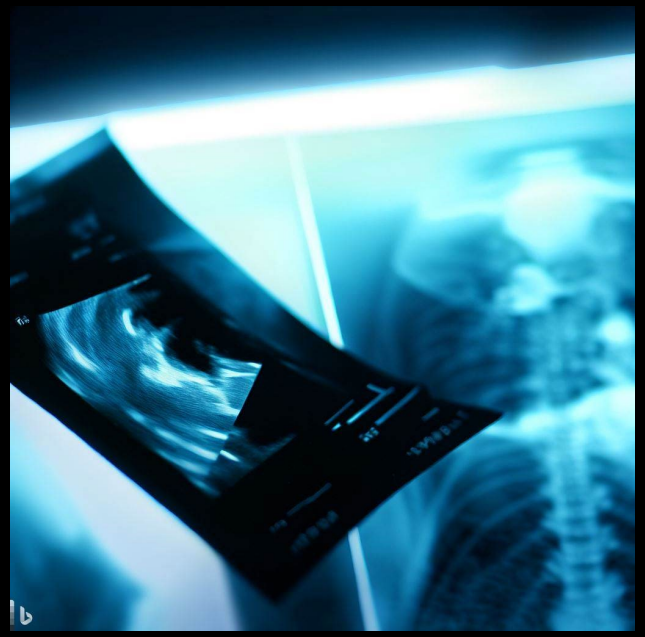

Mapping the Utility of Radiography and Ultrasound for the IMPACT Conditions List

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No disclosures

Introduction

- → Imaging is central to modern diagnostics. To date, only ultrasound utilized in spaceflight.
- → Advancing the level of care on exploration-class missions and permanent off-world habitats will require more advanced imaging capabilities in order to minimize mission medical risk.
- → The IMPACT tool suite was designed to allow exploration-class mission trade space assessment.
  - → The IMPACT Condition List (ICL) includes 120 possible inflight medical conditions established by expert opinion and flight data

Above top: Butterfly iQ handheld ultrasound
Above bottom: Ultrasound 2 aboard the ISS

1	Abdominal Wall Hernia	31	Dental Fracture/Exposed Pulp	61	Gravity Well - Entry Motion Sickness	91	Small Bowel Obstruction
2	Abnormal Uterine Bleeding	32	Dental Luxation/Avulsion (Tooth Loss)	62	Gravity Well - Neurovestibular Disturbance	92	Space Adaptation - Back Pain
3	Acute Coronary Syndrome	33	Dislocation - Finger	63	Gravity Well - Orthostatic Intolerance	93	Space Adaptation - Constipation
4	Acute Radiation Syndrome	34	Dislocation - Shoulder	64	Headache	94	Space Adaptation - Epistaxis
5	Allergic Reaction (Mild To Moderate)	35	Diverticulitis, Acute	65	Headache - CO2 Induced	95	Space Adaptation - Headache
6	Altitude Sickness	36	Dust Exposure - Lunar	66	Hearing Loss	96	Space Adaptation - Insomnia
7	Anaphylaxis	37	Ebullism	67	Hearing Loss - Noise-Related	97	Space Adaptation - Nasal Congestion
8	Appendicitis	38	Epistaxis	68	Hemorrhoids	98	Space Adaptation - Space Motion Sickness
9	Arthritis, Acute	39	EVA Related Decompression Sickness	69	Herpes Zoster Reactivation (Shingles)	99	Space Adaptation - Urinary Retention
10	Atrial Fibrillation/ Atrial Flutter	40	EVA Related Dehydration	70	Mouth Ulcer	100	Space Adaptation - Urinary Incontinence
11	Barotrauma (Ear/Sinus Block)	41	EVA Related Fingernail Delamination	71	Nephrolithiasis	101	Spaceflight Associated Neuro-Ocular Syndrome (SANS)
12	Benzodiazepine or Opioid Overdose	42	EVA Related Hand Injury	72	Neuropathy - Central, Impingement Related	102	Sprain/Strain - Back
13	BHP - Adjustment Disorder	43	EVA Related Heat Illness	73	Otitis Externa	103	Sprain/Strain - Lower Extremity
14	BHP - Anxiety	44	EVA Related Paresthesia	74	Otitis Media	104	Sprain/Strain - Neck
15	BHP - Depression	45	EVA Related Shoulder Injury	75	Pancreatitis, Acute	105	Sprain/Strain - Upper Extremity
16	BHP - Grief Reaction	46	EVA Related Suit Contact Injury	76	Pregnancy, First Trimester	106	Streptococcal Pharyngitis
17	BHP - Psychosis Secondary To Depression	47	Eye - Retinal Injury	77	Pregnancy, Risk For	107	Sudden Cardiac Arrest
18	BHP - Sleep Disturbance	48	Eye Foreign Body	78	Prostatitis, Acute	108	Tendinopathy/Enthesopathy/Bursitis/Over-Use Injuries - Lower Extremity
19	BHP - Spaceflight Related Relationship Problems	49	Eye Irritation/Corneal Abrasion/Ulceration	79	Rash, Spaceflight Associated	109	Tendinopathy/Enthesopathy/Bursitis/Over-Use Injuries - Upper Extremity
20	Burn - Chemical Eye	50	Eyelid And Anterior Eye Infection	80	Reactive Airway	110	Toxic Dermal Exposure
21	Burn - Chemical Skin	51	Fracture - Arm	81	Respiratory Failure	111	Toxic Inhalation Exposure
22	Burn - Mild, Thermal	52	Fracture - Cervical Spine	82	Respiratory Tract Infection - Lower	112	Toxic Inhalation Exposure - Combustion Products
23	Burn - Moderate To Severe, Thermal	53	Fracture - Distal Leg	83	Respiratory Tract Infection - Upper	113	Trauma - Abdominal Injury (Blunt)
24	Cerebrovascular Accident	54	Fracture - Femur	84	Seizures	114	Trauma - Chest Injury (Blunt)
25	Cerumen Impaction	55	Fracture - Hand	85	Sepsis	115	Trauma - Minor Head
26	Choking/Obstructed Airway	56	Fracture - Wrist	86	Shock - Cardiogenic	116	Trauma - Severe Head
27	Cholelithiasis/Biliary Colic, Acute	57	Fracture- Thoracic/Lumbar Spine	87	Skin Abrasion	117	Traumatic Hypovolemic Shock
28	Dental Abscess	58	Gastritis/Reflux/Esophagitis	88	Skin Infection - Bacterial	118	Urinary Tract Infection
29	Dental Crown Loss	59	Gastroenteritis/Acute Diarrhea	89	Skin Infection - Viral/Fungal	119	Vaginal Yeast Infection
30	Dental Filling Loss	60	Glaucoma, Acute Angle-Closure	90	Skin Laceration	120	Venous Thromboembolism

Impact Condition List v1.0 from Kreykes et al. 2023

Goal

→ To evaluate the clinical utility of ultrasound (US) and radiography (XR) for the diagnosis and management of each of the ICL conditions

Purpose

→ To identify the conditions for which XR adds value and thereby define the needed capabilities of an inflight portable XR system

Methods

→ For each condition, two reviewers performed a rapid systematic literature review of professional society guidelines and applied subject matter expert clinical experience to evaluate the utility of US and XR for both diagnosis and management.

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- → All scoring was recorded with evidence tracing and evidence level scoring

Methods

- → Utility was rated on a semi-quantitative scale from 0 to 2.
  - → 0: No or negligible utility
  - → 1: Some utility but not a necessity or low sensitivity/specificity; not routinely utilized in terrestrial practice
  - → 2: Necessary or terrestrial standard of care for diagnosis or management

Methods

- For each utility score, evidence supporting that score was rated on an alphabetical scale, approximately corresponding to the USPSTF evidence levels:
  - **A High**: Endorsement by professional society guidelines OR Evidence from a systematic review or meta-analysis of all relevant randomized controlled trials
  - **B Moderate**: Evidence from evidence summaries or guidelines developed from systematic reviews of non-randomized studies
  - **C Low-Moderate**: Evidence from meta-syntheses of a group of descriptive or qualitative studies, evidence summaries of individual studies, one properly designed randomized controlled trial
  - **D Low**: Evidence from nonrandomized controlled clinical trials, nonrandomized clinical trials, cohort studies, case series, case reports, and individual qualitative studies OR Expert opinion without evidence level above
  - **X Reviewer experience**: Experience of SMEs, including the authors'

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- → Utility score and unique capabilities do not include differences in modality training times, ease of acquisition and interpretation, or field of view
- → Ultrasound operator skill is assumed to be high enough to replicate literature.
- → Utility score has no bearing on MEDPRAT ability/inability to treat

Process Example:
Diagnosis: Cholelithiasis/biliary colic, acute

- → Condition: Cholelithaisis/biliary colic, acute
  - → Best case: A course of uncomplicated biliary colic which resolves spontaneously or causes minimal disturbance requiring only symptomatic pain management.
  - → Worst case: Acute cholecystitis with likely complications requiring significant pain management, antibiotic administration, and likely definitive surgical management.
- → Translation of condition to symptom/complaint:
  - → Acute atraumatic abdominal pain, acute atraumatic epigastric abdominal pain
- → Evaluation of ACR and ACEP guidelines for matches:
  - → Exact Match, "Right upper quadrant pain. Suspected biliary disease. Initial imaging."
  - → Exact Match, “Acute nonlocalized abdominal pain. Not otherwise specified. Initial imaging.”
- → Rate on 0-2 scale based on ACR guidelines of “usually appropriate”, ” may be appropriate”, and “usually not appropriate”, using highest score from any match:
  - → “US abdomen: Usually appropriate” → US utility score of 2 for diagnosis
  - → “Radiography abdomen: May be appropriate” → XR utility score of 1 for diagnosis
- → Determine via two independent assessments if any unique or complementary capabilities exist:
  - → YES, both modalities: US for superior gallbladder evaluation, XR for bowel gas pattern, overall stool burden, bowel obstruction, etc.

Process Example:
Management: Cholelithiasis/biliary colic, acute

- → Condition: Cholelithaisis/biliary colic, acute
  - → Best and worst cases unchanged
  - → Symptom/complaint unchanged
- → Identification of management options for condition or explicitly stated complication of condition
  - → “...likely definitive surgical management” → Potential use of percutaneous cholecystostomy
- → Rate both imaging modalities for their use in the identified intervention on a 0-2 scale based on “No or negligible utility”, “Some utility and/or not necessary”, and “Necessary OR terrestrial standard of care OR high quality evidence supporting utility”
  - → US: Necessary for cholecystostomy tube placement (in absence of CT) → 2
  - → XR: Brief fluoroscopy/serial radiograph as adjunct is terrestrial standard of care to confirm placement (though not necessary) → 2
- → Assess for unique capabilities
  - → Yes, both. US required for placement. XR allows for potential cholecystogram.

Process Example:
Diagnosis: Fracture - Femur

- → Condition: Fracture - Femur
  - → Best case: A closed, non-comminuted, non-segmented, non-displaced, or minimally displaced fracture resulting in no neurovascular compromise to the affected limb.
  - → Worst case: A fracture that is: open, comminuted, segmented, moderately to severely displaced, intra-articular, or results in neurovascular compromise to the affected limb, likely requiring surgical intervention.
- → Translation of condition to symptom/complaint:
  - → Acute injury to thigh
- → Evaluation of ACR guidelines for matches:
  - → ACR Exact Match, "Acute hip pain. Fall or minor trauma. Suspect fracture. Initial imaging."
- → Rate on 0-2 scale based on the ACR guidelines of “usually appropriate”, ” may be appropriate”, and “usually not appropriate”:
  - → ACR: “US hip: Usually not appropriate” → US utility score of 0 for diagnosis
  - → ACR: “Radiograph: Usually appropriate” → XR utility score of 2 for diagnosis
- → Rapid systematic review for US utility given score of 0 or 1:
  - → Identification of observational studies demonstrating efficacy, increase score to 2 but assign D as evidence level (A evidence level if ACR guideline)
- → Determine via two independent assessments if any unique or complementary capabilities exist:
  - → Yes, US. US: can evaluate directly for vascular, ligament or tendon injury.

Process Example:
Management: Femur fracture

- → Condition: Fracture - Femur
  - → Best and worst cases unchanged
  - → Symptom/complaint unchanged
- → Identification of management options for condition or explicitly stated complication of condition
  - → “...open, comminuted, segmented, moderately to severely displaced, intra-articular, or results in neurovascular compromise to the affected limb, likely requiring surgical intervention.” → Potential need for reduction and fixation
- → Rate both imaging modalities for their use in the identified intervention on a 0-2 scale based on “No or negligible utility”, “Some utility and/or not necessary”, and “Necessary OR terrestrial standard of care OR high quality evidence supporting utility”
  - → XR: Brief fluoroscopy/radiograph is terrestrial standard of care to confirm satisfactory alignment post-reduction→ 2
  - → US: Not routine clinical practice, raters unsure of score.
- → Rapid systematic review for US for post-reduction alignment
  - → Identification of observational studies for other long bones post-reduction showing some efficacy → 1
- → Assess for unique capabilities
  - → None for postreduction alignment assessment

Results

Phase of care	Utility score: US > XR	Utility score: XR > US	Utility score: XR = US	XR provides unique, complementary capabilities but possesses </= utility score
Diagnosis # of conditions, % of total	**16 (13%)**	**14 (12%)**	**27 (23%)**	**12 (10%)**
Management # of conditions, % of total	**7 (6%)**	**10 (10%)**	**18 (15%)**	**10 (8%)**

Results – XR for Diagnosis

- XR surpasses ultrasound
  - Arthritis, acute
  - Choking/obstructed airway
  - Dental abscess
  - Dental crown loss
  - Dental filling loss
  - Dental fracture/exposed pulp
  - Dental luxation/avulsion (tooth loss)
  - Dust exposure – Lunar
  - Fracture – Cervical spine
  - Fracture – Thoracic/lumbar spine
  - Gastritis/reflux/esophagitis
  - Neuropathy – Central, impingement related
  - Toxic inhalation exposure
  - Toxic inhalation exposure – combustion products
- XR equal to or less than US but unique/complementary capabilities
  - Abdominal wall hernia
  - Acute coronary syndrome
  - Appendicitis
  - Atrial fibrillation/atrial flutter
  - Cholelithiasis/biliary colic, acute
  - Diverticulitis, acute
  - Ebullism
  - Eye foreign body
  - Nephrolithiasis
  - Trauma – abdominal injury (blunt)
  - Trauma – chest injury (blunt)
  - Traumatic hypovolemic shock

Results – XR for Management

- → XR surpasses ultrasound
  - → Choking/obstructed airway
  - → Ebullism
  - → EVA related decompression sickness
  - → Fracture – cervical spine
  - → Fracture – distal leg
  - → Fracture – femur
  - → Fracture – hand
  - → Fracture – wrist
  - → Fracture - thoracic/lumbar spine
  - → Trauma – chest injury (blunt)
- → XR equal to or less than US but unique capabilities
  - → Appendicitis
  - → Cholelithiasis
  - → Diverticulitis, acute
  - → Nephrolithiasis
  - → Reactive airway (now removed from list)
  - → Seizures
  - → Cardiogenic shock
  - → Sudden cardiac arrest
  - → Trauma - chest injury (blunt)
  - → Traumatic hypovolemic shock

Discussion

- → Radiography would provide complementary or superior imaging capabilities relative to US for diagnosis of 22% of ICL conditions and for management in 16%
- → Dental disease, musculoskeletal trauma, inhalational injury/exposure comprise majority, though XR also provides auxiliary capabilities with respect to the acute abdomen and its interventions as well as medical device placement
- → Presence of IV/enteric contrast material (e.g. Omnipaque) uniquely extends the utility of XR for conditions as gastritis/reflux

Above top: Handheld radiography system
Above bottom: Portable radiography equipment in parabolic flight

Next Steps

- → Shift from qualitative to quantitative assessment to allow for possible eventual incorporation into MEDPRAT
  - → How much risk would XR buy down? And at what mass/volume/power penalty?
  - → First step is including incidence data for each condition
- → Concretely define which capabilities are needed to maximize XR utility
  - → What kVp, mA, detector size are needed to image our conditions of concern?
- → Expanded XR capabilities
  - → Can we get a high enough frame rate for basic fluoroscopy? If we rotate patient, can we develop limited cone beam CT capability?

Thank you for your time and attention!

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