Surgical Emergencies in Space: Management and Protocol Development for Artemis and Martian Missions

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BACKGROUND

As human spaceflight expands to Lunar and Martian missions, medical care must evolve from evacuation-based support to autonomous, in-mission capability. Surgical emergencies pose high-risk threats to crew health (LOC) and mission (LOM). While **non-operative management (NOM)** has shown success on Earth, its reliability in space is limited. High recurrence/crossover rates from Earth-based trials (appendicitis) are also of particular concern.

NASA's medical models (IMM, IMPACT) identify **20 reversible surgical conditions** likely to occur during long-duration missions, with appendicitis and non-fatal trauma serving as the prototypical use cases. This review synthesizes data from 140 peer-reviewed studies across aerospace medicine, surgery, immunology, systems engineering and biochemistry to propose a space-adapted surgical framework.

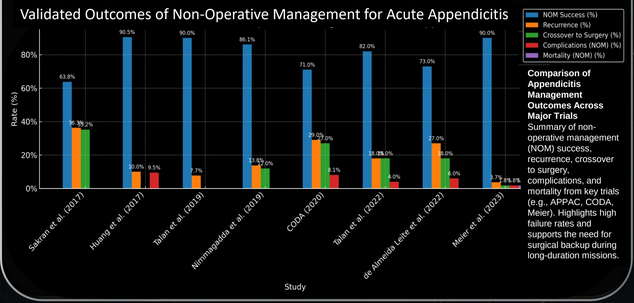
OBJECTIVES

- **Characterize** the most likely and highest-risk surgical emergencies during long-duration spaceflight using appendicitis as a model condition
- **Evaluate** the limitations of NOM in microgravity environments based on outcomes from Earth-based trials
- **Develop** space-adapted clinical protocols for diagnosis, triage, operative intervention, and recovery
- **Integrate** AI-based decision support tools (AI-CDSTs), modular surgical systems, and wearable biosensors into in-mission surgical care
- **Propose** a scalable framework for autonomous surgical readiness applicable to NASA, Artemis, and future Mars missions

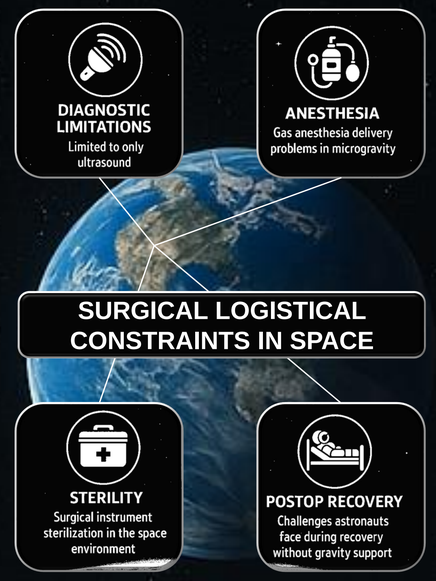
KEY FINDINGS

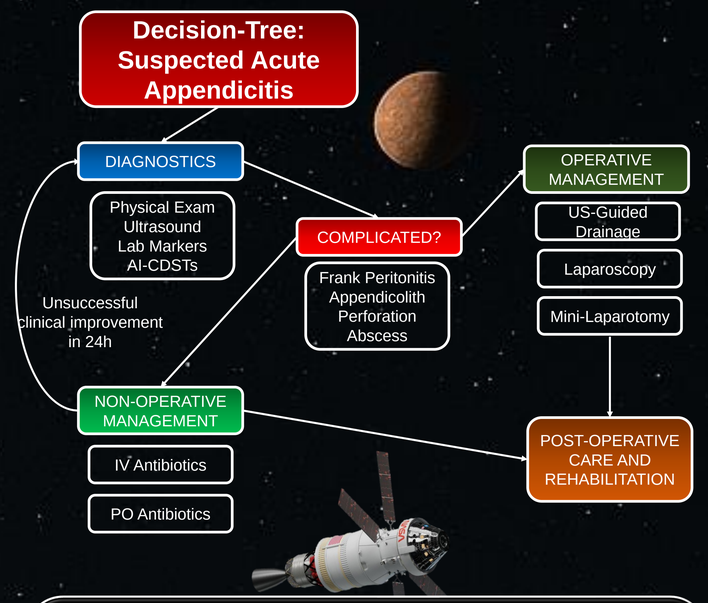
Terrestrial data and meta-analyses show **NOM** of uncomplicated appendicitis achieves initial success in ~70–90% of cases, but **recurrence rates reach up to 46%**, and **over 30% of patients ultimately require surgery** due to symptom progression, antibiotic resistance, or presence of an appendicolith**. These failure rates are mission-critical in space**, where crossover is often not feasible and even modest recurrence or complication rates may be operationally unacceptable. **Takeaway:** While NOM is attractive for resource-limited settings, Earth-based outcomes data suggest that **reliable surgical capability must be considered** in spaceflight medical planning to mitigate unacceptable failure and recurrence risks.

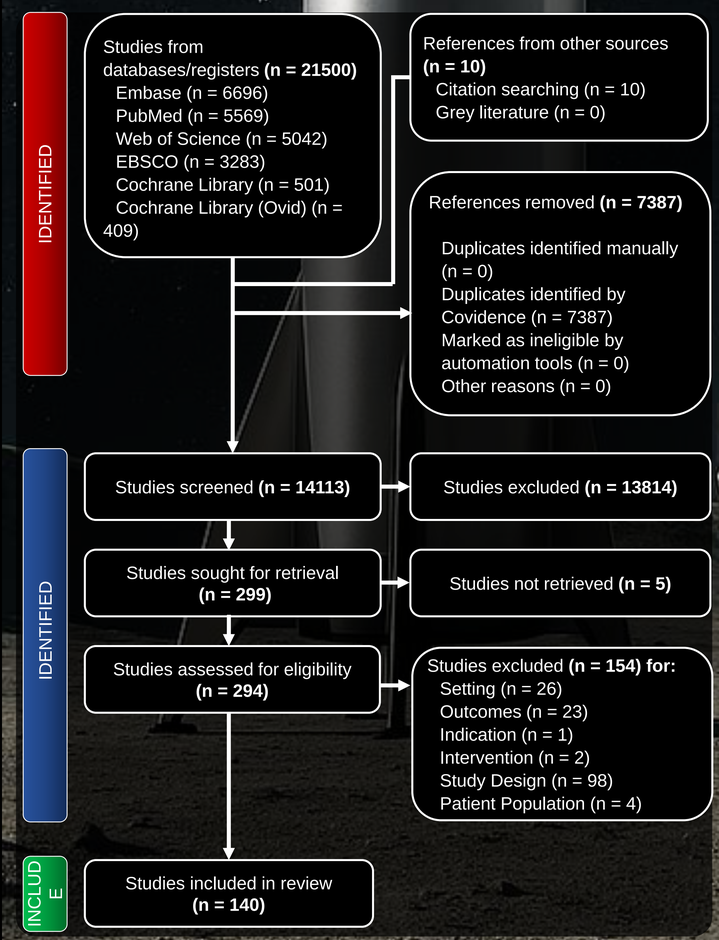
Validated Outcomes of Non-Operative Management for Acute Appendicitis

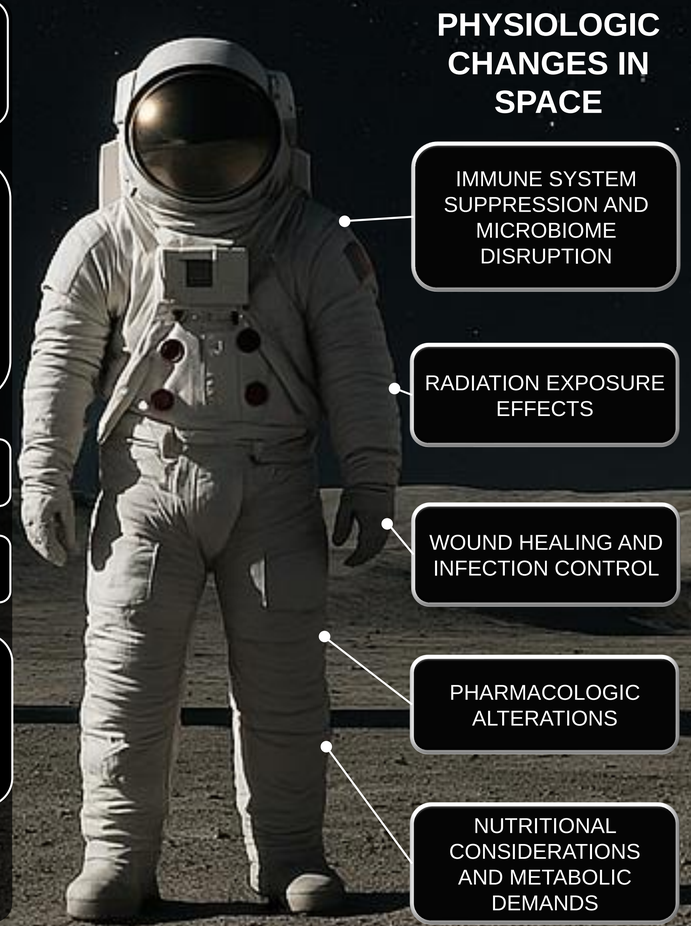


Comparison of Appendicitis Management Outcomes Across Major Trials
Summary of non-operative management (NOM) success, recurrence, crossover to surgery, complications, and mortality from key trials (e.g., APPAC, CODA, Meier). Highlights high failure rates and supports the need for surgical backup during long-duration missions.









SURGICAL READINESS TOOLS

AI-Clinical Decision Support Tools
Dynamic, case-specific guidance to aid crew in diagnosis and procedural steps; integrate with EHR or HMS software, biosensors, procedural libraries

Crew Medical Training Modules
Just-in-time simulation; VR/AR modules for high-acuity, low-frequency scenarios

Ultrasound & Diagnostic Platforms
Compact, rugged, US units with AI support; augmented reality overlay for anatomy recognition in zero-G

Sterility Maintenance Systems
Microgravity-compatible field sterilization kits; enclosed, negative-pressure procedural domes and irrigation

Crew Physiologic Monitoring
Continuous AI-integrated monitoring with trending; wearable for predictive analysis

POST-OPERATIVE CARE

Stage	POD #	Activities
Phase I	0-1	Pain control, breathing exercises
Phase II	2-3	E4D 30m q2h, soft diet, mobility
Phase IIIA	4-5	Resistance bands, flywheel
Phase IIIB	6-7	Functional/cognitive assessments
Phase IVA	8-14	Grip strength, redo assessments
Phase IVB	14+	Functional progression
All Stages		PTPV Motion Capture, MedBridge

SURGICAL PROTOCOL DEVELOPMENT

CONDITION SPECIFIC CHECKLISTS → Each of the top 20 most likely surgical conditions will have stepwise triage protocol
- Signs/symptoms, imaging and biomarkers for diagnostic recognition

RISK STRATIFICATION ALGORITHMS → Bayesian models for surgical risk prediction in microgravity using physiologic and operational data

PHASED OPERATIVE DECISION TREES → Flowcharts for transitioning from non-operative to operative care with embedded criteria

TELE-SURGICAL AND TELEMONITORING PROTOCOLS → Delay-tolerant autonomous procedural guidance with remote support with local execution

INTEGRATED SURGICAL SAFETY PROTOCOLS → Rooted in WHO or DoD surgical safety checklists, adapted to resource limited/autonomous environment

DISCUSSION AND CONCLUSIONS

Surgical emergencies like appendicitis and trauma represent mission-critical risks during long-duration spaceflight. Microgravity alters immunity, wound healing, and drug efficacy—undermining the success of non-operative management. This review outlines a **scalable protocol** for autonomous surgical care, grounded in evidence and tailored to the operational constraints of space:

- **Structured diagnostic algorithms** integrating symptom progression, biosensor trends, and AI decision support with **escalation criteria** to surgical intervention
- Telerobotic capabilities or surgically trained crew members
- **Procedure-specific packs** and modular enclosures designed for safe, sterile operation in microgravity
- **Post-operative recovery protocols**, aligned to post-op day (POD) for mobility, nutrition, and wound care with **rehabilitation milestones** guided by wearable biosensors and cognitive tools to track recovery without ICU-level oversight

Surgical capability is no longer optional for exploration-class missions. Embedding standardized, autonomous, and space-adapted protocols will be essential to protect crew health, reduce mission risk, and sustain human presence beyond Earth.

RESOURCES

140 Literature Works Cited in manuscript