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Regional Anesthesia in Lunar Gravity: Feasibility of Ultrasound-Guided PENG Block by Experts and Novices on 0.16G Parabolic Flight

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Lunar Block



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Disclaimer

No conflict of interest to disclose

This study does not involve human or animal subject, no biomedical data is recorded (technical study on a simulator)

Abstract

Spaceflight is associated with significant physiological changes, including bone loss in the pelvis and lower limbs, muscle atrophy, altered neurovestibular function and disruption of sensitive-motor pathways [1]. In addition to bone loss, there are significant alterations in trabecular architecture, resulting in not only a reduction in bone quantity but also in its microstructural quality. These qualitative changes further compromise bone strength and may contribute to increased susceptibility to pain following joint injuries or fractures during extended missions. For deep space exploration missions, these effects are predicted to be exacerbated by prolonged duration and galactic cosmic ray radiation exposure, potentially increasing the risk of pain from joint injuries and fractures [2]. The partial gravity of the moon coupled with altered vestibular function and the challenges of working on rough lunar terrain led to several falls during the Apollo-era missions [3] along with several shoulder injury events reported due to ergonomic issues of operating inside an extravehicular activity (EVA) suit [4,5]. While current risk assessments classify fractures in lunar gravity as a low probability hazard, there remains substantial uncertainty on the confidence level of current models due to lack of complete understanding of space-induced osteoporosis and density measurement models [6,7,8], as well as the absence of any human lunar expeditions in the last half-century.

Contrary to the low amount of lunar surface hours performed in the Apollo missions, less than 20 hours of EVA were performed, upcoming lunar expeditions planned by several space agencies aim for extended stays with higher workload and more than 30'000 hours of EVA, potentially raising the risk of traumatic injury events [9]. The new xEMU spacesuit, with increased mass and enhanced mobility compared to Apollo suits, may improve ergonomic task performance but raises concerns about increased hip fracture risk due to greater hip joint mobility, which contrasts with the motion-restricting design of earlier lunar suits that may have reduced lower body injury potential [9]. The consequences of events such as femoral neck fracture would pose serious medical implications for astronauts on long-duration missions. Accidents on the lunar surface will thus necessitate effective mitigation strategies to ensure crew health as well as minimize disruptions to mission operations.

Furthermore, any treatment during missions will rely on the astronauts themselves, who will have only minimal pre-flight training and no professional expertise in pain management. Regional anesthesia is well-established in both hospital and remote care settings on Earth [10, 11, 12]. Its effectiveness in pain control, portability, light equipment load, low cost, relative procedural ease and its absence of neither cognitive alteration nor respiratory depression, as opposed to general anesthesia, make it a potentially ideal analgesic tool for trauma scenarios on the lunar surface [13,14, 15]. Regional anesthesia can allow pain control and also permit specific surgeries. Furthermore, the use of perineural catheterization enables prolonged analgesia, supporting patient stabilization and facilitating delayed medical evacuation to Earth when immediate surgical care is not available. This study will establish challenges associated with performing a simulated ultrasound-guided regional anesthesia (UGRA) by non-anesthetists on a simulator during lunar gravity. In order to close knowledge gaps in pain management for lunar medical operations, experts and non-expert technical results will be compared using a high-fidelity sono-anatomical phantom during a lunar gravity parabolic flight. Findings may enhance pain management protocols for future medical operations on the lunar surface and beyond. The results can also be extrapolated to Earth where training non-experts in UGRA has not yet seen widespread use or standardization outside of the operating room, despite evidence supporting feasibility for non-anesthetist emergency doctors in hospitals as well as paramedics and nurses in remote settings [11,16,17,18,19].

Democratization of UGRA for targeted opioid-free pain control may also improve patient recovery, provide superior localized pain control and help improve patient safety by reducing need for prescription of opioids

Title

- 1 **Regional Anesthesia in Lunar Gravity: Feasibility of Ultrasound-Guided PENG Block by Experts and Novices on a nerve block phantom simulator during 0.16G Parabolic Flights**

Introduction

- 2 Spaceflight is associated with significant physiological changes, including bone loss in the pelvis and lower limbs, muscle atrophy, altered neurovestibular function and disruption of sensitive-motor pathways [1]. In addition to bone loss, there are significant alterations in trabecular architecture, resulting in not only a reduction in bone quantity but also in its microstructural quality. These qualitative changes further compromise bone strength and may contribute to increased susceptibility to pain following joint injuries or fractures during extended missions. For deep space exploration missions, these effects are predicted to be exacerbated by prolonged duration and galactic cosmic ray radiation exposure, potentially increasing the risk of pain from joint injuries and fractures [2]. The partial gravity of the moon coupled with altered vestibular function and the challenges of working on rough lunar terrain led to several falls during the Apollo-era missions [3] along with several shoulder injury events reported due to ergonomic issues of operating inside an extravehicular activity (EVA) suit [4,5]. While current risk assessments classify fractures in lunar gravity as a low probability hazard, there remains substantial uncertainty on the confidence level of current models due to lack of complete understanding of space-induced osteoporosis and density measurement models [6,7,8], as well as the absence of any human lunar expeditions in the last half-century.

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equipment load, low cost, relative procedural ease and its absence of neither cognitive alteration nor respiratory depression, as opposed to general anesthesia, make it a potentially ideal analgesic tool for trauma scenarios on the lunar surface [13,14, 15]. Regional anesthesia can allow pain control and also permit specific surgeries. Furthermore, the use of perineural catheterization enables prolonged analgesia, supporting patient stabilization and facilitating delayed medical evacuation to Earth when immediate surgical care is not available.

This study will establish challenges associated with performing an ultrasound-guided regional anesthesia (UGRA) by non-anesthetists on the moon. In order to close knowledge gaps in pain management for lunar medical operations, experts and non-experts will be compared using a high-fidelity sono-anatomical phantom during a lunar gravity parabolic flight. Findings may enhance pain management protocols for future medical operations on the lunar surface and beyond. The results can also be extrapolated to Earth where training non-experts in UGRA has not yet seen widespread use or standardization outside of the operating room, despite evidence supporting feasibility for non-anesthetist emergency doctors in hospitals as well as paramedics and nurses in remote settings [11,16,17,18,19]. Democratization of UGRA for targeted opioid-free pain control may also improve patient recovery, provide superior localized pain control and help improve patient safety by reducing need for prescription of opioids.

Objective

3 The objective of this study is the feasibility of simulated ultrasound-guided regional anesthesia by novice operators with minimal training on a simulator phantom in lunar gravity parabolic flights

4

Primary Outcome

5 The primary outcome is success rate of US-guided peripheral nerve block such as the PENG block, on a sonoanatomic phantom in lunar gravity (0.16G) conditions, assessed by two blinded experts.

6

Secondary Outcomes

7

- 8 Expert vs Novice technical performance of simulated PENG block in lunar gravity on a sono-anatomic PENG block simulator (no biomedical data is collected, no human or animal subjects are involved).

Block success rate : binary

- Tip-target distance : continuous - measurement of center of ideal target area evaluated by blind expert and tip of needle in mm (Ultrasound recording)

Timing : continuous - from ultrasound and video camera recordings

T1: Time-to-sonoID = time from probe placement on simulator to optimal positioning for correct target sonoanatomy.

T2: Time-to-Insert = time from needle insertion to reach target area

T3: Time-to-Block = total time of sonoID time + Insert time + Injection time

Needle repositioning (retraction) rate = number of times needle is repositioned (retracted) (Ultrasound recording)

NASA-TLX workload score to determine cognitive/mental difficulties associated with simulated UGRA in a lunar gravity parabolic flight.

Learning curve of simulated PENG block procedure on a high-fidelity mannequin in 1g vs 0.16g

9

Protocol Design

- 10 Simulated nerve block choice : PENG

Astronauts on the lunar module will most likely not all be specialized anesthetists and therefore will most likely lack expertise in UGRA. Choice of the location of the nerve block will be made on the risk profile of lunar surface missions injuries. Choice of nerve block technique will be made on ease of locating both external physical and internal sono-anatomical landmarks, ease of needle insertion, high efficacy, minimal counter-

indications, and minimal risk of side effects (especially to CNS or Respiratory system). Preferably chosen are those considered as beginner skill level blocks. PENG block was chosen for its relative simplicity, effectiveness, low risk of adverse events, motor sparing potential.

Simulated nerve block was done on a sono-anatomic simulator phantom not involving human or animal subjects, using a portable ultrasound device.

11 Experience level:

- Experts : anesthesiologists with experience in UGRA and PENG blocks (n = 4)
- Novices: non-anesthesiologist medical doctors with no experience in PENG blocks, non-medical professionals (n = 6)
- Standardized 1 day training course 6 weeks before flight

Gravity Levels:

Normogravity 1G : ground control on earth

After each flight

Lunar Gravity 0.16G : parabolic flights (28-30 seconds each parabola) on parabolic flights operated by Novespace.

3 flights, each flight will have 30 parabolas of 25 seconds of lunar gravity

1 flight = 6 sets of 5 consecutive parabolas with 5 min break

Ethics Statement

- 12 The protocol is a technical study on a simulator phantom, does not involve human subjects as defined by the French Public Health Code (Article R1121-1, amended by Decree No. 2017-884 of May 9, 2017) and therefore does not fall under the jurisdiction of a Human Protection Committee.

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