ORIGINAL ARTICLE

Environmental Impacts of Abdominal Imaging: A Pilot Investigation

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Abstract

Purpose: Clinical decision making regarding the use of imaging is appropriately centered on diagnostic efficacy and individual patient factors. However, health policy and imaging guidelines may incorporate other inputs, such as cost-effectiveness and patient preference. In the context of climate change and resource scarcity, the environmental impacts of imaging modalities including ultrasound, CT, and MRI will also become relevant. The purpose of this study was to estimate the environmental impacts of various abdominal imaging examinations.

Methods: Using commercially available software (SimaPro) and data from user manuals and field experts, a streamlined life cycle assessment was performed to estimate multifactorial environmental impacts of the production and use of ultrasound, CT, and MRI per abdominal imaging examination.

Results: Ultrasound consumed less energy in both production and use phases (7.8 and 10.3 MJ/examination, respectively) than CT (58.9 and 41.1 MJ/examination) or MRI (93.2 and 216 MJ/examination). Ultrasound emitted fewer CO_2 equivalents in production and use phases (0.5 and 0.65 kg/examination) than CT (4.0 and 2.61 kg/examination) or MRI (6.0 and 13.72 kg/examination). Potential human health effects from pollutant emissions were found to be smallest with ultrasound in both production and use phases.

Conclusions: Among the three imaging modalities, ultrasound was found to have the least environmental impact, by one or more orders of magnitude in various domains. This analysis provides an initial framework for comparing environmental impacts across imaging modalities, which may provide useful inputs for cost-effectiveness analyses and policymaking.

Key Words: Sustainability, greenhouse gas, computed tomography, magnetic resonance imaging, ultrasound

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INTRODUCTION

When physicians make decisions about imaging use, diagnostic efficacy is the primary consideration. As a decision support tool, the ACR Appropriateness Criteria intentionally exclude cost and availability from their guidelines [1]. On a societal level, organizations such as the US Preventive Services Task Force incorporate population outcomes but still do not consider costs [2]. Advocates for patient-centered care such as the Patient-Centered Outcomes Research Institute argue that patient experience and value assessments are additional priorities [3]. Although broad ranging, these considerations do not incorporate the physical realities of producing, operating, and maintaining imaging equipment. However, as the utilization and export of medical imaging expand, the environmental impact of imaging will become increasingly relevant.

Medical imaging enjoys continued growth in the United States. In 2006, approximately 377 million radiologic procedures were performed in the United States [4,5]. CT utilization has continued to increase by as much as 10% per year, with an estimated 80 million CT examinations now performed annually [5,6]. MRI and ultrasound utilization shows similar though less pronounced trends [7,8]. MRI utilization in the United States more than tripled from 1996 to 2014 [9].

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At a societal level, decisions about medical imaging use should incorporate not only diagnostic efficacy and cost but also environmental impact. Water, fossil fuels, and helium are all in limited supply. Two-thirds of the world contends with severe water scarcity at least 1 month of the year [10]. In the United States, we have entered a phase of water scarcity in many western states in particular [11]. Lacking access to electricity, 3 billion people worldwide heat their homes and cook with biomass fuel such as wood, peat, and dung, with attendant complications of respiratory problems and air pollution [12]. The stability of the electrical grid is imperfect even in developed countries [13]. The planet has a finite quantity of helium, which is used to cool the superconducting magnets in the majority of contemporary MRI systems [14]. To include these environmental considerations in medical imaging use decisions, data are needed.

Life cycle assessment (LCA) is a tool used in sustainability research to estimate the cumulative environmental impact of a product (often measured as energy and emissions), from extraction of raw materials through production, use, and end-of-life disposition [15,16]. The purpose of this study was to use a streamlined LCA to establish preliminary estimates for the environmental impacts of ultrasound, CT, and MRI in a basic clinical scenario: abdominal pain, one of the most common causes for a visit to the emergency department [17].

METHODS

Prototype ultrasound, CT, and MR machines were selected on the basis of a convenience sample of equipment currently in use at the University of Michigan medical center. The specific equipment studied included the GE LOGIQ E9 ultrasound system (GE Medical Systems, Waukesha, Wisconsin), the GE Discovery HD750 CT scanner (GE Medical Systems), and the Philips Ingenia 1.5-T MRI scanner (Philips Medical Systems, Amsterdam, the Netherlands). All are mainstream contemporary imaging systems reflecting technological advances of the past 3 to 5 years, although they are not necessarily the most expensive or newest systems. This study was not concerned with drawing comparisons among manufacturers but rather between imaging modalities. Because the research question was environmental impact, the diagnostic efficacy of ultrasound, CT, and MRI for evaluation of an adult patient's abdominal pain was not quantified or compared.

LCA

Meaningful comparison in LCA requires the definition of a functional unit for each object or process being compared. We defined the functional unit as one abdominal imaging examination and divided the total abdominal examination time for each modality into active and idle periods (Table 1). The active period includes image acquisition (scan time) and is the stage of highest power consumption. The idle period is the amount of time remaining in the scheduled appointment, after accounting for the active scanning period, and includes equipment warm-up and cool-down times. Machines in the idle period were assumed to be operating at minimum power. We assumed that the MRI machine was never turned off and thus had no discrete warm-up and cool-down times.

Production Phase

Production phase included all manufacturing steps through machine purchase. Energy requirements, resource utilization, and emissions produced during manufacture were estimated using an economic input-output LCA method [18], on the basis of purchase price and equipment sector. Real market value of equipment was approximated using Novation commercial group pricing structure (Vizient, Irving, Texas) (Table 1).

Table 1. Initial assumptions used for impact estimates

	Ultrasound	CT	MRI
Total examination time (s)	1,800	1,800	3,600
Active period (s)	1,500	60	2,100
Idle period (s)	300	1740	1,500
Purchase price (USD)	178,000	1,850,000	2,290,000
Equipment life expectancy (y)	7	10	15
Total examinations/lifetime (24 h)	122,600	175,200	131,400
Total examinations/lifetime (8 AM to 5 PM)	45,975	65,700	49,275
Shielding thickness (inches)	Not applicable	1/16 in Pb	1/32 in Cu