General Approaches to Surgical Procedures in Space

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Abstract

Background: As human spaceflight progresses toward long-duration and deep space missions, reliance on telemedicine and medical evacuation becomes increasingly impractical due to communication delays and limited resources. This shift necessitates the development of autonomous, Earth-independent medical capabilities, particularly for procedural and surgical interventions. The space environment introduces unique challenges, including microgravity, constrained resources, sterility, atmosphere management, and limited crew medical training.

Methods: This chapter synthesizes current literature, historical astronaut medical data, and mission planning frameworks to evaluate the feasibility of performing medical procedures in space. Key environmental and operational constraints are examined, including microgravity effects, sterility and contamination risks, equipment limitations, atmospheric management, and crew training. Additionally, procedural modalities such as open surgery, laparoscopic surgery, robotic-assisted surgery, and interventional radiology are compared based on feasibility within spaceflight constraints. Ethical considerations are also analyzed within the context of austere medical care and resource-limited environments.

Results: Microgravity significantly alters procedural dynamics, affecting patient and provider positioning, fluid behavior, and instrument control. Resource limitations restrict the availability of medical equipment and necessitate the use of multipurpose tools and techniques. Among procedural approaches, interventional radiology and percutaneous techniques demonstrate feasibility due to lower resource requirements and reduced need for specialized personnel. Open surgery remains a critical but personnel-intensive option, while laparoscopic and robotic-assisted techniques are limited by equipment demands and environmental constraints. Infection risk may be mitigated through modified sterility practices and antimicrobial strategies. Ethical challenges emerge in triage, resource allocation, and balancing individual patient care with crew survival.

Conclusion: Effective medical care during deep space missions will require a paradigm shift toward autonomous, resource-efficient, and adaptable procedural strategies. Interventional and minimally invasive techniques offer promising solutions within current constraints, while advances in training, decision-support systems, and medical technologies will be essential to expanding capabilities. Ethical frameworks must also evolve to guide care in austere, high-risk environments. Integrating these approaches is critical to ensuring crew safety and mission success in future human space exploration.