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EARLY KIDNEY STONE DETECTION WITH INTEGRATED ULTRASOUND AND ELECTRICAL IMPEDANCE TOMOGRAPHY

Abstract

Nephrolithiasis poses a significant threat to astronaut health and wellbeing due to dehydration, stasis, and bone demineralization that occur with prolonged microgravity exposure. Detecting kidney stone formation early on is beneficial, as smaller stones (¡ 5 mm) are easier to pass and non-invasive treatments, such as lithotripsy, depend on localizing the stone with high-contrast imaging (e.g., fluoroscopy, x-ray) first. Ultrasound is the current imaging system used in space, but detecting small stones with ultrasound alone is challenging for non-specialists. Astronauts on deep space missions will need to monitor and diagnose medical conditions such as nephrolithiasis without relying on additional large imaging systems or telemedical support, as spacecraft constraints and communication limitations make these solutions unfeasible. Significantly higher contrast can be obtained by imaging the bioelectric properties, as these are sensitive to cellular content, tissue type, and pathology, allowing for stone detection within soft tissue. Electrical impedance tomography (EIT) is a low resource, non-invasive, non-ionizing technology that produces images of these electrical properties and can detect a range of space-related medical conditions (e.g., nephrolithiasis, tissue injury, muscle atrophy, thoracic function, cancer presence). Combining ultrasound and EIT (US-EIT) can produce high-contrast images without the need for additional equipment or expertise, providing astronauts an intuitive imaging tool for detecting kidney stone presence and effectively monitoring health on long-duration missions. An integrated US-EIT probe was developed using a 16-channel flexible electrode array and C1-6 transducer for dual-modality imaging with the Vivid E95 Flexible Ultrasound System (FUS). A phantom imaging setup was built for deep tissue sensing; to ensure sufficient depth sensitivity for kidney imaging, distal electrodes are placed opposite the probe, forcing current to flow through the simulated kidney region. Software developed in MATLAB overlays the EIT image on the FUS image to provide higher contrast for localizing stones during image acquisition. US-EIT imaging experiments were performed on gel phantoms simulating abdominal structures to validate the deep tissue sensing setup and determine image accuracy. Various sizes of insulative inclusions were embedded in the gels to simulate kidney stone presence, and US-EIT imaging was performed to evaluate sensitivity to kidney stone inclusions and assess US-EIT capabilities for non-invasive early kidney stone detection. Enhancing EIT with ultrasound will provide a space-compatible medical imaging system that will enable astronauts to detect kidney stones early on for improved treatment outcomes and quality of life on deep space missions.