that the medicines that you have are suitable for the risks [of] that the environment… if it needs to be kept at a certain temperature or something." (Pre-focus group; MS 001)

Training was also considered to be of importance, to increase familiarity and optimise the functionality of the MK.

"Training on what the medication in the kit is, even if it's just a definition of opioids, you cannot assume that someone knows what those are, or the definition of antidepressants. I know the [simulation] kit had antidepressants, which just by the name, you know how they're supposed to be used, but they might have other uses that we are not aware of… and then explaining where everything is located." (Postfocus group; SS 003)

Familiarity with the location of emergency medications was highlighted, as quick access of these is crucial to effective patient treatment.

"I think the most important thing is… knowing where the emergency medication is, and the emergency stuff in case of [emergency]. Because the ibuprofen you can search for an hour, it doesn't matter, but the other one [emergency medication] is really important…like the EpiPen, the oxygen..." (Post-focus group; MS 004)

Enhanced design and organisation

This sub-theme highlights the requirement for improved design and organisation of the medical bag.

"I would like to see a well- organised and well-protected medical bag, organised in a logical way, rather than... a bag of stuff which I haven't seen before." (Pre-focus group; MS 003)

Participants suggested the development of two separate MKs, one standard kit, and one for emergency, to allow distinguishability.

"There wasn't really a distinction between urgency medicine and overthe-counter medicine. So, have really good distinguishment, have two kits, like one for medical urgency…" (Post-focus group; MS 004)

The implementation of personal MKs for all crew, was advised by participants, to reduce the size of the main MK and aid medication management.

"I think it's essential that everybody has a basic medical kit because then it can mean that your group kit is so much smaller, because each person is carrying another 100 or 200 grams. They know where it [medication] is, so they can manage their own issues." (Post-focus group; MS 001)

Organisation of the MK by procedure was proposed. Participants suggested that all equipment required for a specific procedure or purpose should be prepackaged together, for easy access and efficiency.

"In the middle of the night trying to find the needle to do the decompression… I was fumbling trying to find the green needle. And I couldn't find it. It was quite difficult to find the thing that I wanted. And actually, that made me think having equipment for each procedure you need to do might be helpful, like already packaged. I like to think of having equipment or medications according to a purpose rather than 26 random things. All the [procedural] kits have different things put together. That way when you pick up the [procedural] kit, you know, everything should be in there. Then you're not trying to look for different things. Something like that might be useful." (Post-focus group; MS 002)

Clear labelling of the various sections in the MK, by order of priority was recommended by participants.

"Having it [medical kit] very clearly labelled, and by sections, so that the top section is emergency, and the next section is the most commonly used [medicines], for instance like analgesics. That would've been really helpful." (Post-focus group; MS 001)

Colour-coding sections of the MK was also suggested by participants to aid with quick identification of items, especially in low visibility conditions.

"Maybe colour coding, as well as just being a different label might have helped you in the darkness, say yellow is for pain, red is for emergency, something like that." (Post-focus group; MS 001).

Participants proposed the idea of creating a medical bag which can be attached to other bags, to facilitate manageable transportation of all equipment.

"The possibility to integrate it [medical kit] onto your own backpack…having it as an addition that you could hang or attach to other bags…we had too much stuff, so having this [medical kit] somehow attachable would have helped." (Post-focus group; SS 002).

Suggestions were also made for the implementation of a more accessible medical bag, to increase efficiency of the crew.

"They're [medical kits] not the most user friendly because you have to stop what you're doing, take your backpack off and then open it. So, I think a smaller, easy to access bag, for commonly used medications is what we need because it's about practicality." (Post-focus group; MS 002)

Optimisation of medication in the kit

This sub-theme refers to enhancement of various aspects of the medication in the MK, specifically improvement of the medication packaging and increasing sustainability. Participants suggested that labelling of the medications required improvement, as well as increasing the distinguishability of the tablets themselves.

"The labelling should be better and also like visualisation of the pills, that is simpler for them [crew] to get. I think it makes it easier… like the pink one is the ibuprofen and the not pink one is the other one." (Post focus group; MS 004)

Participants emphasised the importance of minimising packaging, as it affected ease of access.

"Reducing packaging. I don't know if they necessarily need to be in their little boxes. I'm not sure how useful that was for me, trying to open three different things to get to [one item] … because I think [it affected] ease of access." (Post-focus group; MS 002)

The concept of a digital medication dispenser, which displays the count of tablets remaining was proposed by participants.

"I think you just need an easy dispensing mechanism… something we can click and just get it [medication] out…then you're not counting it. So, it says you now have two tablets left in there. Like a digital thing, you just dispense it, you get the tablet, and it also tells you what's left." (Post-focus group; MS 002)

Across both missions, participants agreed it would be more beneficial to use multi-purpose items.

"Maybe sometimes less is more… reusing things for different purposes and instead of having the same thing or having too many medications, having one instead that could be used for multiple [purposes]." (Post-focus group; SS 002)

Documentation

Flow charts were recommended to guide crew on the order in which treatments should be administered.

"A flowchart for pain, because if the medics had been taken out and you were in charge, maybe a flowchart [of treatment options] would be helpful." (Post-focus group; MS 001)

Participants suggested implementing brief descriptions of each medication on the inventory list, to enable any crew member to gain an understanding of the purpose and use of each medication.

"Half of the things or even more than half the things, I couldn't even pronounce the actual name. I [did] not know at all what that [medication] was. So, it would have been helpful to have a little bit of maybe a list not just the name, but you know one sentence that this is for 'x', and this is for 'y'." (Post-focus group; SS 001)

Participants recommended that documentation should be kept in the medical bag itself, to ensure consistent accessibility.

"It [checklist] should have been within the pharmacy kit, because then whenever we go in there, we could have recorded what we used and who it was given to." (Post- focus group; MS 001)

The implementation of dosage instructions was recommended by participants, to aid crew.

"Maybe not for the most common types of medicine, like ibuprofen because you know the dose of those, because you use them pretty often. But for the more extreme or weird types of medicine, it could have helped to know the dose. Because I remember when we had to give the morphine to the patient, I was like, how much? Like the whole bottle? two drops? I have no idea. So just maybe like a basic chart…So, if you're in a place where there are no doctors and you have to deal with it, then you are not killing the patient because you're giving too much morphine or whatever." (Post- focus group; SS 001)

Recommendations were made for a single set of documentation to be used, to avoid duplications and errors.

"Some of us were writing on this. Some of them were writing on a different one. Others were writing on the paper that was in the green pharmacy bag. So, we probably duplicated and made loads of errors 30 that way… So maybe something like having one document for everything so that we also can check afterwards what's missing." (Post-focus group; MS 001)

The development of a formulary similar to the British National Formulary (BNF) for remote medicines, was proposed by participants.

"I think it would be nice to have some sort of like a BNF type thing for remote medicine… a book that gives you some guidance… and something that is standardised… so, you can use it across multiple countries as well, which would be helpful

Discussion

In terms of the advantages, the kit is well structured and easy to access. A diary was used to keep record and track the medication administration and as a result the quantities consumed and the remaining quantities. There was a great variety of medications. In extreme environments, they could use the same medication for different symptoms. For instance a motion sickness medication was used for better sleep. The quantities were much greater than the ones required to cover a variety of possible cases, which eventually were not used so they can be stored and reused since the expiration date is much later. Although there is no access to medical facilities, health care team in the mission control is available 24/7 to provide support over the phone and the medication is always given after communication with the doctor and there is a protocol for medication management. This process leads to trust between the doctors and the crew regarding the use of the medical kit. Moreover, before the mission there was a meeting with the doctor to discuss the procedures. Daily health check-ins ensuring everyone is healthy, helped for the success of the mission.

In terms of the disadvantages of the kit, all the medication packaging looked the same which may be confusing in emergencies. Although there is a list of drugs, if you do not know the corresponding official medicine and substance name you cannot find it. They cannot be easily used by non-medical crew Although there is a protocol of medicine administration and the doctor is available anytime, there is no protocol for the communication with the doctor.

Regarding packaging, backpacks were used which are not useful for immediate access in emergencies.

Overall, this case study provides a great overview of the advantages, disadvantages and recommendations of the simulation medical kits, which may be expanded in space missions.

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