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Choosing radiology imaging modalities to meet patient needs with lower environmental impact

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ABSTRACT

Every patient that comes to Radiology has a different category of health problem. Based on diagnoses, each patient gets the appropriate imaging to aid in their treatment. The Healthier Hospital Initiative (HHI, www.healthierhospitals.org), Healthcare Without Harm (www.https://noharm.org/), and Practice Greenhealth (www.https://practicegreenhealth.org/) are important efforts on the part of healthcare providers to move toward sustainability. This initiative has raised awareness of energy utilization, and provides tools for measuring hospital energy use. However, the coupling of patient healthcare teams (RN, MD, administrators) making the decisions that achieve quality patient care, with a goal of lower environmental impact has yet to be widely explored. This study examines the use of the American College of Radiology (ACR) Appropriateness Criteria as guidance for similar, “usually appropriate” imaging modality choices (that is, ratings of 7, 8, and 9) and then identifies which is the lower energy use modality alternative. Overall, in the ten ACR patient categories (with 162 subcategories which have overall 810 variants), there are approximately 48% of patient conditions where there are similar imaging modalities with a “usually appropriate” rating. The largest percentage interchangeability is in the cardiac category. Thus the potential to choose a lower energy imaging alternative appears to exist. As examples, six patient variants are used to illustrate the potential to reduce Radiology Department energy use. These examples provide approximate energy reduction imaging alternatives that if selected, in even 1%–10% of patient cases, (versus the 48% of comparative “usually appropriate” imaging) would lead to an annual U.S. healthcare improvement of 24–240 million kWh per year. This modest improvement would be a direct contribution to healthcare sustainability by the Radiology community without any technology change.

1. Introduction

Energy use in hospitals has often been studied (U.S. Environmental Protection Agency, 2015; Sheppy et al., 2014; Department of Environment, Transport, and the Regions’ Energy Efficiency, 2013), but only portrayed in terms of the infrastructure metrics, such as size, number of beds, overall medical equipment. A few studies to relate energy use to different radiology imaging modalities have been published (Esmaeili et al., 2011; Soltani et al., 2015; Esmaeili et al., 2015; McCarthy et al., 2014; Martin et al., 2018). However, Radiology is an important department in hospitals for those who have been in an accident or have a condition that needs imaging for diagnosis. In the 1990s, ACR (American College Radiology) recognized the need of guidelines that help for appropriate use of imaging technology. These guidelines became known as the ACR Appropriateness Criteria (ACR AC) (Anon, 2019). In 1993, K.K. Wallace formally introduced this organization to the concept of eliminating misuse of radiology services (Anon, 2019). The ACR Appropriateness Criteria® are evidence-based guidelines to assist referring physicians and other providers in making the most appropriate imaging or treatment decision for a specific clinical condition (Anon, 2019). The ACR defined 10 categories of patient conditions for which radiological images can improve patient care. Imaging modalities for each patient condition are each ranked by ACR as to provide the greatest patient information benefit. The highest rank is a 9 and the ranks of 7–9 are considered “usually appropriate”. Rankings below 7 are less recommended. Efficient use of radiology is the main concern for ACR, so they engaged the guidelines to provide more quality in healthcare. Developing the guidelines by imaging experts and specialists added more benefits in interventional radiology, radiation oncology, and diagnostic imaging. The ACR provides free data

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Table 1
List of categories of diagnostic patient conditions (162 subcategories).

#	Categories	Subcategories
1	Breast	6
2	Cardiac	10
3	Gastrointestinal	17
4	Musculoskeletal	27
5	Neurologic	20
6	Pediatric	12
7	Thoracic	16
8	Urologic	21
9	Vascular	18
10	Womens	15

on their websites for researchers or individuals to use ACR Appropriateness Criteria for scientific or other valuable information. There is also the Journal of the American College of Radiology (JACR), which published ACR Appropriateness Criteria to improve education about appropriate imaging for better patient care. There are many imaging services in the U.S. healthcare system and the most modalities used in the recent 15-year period are Radiography (x-ray) (55.1%), Sonography (ultrasound) (19.1%), Computed Tomography (CT) Scan (12.5%) and Magnetic Resonance Imaging (MRI) (5.1%) (Sheppy et al., 2014). The first objective of this paper is to evaluate the ACR commonly used modalities with regard to environmental footprints. For these footprints, we utilize the detailed energy and environmental emissions analyses of radiology imaging modalities. The reader is directed to the following sources for the details of time measurements, power use, boundaries of analysis, and consumables or reusables employed in each patient imaging. These are MRI) (Esmaeili et al., 2018), CT (Esmaeili et al., 2015), X-ray (Esmaeili, 2016), and ultrasound (US) (Esmaeili, 2016). In the first objective, we seek to evaluate the ACR "usually appropriate" imaging modalities (ratings of 7–9) for each of the 810 patient conditions (variants) that has the lowest environmental impact. The second objective is to illustrate comparative examples of the energy improvement for some patient variants with multiple appropriate modalities that comes from selecting the lower energy alternative. This analysis is focused on the prescribed use of radiology modalities and can thus be used by readers. We do not address misuse, overuse, poor maintenance, nor inefficient management.

2. Methodology

The American College of Radiology established the modality appropriateness rating in ten categories that encompass most all patient conditions encountered on a routine basis that require imaging (https://acsearch.acr.org/list). Within these ten categories there are subcategories, each with a number of variants and overall 810 patient variants. Each variant ratings are prepared by separate committees of specialist (usually 10–15 persons) and these are listed on the ACR website. The literature for each variant was assembled and reviewed to select those publications directly related to review or comparisons of modalities. The appropriateness categories are

1) usually appropriate (scores 7–9),
2) may be appropriate (scores 4–6), and
3) usually not appropriate (scores 1–3).

In the same website, any radiation exposure per patient is listed and the appropriateness vote of the committee is listed.

These ten categories of diagnostic patient conditions for radiology in which there are 6–27 subcategories are in Table 1 (https://acsearch.acr.org/list). We put all ten ACR categories for imaging modalities in different Tables and then listed the entire imaging choices for each variant. The number of variants ranges from 1 to 4 or more in each clinical condition in the subcategories. We excluded variants that were below the "usually appropriate" rating scale (that is, from 1 to 6). After that we eliminated variants if there were no alternatives for a given modality. Only those variants with more than one "usually appropriate" rated modalities were selected for a summary. As an example, the breast category is shown in Table 2. Across the breast subcategories, twelve variants had multiple "usually appropriate" ratings. Table 2 analysis was repeated for the other nine patient conditions.

Thus the first analysis was based on the ACR appropriateness criteria and the ten categories that were studied for patient condition and specific choice of imaging modality. If two or more modalities have the highest rating, then for those patients, there are alternative choices (e.g. Crohn's disease enterography rated 9 for CT & MRI). Our second analysis was to use life cycle studies to establish a complete energy profile (electricity & consumables), for CT & MRI, Table 3, and then to evaluate the energy savings by selecting alternatives. The details of the electrical energy and the consumables cradle-to-gate manufacturing energy are given in papers on x-ray (Esmaeili, 2016), MRI (Esmaeili et al., 2018) and CT (Esmaeili et al., 2015)

3. Results

After we listed all categories with the variants, we picked only those variants in which there are two or more modalities that scored 7, 8, or 9

Table 2
Alternative modalities with scores in different variants in breast category.

Condition	Average ACR criteria - 7–9 range only	Variants	Modality	Score	Modality	score	Modality	Score
Breast Cancer Screening	9	Variant 1	MRI	9	DBT	9	Mammography	9
Breast Cancer Screening	8.33	Variant 2	MRI	7	DBT	9	Mammography	9
Breast Cancer Screening	9	Variant 3	DBT	9	Mammography	9		
Evaluation of Nipple Discharge	9	Variant 2	US	9	DBT	9	Mammography	9
Evaluation of Nipple Discharge	9	Variant 3	US	9	DBT	9	Mammography	9
Evaluation of Nipple Discharge	8.67	Variant 5	US	9	DBT	8	Mammography	8
Evaluation of the Symptomatic Male Breast	8.5	Variant 5	US	8	Mammography	9		
Palpable Breast Masses	9	Variant 1	DBT	9	Mammography	9		
Palpable Breast Masses	8	Variant 3	US	8	DBT	8	Mammography	8
Palpable Breast Masses	8.33	Variant 7	DBT	8	Mammography	8		
Palpable Breast Masses	8	Variant 11	US	8	DBT	8	Mammography	8
Stage I Breast Cancer: Initial Workup and Surveillance for Local Recurrence and Distant Metastases in Asymptomatic Women	8.5	Variant 9	DBT	9, 8	Mammography	9, 8		

Table 3
Natural Resource Energy Consumption of Four Imaging Practices (Esmaeili et al., 2015, 2018; Esmaeili, 2016).

	MRI	CT-scan (GE)	CT-scan (Philips)	X-ray (GE)	X-ray (Philips)	Ultrasound
TOTAL (nre-MJ per Patient	1,046	263	170	45.1	33.6	30.8

Table 4
Summary of the ten ACR diagnostic categories with percentage of comparable variants at the “usually appropriate” rating (7–9).

#	Categories	Summary	The percentage of comparison variants %
1	Breast	There were 47 variants in the breast diagnostic category, 20 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 27 variants, 15 variants were removed because there were no alternatives for the modalities. So, 12 variants are the remaining out of 47 that will be compared between modalities to select the lower energy for hospital sustainability	26
2	Cardiac	There were 24 variants in the Cardiac diagnostic category, 2 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 22 variants, 2 variants were removed because there were no alternatives for the modalities. So, 20 variants are the remaining out of 24 that will be compared between modalities to select the lower energy for hospital sustainability	83
3	Gastrointestinal	There were 78 variants in the Gastrointestinal diagnostic category, 3 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 75 variants, 28 variants were removed because there were no alternatives for the modalities. So, 47 variants are the remaining out of 78 that will be compared between modalities to select the lower energy for hospital sustainability	60
4	Musculoskeletal	There were 238 variants in the Musculoskeletal diagnostic category, 23 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 215 variants, 117 variants were removed because there were no alternatives for the modalities. So, 91 variants are the remaining out of 238 that will be compared between modalities to select the lower energy for hospital sustainability	38
5	Neurologic	There were 164 variants in the Neurologic diagnostic category, 12 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 152 variants, 76 variants were removed because there were no alternatives for the modalities. So, 76 variants are the remaining out of 164 that will be compared between modalities to select the lower energy for hospital sustainability	46
6	Pediatric	There were 55 variants in the Pediatric diagnostic category, 29 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 26 variants, 13 variants were removed because there were no alternatives for the modalities. So, 13 variants are the remaining out of 55 that will be compared between modalities to select the lower energy for hospital sustainability	24
7	Thoracic	There were 56 variants in the Thoracic diagnostic category, 7 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 49 variants, 25 variants were removed because there were no alternatives for the modalities. So, 24 variants are the remaining out of 56 that will be compared between modalities to select the lower energy for hospital sustainability	43
8	Urologic	There were 48 variants in the Urologic diagnostic category, 8 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 40 variants, 15 variants were removed because there were no alternatives for the modalities. So, 23 variants are the remaining out of 48 that will be compared between modalities to select the lower energy for hospital sustainability	48
9	Vascular	There were 38 variants in the Vascular diagnostic category, 1 was excluded because this is under the appropriate rating scale of 7–9. The remaining is 37 variants, 5 variants were removed because there were no alternatives for the modalities. So, 29 variants are the remaining out of 38 that will be compared between modalities to select the lower energy for hospital sustainability	76
10	Women’s Imaging	There were 62 variants in the Women’s diagnostic category, 5 were excluded because these are under the appropriate rating scale of 7–9. The remaining is 57 variants, 38 variants were removed because there were no alternatives for the modalities. So, 19 variants are the remaining out of 62 that will be compared between modalities to select the lower energy for hospital sustainability	31

and so these might be considered alternatives that still give good patient information. It is recognized that for any given variant, not every modality with a “usually appropriate” rating (like a 9) can always be used. There is probably no single reason for the lack of interchangeability. These reasons could involve the way radiologists are trained, limits in technology, or accessibility. However, it is important to understand just how many variants have multiple ‘usually appropriate” rated modalities. Table 4 summarizes the total variants in each ACR category and what percent have alternative modalities with ‘usually appropriate” ratings. Across all ten ACR patient categories, 354 patient condition variants appear to have multiple “usually appropriate” modalities. Across the ten patient categories, the range of variants in the ten categories with interchangeable (“usually appropriate”, ratings 7–9) modalities was 23%–83% with the median of 48%, nearly half. The cardiac category had the highest level of potential interchangeability. This implies there is some reasonable potential for selecting alternative modalities that achieve quality care through patient diagnosis imaging, but at a lower energy demand.

Energy savings in radiology translates into reduced costs and lower environmental impact. To the extent that there are some interchangeability among ACR “usually appropriate” modalities, an energy savings analysis was conducted on six examples. These six variants were selected by the radiology community to demonstrate potential energy savings by selecting realistic modalities with the lowest energy per patient, while achieving similar patient imaging information. One example is from the neurologic category under the headache conditions (variant 4) in which selecting the CTA (ACR rating of 8) compared to MRI (ACR rating of 8) saves about 800 MJ/patient (230 kW h/patient). The other examples were selected to cover other ACR patient categories for diagnostic, gastrointestinal, vascular, and urologic imaging. One example, chronic liver disease evaluation/follow-up, had a third alternative, ultrasound, for which the energy savings was over 1000 MJ/

Table 5
Examples of patient conditions (variants) for which multiple ACR "usually appropriate" modalities are available in which energy savings would occur and patient diagnostic quality would be maintained.

ACR Diagnostic Category (Variant)	Modality ("Usually Appropriate rating")	Modality ("Usually Appropriate rating")	Modality ("Usually Appropriate rating")	Energy Savings	Energy Savings
Gastrointestinal (Chronic liver disease evaluation/follow-up – var.2)	MRI (8)	US (7)	CT (7)	US instead of MRI	US instead of CT
Energy use, MJ/patient	1,050	31	216	1,020	140
Gastrointestinal (Crohn's disease follow-up – var 2)	MR enterography (9)	CT enterography (9)			CT instead of MRI
Energy use, MJ/patient	1050	216			830
Neurologic (headache – var. 4)	MRA (8)	CTA (7)			CT instead of MRI
Energy use, MJ/patient	1,050	216			830
Vascular (renovascular hypertension – var.1)	MRA (8)	CTA (8)			CT instead of MRI
Energy use, MJ/patient	1,050	216			830
Urologic (Post-treatment Follow-up of Prostate Cancer – var. 1)	MRI (7)	CT (7)			CT instead of MRI
Energy use, MJ/patient	1,050	216			830
Pediatric (follow-up abdominal malignancy)	MRI	CT			CT instead of MRI
Energy use, MJ/patient	1,050	216			830

patient (280 kW h/patient). One could also chose ultrasound versus CT in this case for small energy savings of 180 MJ/patient (50 kW h/patient).

These are illustrative examples since discussion in the radiology community is needed to ascertain how many of these 354 patient conditions for which there are similar ACR "usually appropriate" modalities could be considered interchangeable with no significant difference in patient diagnostic results. However, the following broad evaluation for patient conditions (354) was made. Given the energy values in Table 3, the representative energy savings would be between 140–1010 MJ/patient.

The hypothesis of this study is that using our quantitative imaging energy data we can estimate U.S. hospital energy savings by selecting the imaging device with equivalent rating (7 s, 8 s, or 9 s), but with a lower energy use. In order to make such estimates, data on the distribution of imaging modalities and numbers of U.S. patients receiving imaging annually were needed. Several sources of such data were located, Table 6, and values judged representative were established. The energy reduction was derived from the small sample of patient conditions shown in Table 5. For MRI substitutions, a typical energy reduction was 830 MJ/patient while for CT it was 140 MJ/patient. From Table 4, in all 354 patient categories the median interchangeability was 48%. However, with a more conservative estimate that even if 1% or 10% of the interchangeable MRI and CT would be replaced by another "usually appropriate" imaging modality were selected for this analysis. With the U.S. MRI and CT imaging numbers, Table 6, and the median energy savings, approximately 17–170 million kWh in the U.S. for MRI decisions in use alternatives (1%–10% of possible patient conditions) of "usually appropriate" imaging and 7–70 million kWh for CT change. This is a total of 24–240 million kWh represents the contribution of the Radiology community by patient decision changes to healthcare sustainability improvement (equivalent to the avoidance of about 35,000 cars per year). These energy savings to the healthcare system of selecting the usually appropriate imaging modality with the lower environmental impact translates into about \$2.5 million – \$25 million dollars per year (10.4 cent/kWh, commercial).

4. Conclusion

The ACR recommendations of modality choices across the ten categories have a significant number of patient conditions (variants), but for 48% of these there are alternative modalities that are "usually appropriate" (score 7–9) and can be chosen as alternatives. The patient category with the highest degree of possible interchangeability was cardiac. This represents an opportunity to reduce hospital energy use and public health impact through changes in radiology decision-making rather than technology changes. That is, the selection of imaging modality can be changed to lower environmental impact, while still delivering quality patient care. The authors understand that for patients receiving frequent imaging for health reasons, with computed tomography or x-ray imaging modalities, the radiation health risk of these devices may override the environmental benefits. However, the majority of patients receive few radiology procedures and using the environmental impact of this study as one of the parameters for selection of the type of imaging performed may be useful and worth the attention of the radiology community. These results are not to dictate radiology changes, but provide information that for the first time will allow the radiology community to participate in improving hospital sustainability. The purpose is to engage radiologist to use their ingenuity and creativity to examine procedures, patient-based decisions, and other avenues to seek cost and sustainability improvements. At the clinical level, it may be feasible to add to the ACR Tables a designation of which of the usually appropriate imaging modalities has the lower environmental footprint as a means to assist in imaging decisions. As healthcare evolves and reimbursement patterns change, there is a foreseeable chance that bundled payments could be in the form of an all-inclusive

Table 6
U.S. data on radiology imaging modalities., 6a U.S. imaging distribution estimates, 6b Imaging estimates in U.S. population, 2016.

A

	American College of Radiology and Radiology Business Management Association, 2013 (American College of Radiology and Radiology Business Management Association, 2013)	Smith-Bindman, et al., 2012 (Smith-Bindman et al., 2012)	Smith-Bindman, 2008 (Smith-Bindman et al., 2008)	
	Imaging distribution	Percent of cross-sectional imaging	Percent of cross-sectional imaging	Representative percent of total annual imaging
CT, % of cross-sectional imaging	25	34	37	12
MRI, % of cross-sectional imaging	17	14	15	5
US, % of cross-sectional imaging	58	52	47	17
all cross-sectional imaging as percent of total imaging	29	37	33	
nuclear medicine as percent of total imaging	1	4	2	2
x-ray imaging as percent of total imaging	70	60	67	65
Total imaging	100			100

B

	Estimates of total imaging by modality, patient images per thousand population					Estimated total U.S. imaging by modality based on 2016 population (322,762,018)
	Mettler, et al. 2009 (2006 basis) (Mettler et al., 2009)	Smith-Bindman (assuming Washington State Group Health population is similar to general population, 2006 basis) (Smith-Bindman et al., 2008)	IMV, 2013 (IMV, 2013)	IMV, 2014 (IMV, 2014)	Value judged representative (basis 2014)	
CT	224	181	240		52.2	16,848,176
MRI		72		110	23.2	7,488,078
US		225			65.25	21,060,221
all cross-sectional imaging as percent of total imaging					140.65	45,396,475
nuclear medicine as percent of total imaging		33			30	9,682,860
x-ray imaging as percent of total imaging	980	936			960	309,851,520
Total imaging		1447				

payment for the patient and not a specific modality-driven reimbursement. Hospitals might then utilize these imaging in-house energy and consumables information to reduce costs.

Declaration of Competing Interest

The authors have no financial or technical conflicts of interest.

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