



Background

- Human spaceflight is progressing toward long-duration and deep space missions
- Telemedicine and medical evacuation will be impractical due to communication delays and increasing distance from Earth
- Need to develop autonomous, Earth-independent medical capabilities especially for procedural and surgical interventions
- Environmental factors in space create unique challenges for providing medical care



Methods

- Synthesis of current literature, historical astronaut medical data, and mission planning frameworks
- Comparison of procedural modalities including open surgery, laparoscopic surgery, robotic-assisted surgery, and percutaneous techniques
- Ethical considerations analyzed in the context of austere medical care and resource-limited environments



Results



Space Environment

Key Challenges

Microgravity:

- Floating patients
- Floating providers
- Floating tools



Adaptations & Solutions

- Restraint systems for patients/providers
- Instrument restraint systems: Velcro, magnetic, straps

Sterility & contamination control



- Suction & sponges
- Disinfection protocols
- Antibiotic stewardship

Finite equipment & supplies



- Risk assessment and mission planning
- Versatile, multi-use tools
- 3D-printing capabilities

Limited crew training



- Just-in-time training
- Decision support systems (e.g. AI)
- Increase cross-training for astronauts



Procedural Modalities

Open Surgery

- ✓ Direct visualization and access
- ✓ No specialized equipment
- ✗ Complicated body positioning
- ✗ Floating organs, maintaining sterility
- ✗ General anesthesia and team

Robotic Surgery

- ✓ Reduced physical & cognitive demand
- ✗ Communication latency & degradation
- ✗ High mass, volume, and power requirements
- ✗ Maintenance and repair

Laparoscopy

- ✓ Minimally invasive
- ✗ Management of insufflation gases
- ✗ High mass, volume, power requirements
- ✗ Substantial skill requirements

Interventional Radiology & Percutaneous Techniques

- ✓ No general anesthesia
- ✓ Less and fewer tools
- ✗ Need advanced imaging equipment
- ✗ Heavily dependent on operator skill

Ethical Considerations

- Austere standards of care
 - Triage algorithm does not exist
- Resource allocation
 - Individual patient care vs crew survival
- Temporizing & palliative care
 - Moral injury
- Collaborative decision-making
- Confidentiality



Key Takeaways

- Autonomous medical capability is essential for deep space missions
- Microgravity fundamentally alters procedural medicine
- Open surgery and interventional radiology/percutaneous show promise for use in space with adaptations
- Ethical frameworks must adapt to extreme environments

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