Clinical and Economic Value of Medical Imaging

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Clinical and Economic Value of Medical Imaging: Abstract

Advances in medical imaging technology continuously improve the delivery of healthcare to patients. Given rising healthcare costs and the need to responsibly steward financial resources, this paper highlights scientific, peer-reviewed studies that demonstrate improved patient outcomes (including survival and quality of life) and cost savings associated with various imaging technologies.

This review builds upon previous research conducted in 2008, with an additional focus on cost-effectiveness evaluations. A comprehensive search methodology was used to critically evaluate publications from the past five years indexed in the U.S. National Library of Medicine (MEDLINE) and from leading health policy journals. Resulting analyses indicate that medical imaging provides a sound economic investment in addition to clinical advantage. Imaging provides substantial cost savings by reducing the number of unnecessary surgeries and shortening patient recovery time while also improving disease survival rates. For example:

- Ultrasonography has yielded savings of more than $4,000 per patient by reducing the occurrence of unnecessary, invasive breast cancer procedures.[1]
- Computed tomography (CT) angiography can save an estimated $1,455 per patient by reducing unnecessary cardiac catheterizations.[2]
- CT and integrated positron emission tomography (PET)/CT have led to a 6.7% reduction in all cancer mortalities, including a 20% reduction in lung cancer alone.[3]

In addition to the cost-saving benefits, diagnostic imaging has revolutionized disease screening, continuously improving clinical outcomes. Screenings made possible by sophisticated imaging can also save lives, as evidenced by recent breast cancer trends. For example, the *Journal of the American Medical Association* notes that mammography (in addition to improvements in therapy) has been associated with a 24% decrease in the death rate from breast cancer (even after taking patient age into account) from 1989-2003.[4]

The medical literature demonstrates that these technologies carry the potential to reduce the economic and human costs of unnecessary and invasive procedures, improving patient outcomes and quality of life through early detection and better treatment options.

Notes: All cost estimates in this paper have been updated to 2011 USD using the medical care services component of the consumer price index (CPI). Appendix A provides a summary of all recent publications referenced in this white paper (i.e. articles published since the original version of this white paper in 2007, through the end of literature searches in June 2012).

Introduction

With healthcare expenditures continuing to rise steadily, recently reaching 17.6% of the gross domestic product (GDP),[5] policymakers and insurers seek to control costs by evaluating both the clinical and economic effectiveness of key medical interventions. Though countless peer-reviewed studies demonstrate the value of medical imaging to improve patient outcomes and drive down spending, reimbursement for medical imaging services has been cut drastically. For example, the Deficit Reduction Act of 2005 reduced imaging spending by 19.2% in 2007 alone, while the Congressional Budget Office suggests that new provisions of the Patient Protection and Affordable Care Act will reduce payments for medical imaging services by an additional $3 billion.[6]

Recent changes in reimbursement have caused a marked decline in the growth rate of imaging use according to new analyses.[7-12] A 2012 *Journal of the American Medical Association* study of imaging utilization in six large, geographically dispersed health maintenance organizations showed that while utilization increased overall between 1996 - 2010, the growth rate has slowed markedly since 2007.[12] A separate independent analysis of Medicare data in 2011 showed that per beneficiary imaging spending has dropped 13.2% since 2006, which is in contrast to the nearly 20% increase in spending for non-imaging services over the same time period.[10] This decline in imaging use could potentially increase subsequent medical utilization and spending, if patients are not identified for appropriate preventative care. For example, a 2011 study showed that cuts in Medicare Part B reimbursement implemented in 2007 decreased imaging levels for bone imaging in 2010 to 56% of 2006 levels.[11] The authors estimated that these cuts resulted in 800,000 fewer tests that could have prevented approximately 12,000 fractures.[11]

Given the current trends in decreased imaging utilization, this paper outlines several specific clinical areas in which imaging use has been shown to actually save money or provide a cost-effective option in the treatment paradigm. This literature review builds upon a previous review conducted in 2008[13] and highlights studies that demonstrate the enhanced treatment options and improved patient outcomes (including survival and quality of life) of medical imaging, with an additional focus on cost-effectiveness evaluations. The steady increase in coverage decisions made for medical imaging over recent years underscores the need for current research on the clinical and economic value of these technologies.

Cancer

Although medical imaging has improved diagnosis and treatment for many acute and chronic conditions, cancer treatment is one of the clinical areas that has benefited most from these technologies. Ultrasound, magnetic resonance imaging (MRI), positron emission tomography (PET), positron emission tomography/computerized tomography (PET/CT), and single photon emission computed tomography (SPECT) have paved the way for minimally invasive biopsies and surgeries and targeted radiation therapy.[14-17] PET/CT in particular has been shown to improve oncologic care by positively impacting active treatment decisions,[18-24] disease recurrence monitoring,[23, 25-27] and patient outcomes, such as disease-free progression.[28] For instance, researchers have found that FDG-PET (a form of PET/CT) can detect a tumor's response to radiation or chemotherapy within three to four weeks post-treatment, making it possible to more quickly modify therapy regimens and increase treatment effectiveness.[19] Given that chemotherapy or chemo-radio-therapy prior to surgical tumor resection only improves survival for a small percentage of patients, PET/CT may also help reduce costs and unnecessary exposure to toxic therapies by helping physicians to efficiently identify patients who will respond to initial therapy.[18]

"Researchers have found that FDG-PET (a form of PET/CT) can detect a tumor's response to radiation or chemotherapy within three to four weeks post-treatment."

In 1998, the Centers for Medicare & Medicaid Services (CMS) approved reimbursement for FDG-PET to assess solitary lung nodules. CMS later expanded coverage of PET to include a number of cancers (small cell lung, lymphoma, melanoma, esophageal, and recurrent colorectal) for which the value of PET was well documented.[19] In 2005, CMS instituted a new policy called Coverage with Evidence Development (CED) to support the use of promising technologies, and PET and PET/CT were inducted into this program with the goal of providing coverage for all cancers not previously covered. The National Oncologic PET Registry (NOPR) was created to collect data to assess the impact of PET (including PET/CT and FDG-PET) on referring physician treatment decisions. To date, this landmark study includes over 34,000 cases with results showing that physicians modified their intended plan to either treat or not treat in over one-third (38%) of these cases based on information from PET.[29] Physicians moved from non-treatment to treatment nearly four times more often than from treatment to non-treatment (30.0% vs. 8.0% overall) and this pattern was consistent across cancer types.[29] Major changes in planned treatment (e.g., from surgery to chemotherapy) occurred less often than for minor changes in treatment (e.g., adding or removing a therapy) (8.6% vs. 23.3% respectively).[29] The goal of therapy also shifted in 14.1% of the cases post-PET, with an increase in palliative care for patients who were being restaged or evaluated for recurrence.[29]

Breast Cancer

Screenings made possible by imaging scans save lives, as evidenced by breast cancer trends over the last several decades. Mammography has dramatically reduced breast cancer mortality since becoming a recommended routine health screening.[30] Ultrasonography and MRI can further improve outcomes when they are used as a substitute for or adjunct to conventional film mammography for women in higher risk groups, including newly diagnosed women and those who have genetic risk factors.[31] One study found MRI to be significantly more sensitive for detecting breast cancer than film mammography, with 24 out of 28 detected cases of breast cancer identified by MRI (vs. 14 by mammography).[32] Multiple other studies demonstrate this effectiveness, including those that compare mammography to clinical examination.[33, 34]

A growing number of newly diagnosed breast cancer patients are also benefiting from MRI evaluation to determine whether their cancer has spread throughout the breast tissue (multi-centric) or is localized in one particular area, allowing patients and physicians to make better therapy choices (e.g., breast conserving surgery vs. radical surgery) and reduce patients' fear of recurrence from cancerous tissue missed in the initial diagnostic assessment.[31, 35] Due to these benefits, MRI is an integral component of clinical guidelines for breast cancer, including those developed by the American College of Radiology (ACR)[36] and the American Cancer Society (ACS), in which annual MRI is supported as an adjunct to mammography for women at high risk.[37]

The use of ultrasound has also been shown to be cost saving for the preoperative staging and evaluation of patients with breast cancer. Ultrasound provides a non-invasive alternative for the detection of metastases compared to the standard evaluation with sentinel lymph node biopsy (SLNB), which involves the surgical removal of a lymph node for further examination. In a review of patients with breast cancer, with a minimum tumor size of 2.0 cm, use of axillary ultrasonography yielded a cost savings of $4,682 per patient through elimination of unnecessary SLNB procedures.[1] Additionally, two recent economic models comparing the use of preoperative axillary ultrasonography vs. standard care with SLNB showed cost savings ranging from $41 to $747 per patient, with the additional costs of ultrasonography balanced by the cost savings from SLNB procedures avoided.[38, 39] Ultrasonography can also improve the accuracy in localizing non-palpable breast lesions during lumpectomy procedures, specifically through a new technique using hematoma-directed ultrasound. This technique can in many cases eliminate the use of a needle during the procedure and thereby minimize the associated pain and discomfort.[40]

Colorectal Cancer

Imaging is also revolutionizing screening for, and early detection of, colorectal cancer (CRC). Virtual colonoscopy (CT colonography), for example, is an innovative screening tool based on CT technology and is used to detect colorectal cancer in asymptomatic adults.[41] Virtual colonoscopy compares favorably with optical colonoscopy in detecting clinically relevant lesions and requires less time to perform. The mean time for virtual colonoscopy is less than the time required for optical colonoscopy which requires sedation. Results from one of the largest randomized controlled trials (RCTs) to date (the American College of Radiology Imaging Network [ACRIN] trial) showed that in over 2,500 patients undergoing both a CT colonography and standard colonoscopy procedure, 90% of all large lesions (≥10 mm) were detected with CT colonography compared to standard colonoscopy.[42] This sensitivity result is much higher than the test sensitivity reported with early evaluations of CT colonography using older CT technology and convinced one large health plan to change its position from "insufficient evidence" to coverage of CT colonography in the plan's preventative services.[43] As virtual colonoscopy becomes more widely used, it has the potential for extending the benefit of early detection to individuals who might otherwise delay or avoid medical follow-up on early colorectal cancer symptoms in order to avoid the fear and discomfort of optical colonoscopy.

"In over 2,500 patients undergoing both a CT colonography and standard colonoscopy procedure, 90% of all large lesions (≥10 mm) were detected with CT colonography compared to standard colonoscopy."

Pre-operative MRI has shown benefits in both pre-operative treatment of CRC and rectal cancer. A prospective multicenter study in the United States in patients with stage II or III CRC showed that pre-operative MRI results avoided the use of neoadjuvant radiochemotherapy in nearly half of patients (45%) without risk of undertreatment and avoided the side effects associated with chemotherapy in these patients.[44] Additionally, a study conducted in 11 centers in four European countries found pre-operative MRI to be an important factor for improving surgical outcomes for rectal cancer patients.[45]

Clear surgical margins post-resection are an important predictor of survival and local disease recurrence. MRI can be used to proactively identify patients who are likely to have affected margins post-surgery, which provides an opportunity to either deliver pre-operative chemotherapy or modify the surgical plans. Endoscopic ultrasonography also performs a similar role and is considered a standard of care for identifying rectal cancer patients who are candidates for pre-operative neoadjuvant therapy.[46]

Lung Cancer

In the past few years, use of low-dose CT and integrated FDG-PET/CT for the screening and subsequent treatment decisions of lung cancer has been evaluated in clinical trials and economic models. In a pivotal clinical trial including over 50,000 patients aged 55-74 with a history of smoking, low-dose CT was significantly associated with a 20% reduction in lung cancer related mortality and 6.7% reduction in all-cause mortality compared to screening with radiography.[3] Similarly, a model evaluated screening current smokers or former smokers with at least 30-pack years (a pack year is equal to the number of packs smoked per day multiplied by the number of years of smoking). Model results projected that there would be approximately 130,000 additional lung cancer survivors in 2012 if such smokers were screened with low-dose CT vs. a scenario of no screening.[47] The cost of screening was estimated at $18,862 per life-year saved (this is a measure of cost-effectiveness used in economic evaluation, defined as the additional cost for extending life by one year). This estimate is well within the costs cited for cervical, colorectal, or breast cancer screening and well below a common cost-effectiveness threshold of $50,000 per life-year saved. FDG-PET/CT is a recent additional imaging option for patients with lung cancer, with significantly improved overall cancer staging than staging from CT alone.[48] In a single-center retrospective study of lung cancer staging, FDG-PET/CT changed the initial oncologist treatment decisions for 41% of patients, specifically through avoiding thoracotomies in the most advanced cases and treatment with palliative care instead.[48]

"Low-dose CT was significantly associated with a 20% reduction in lung cancer related mortality and 6.7% reduction in all-cause mortality compared to screening with radiography."

Thyroid Cancer

The use of ultrasound-guided fine-needle aspiration biopsy (FNAB) to identify malignancies is also evolving as a novel clinical area for imaging in recent years. A recent model estimated that this technology increased the correct classification of thyroid malignancies from 92% with conventional biopsy to 98%, and was a cost-effective strategy at $318 per additional cancer case that was correctly diagnosed.[49]

Cardiovascular Disease

Cardiac diagnostics and therapeutics is another of the major areas in which medical imaging is proving transformational. Every year, an estimated 1 million individuals visit the emergency room for chest pain. Goldstein et al. found that multi-slice CT (MSCT) effectively rules out or confirms coronary disease as the source of chest pain in 75% of patients, with the remaining 25% sent for confirmatory stress testing.[50] MSCT significantly reduced diagnostic time (3.4 hours vs. 15 hours, $p = 0.001$) and costs ($1,820 vs. $2,148, $p = 0.001$).[50]

In addition to reducing time to diagnosis, medical imaging can also serve as a gatekeeper for triaging patients for expensive or potentially risky procedures. For example, coronary CT angiography (CCTA) can be used to select patients for cardiac catheterization and is effective and cost saving for patients with mildly abnormal or equivocal myocardial perfusion imaging results.[51] In one study, 32% of patients had potentially obstructive plaque on CCTA, requiring catheterization. Selective catheterization resulted in average cost savings of $1,669 per patient.[51]

Coronary Artery Disease

Noninvasive imaging also plays an important role in the management of coronary artery disease (CAD), the leading cause of death for both men and women in the United States Sophisticated cardiac imaging, including radionuclide cardiac imaging, echocardiography, as well as cardiac CT, MRI, and PET, provides anatomical and physiological information, allowing physicians to accurately diagnose patients, stratify them into risk categories, and determine treatment strategies tailored to each patient's needs. The appropriate role and value of these technologies have been codified in clinical guidelines by the American College of Cardiology (ACC).[52]

Among patients with suspected or confirmed CAD, CCTA is frequently used to determine the most appropriate care in both emergency and non-emergency settings. This technology uses a CT scanner to visualize the structures and blood vessels of the heart. CCTA has been evaluated in several recent RCTs and economic models comparing the clinical and economic outcomes between CCTA imaging upon presentation to the emergency department (ED) with acute, low-risk chest pain versus standard care.[2, 53-57] Standard care has traditionally included observation in the ED, cardiac stress testing, or echocardiography. However, this approach can often include unnecessary observation time in the ED when no significant CAD is present.

A rigorous clinical trial evaluating the use of CCTA vs. standard care among patients with acute, low-risk chest pain and possible CAD showed that use of CCTA allowed more patients to be discharged from the ED rather than admitted (49.6% vs. 22.7%) with a shorter time spent in the ED (median 18.0 hours vs. 24.8 hours, $p=.001$).[57] Most importantly, this alternative for triaging

patients with chest pain was a safe strategy, with no significant difference between groups in the occurrence of myocardial infarction or cardiac death within 30 days of the ED visit.[57] In a similar multicenter trial comparing CCTA to rest-stress cardiac myocardial perfusion imaging, CCTA resulted in a 54% reduction in time to diagnosis (median 2.9 hours vs. 6.2 hours, p=.001) and 38.2% lower total ED costs ($2,353 vs. $3,807), without any impact on the incidence of follow-up major adverse cardiac events.[2] CCTA at initial presentation with chest pain can not only decrease resources used in the ED, but also in follow-up visits for cardiac testing. One non-randomized study showed that initial CCTA vs. exercise stress testing significantly reduced subsequent cardiac test utilization (32% vs. 21%, p=.003).[56] Similarly, a trial comparing CCTA plus standard care to standard care alone showed cost savings not only during the initial ED visit for chest pain, but also in the 90 days following the visit (total mean ED and 90-day follow-up cost among patients with CCTA of $10,180 vs. $17,685 for patients with standard care).[54]

Several economic models have translated the outcomes observed in these clinical trials into cost results meaningful to hospitals and health plans. One model evaluating a cohort of hypothetical patients 55-years-old who presented to the ED with acute chest pain of unknown origin showed triaging with CCTA testing resulted in a lower number of deaths within 30 days of the ED visit vs. standard care and fewer missed cases of acute coronary syndrome. This resulted in an average cost savings of $877 per patient in the ED compared to standard care using SPECT and a savings of $476 vs. standard care with stress testing.[53] Another model comparing three patient evaluation scenarios for a hypothetical 45-year-old male presenting to the ED with chest pain and possible acute coronary syndrome showed evaluation with multidetector CT of the coronary arteries with no observation unit stay saved $667 vs. observation with echocardiography and $892 vs. observation with electrocardiogram.[55]

CCTA has also shown benefits in non-emergency settings when used prior to cardiac catheterization by selecting patients who are the best candidates for coronary catheterization. A retrospective study and economic model comparing coronary catheterization in all patients vs. selective catheterization among patients with greater than 50% stenosis identified through CCTA imaging demonstrated that use of CCTA saved an average of $3,061 per patient through avoidance of unnecessary angiography,[58] while another economic model showed use of CCTA provided a cost savings of $842 per patient.[59]

Cardiac MRI has similarly been shown as a safe and cost-saving alternative to traditional triaging scenarios for patients with low-risk chest pain in the ED. A single-center RCT of cardiac MRI vs. usual inpatient observational care led to fewer admissions to the hospital with a median cost savings of $647 per patient. There were no differences in the incidence of acute coronary syndrome between the two groups at 30 days post-discharge.[60]

Stroke & Vascular Disease

Advanced imaging improves outcomes and saves money in the diagnosis and treatment of stroke. In 2001, Gleason, et al. found that a CT angiography-CT perfusion protocol for patients presenting with ischemic stroke symptoms could generate cost savings by identifying and triaging patients with the most benign (lacunar) strokes to a non-acute setting and reducing length of stay for all stroke patients.[61] National net savings for the United States were estimated at nearly $2 billion. A British study determined that conducting CT or MRI studies on all patients presenting with stroke-like symptoms is a cost-effective diagnostic strategy.[62] The "scan all" approach was reported to be less expensive than even a "no scan" approach; savings from shorter hospital stays more than offset the additional scanning-related costs.[62]

An accelerated diagnostic testing protocol to evaluate patients presenting in the emergency department with transient ischemic attack (TIA) symptoms and normal head CT also generated significant cost savings while achieving the same clinical outcomes as the traditional strategy of inpatient admission and observation.[63] The accelerated protocol included carotid imaging (Doppler, magnetic resonance angiography) to evaluate carotid stenosis and echocardiography to detect a possible cardioembolic source. The accelerated protocol facilitated quick discharge for patients whose evaluations were normal and reduced the median length of stay and median costs per patient by approximately half (61.2 hours vs. 25.6 hours at the facility; $1,755 vs. $992 for the initial visit; $1,776 vs. $1,021 in total costs over 90 days).[62] If this protocol were adopted nationwide, savings would be approximately $29 million annually.[62]

Treating Stroke Patients

Stroke results from either restricted blood flow (ischemia) to an area of the brain or from intracranial hemorrhage (ICH). ICH is responsible for 10%-15% of initial strokes, and the 30-day mortality rate for these individuals is 35% to 52%.[64] The American Heart Association (AHA) recommends either CT or MRI imaging for the initial evaluation of patients presenting with stroke-like symptoms in order to rule out conditions that may mimic stroke (e.g., complicated migraine, hypoglycemia), to identify other conditions requiring immediate intervention, and to determine potential causes for stroke in order to implement an appropriate approach for early secondary prevention.[65] In a recent physician review of 233 case histories, simply the availability of imaging results in addition to clinical assessments changed treatment recommendations for 10 of the 23 patients who had ICH,[66] suggesting that CT and MRI results have the potential to improve choice of therapy, and, for example, to safeguard against use of antithrombotic agents in patients with primary intracranial hemorrhage in whom such therapy is contraindicated.

Imaging technologies can provide additional treatment options for stroke by extending critical time windows. Thrombolytic therapy with recombinant tissue plasminogen activator (tPA) is effective as an ischemic stroke therapy and is indicated for use within 3 hours after the onset of symptoms and after CT-based exclusion of symptomatic intracerebral hemorrhage (sICH).[67] A pooled analysis of data on 1,210 patients from five European stroke centers determined that MRI-based assessment with tPA treatment initiated after the 3-hour window increased probability of a favorable outcome by 46.7% over CT-based assessment and treatment within 3 hours.[68] The use of MRI also reduced the odds of sICH by nearly half. This study suggests that MRI evaluations can extend the window of opportunity for successfully treating a substantial number of stroke patients with thrombolytic agents.[68]

MRI profiles can also be used to select stroke patients who should undergo reperfusion within 3-6 hours of symptom onset.[69] Results from the multicenter DEFUSE (Diffusion and Perfusion Imaging Evaluation For Understanding Stroke Evaluation) trial demonstrated that MRI can be used to distinguish patients who would benefit from early reperfusion, those who would receive no benefit, and those who could potentially be harmed. Patients with a perfusion/diffusion mismatch (based on MRI assessment) had much higher odds of a favorable clinical response from early reperfusion (odds ratio 5.4; p=0.039), while those with the target mismatch profile were even more likely to have a positive therapy response (odds ratio 8.7, p=0.011).[69] Patients with no mismatch showed no clinical improvement with early reperfusion, and those with a malignant profile were at risk of fatal ICH with reperfusion.[69]

"MRI-based assessment with tPA treatment initiated after the 3-hour window increased probability of a favorable outcome by 46.7% over CT-based assessment and treatment within 3 hours."

Reducing Stroke Risk

In a different population, imaging helps prevent strokes. Transcranial Doppler ultrasonography screening has been recommended, beginning at age 2, to identify children with sickle cell anemia who are at risk for stroke.[70] Neurological complications are common among children with sickle cell anemia and an estimated 17% of asymptomatic children have structural brain abnormalities that are visible on MRI and suggest that these children may have experienced "silent" infarctions (tissue death resulting from insufficient blood flow). Ultrasound screening can identify children who have abnormal transcranial blood flow velocity (TBV) and who would benefit from transfusions to reduce the risk of stroke.[70]

Managing Other Conditions

Pulmonary Embolism

Beyond CAD and stroke, medical imaging has transformed care for a variety of other cardiovascular diseases. In a study of over 750 patients, Perrier et al. found that multidetector-row CT can be used in the ED to safely rule out pulmonary embolism, while avoiding lower limb ultrasonography that is costly, labor-intensive, and not universally available.[71] A systematic review of the medical literature confirmed that CT is as accurate as conventional pulmonary angiography for ruling out pulmonary embolism and its use can eliminate the need for additional imaging at additional cost.[72]

Aneurysm Detection

Ultrasound screening can also reduce mortality caused by a rupture of abdominal aortic aneurysms (AAA). AAAs are found in 4% to 8% of older men and account for about 15,000 deaths in the United States annually, most occurring in men age 65 years or older. These patients may be asymptomatic for years, but eventually as many as 1 in 3 will rupture if left untreated, and only 10%-25% of individuals who experience a rupture will survive the initial hospitalization. A U.S. Preventive Services Taskforce (USPSTF) review of medical literature found that ultrasound is an accurate and reliable tool for detecting AAAs and that elective surgery following detection results in survival rates close to those of the general population.[73] Analysis combining data from the available studies demonstrated that an invitation to screening could reduce AAA-related mortality in men aged 65-74 by 43%.[73]

"Analysis combining data from the available studies demonstrated that an invitation to screening could reduce AAA-related mortality in men aged 65-74 by 43%."

Imaging also plays a critical role in improving outcomes for patients with intracranial aneurysms. Endovascular detachable-coiling, which relies on real-time fluoroscopic imaging, is a minimally invasive technique that provides better survival (compared to the conventional therapy involving craniotomy and clipping) for patients with ruptured intracranial aneurysms.[74] The International Subarachnoid Aneurysm Trial (ISAT), which randomized 2000 patients to either craniotomy/clipping or endovascular coiling, found that coiling reduced the relative risk of death or dependency by 23.9%.[74] This equates to an absolute risk reduction of 7.4%, which means that out of every 1,000 patients treated, coiling would have helped 74 survive or avoid dependency at one year post-surgery.[74]

Safe Catheter Placement

Ultrasound provides significant value in guiding other procedures, including thoracentesis (the removal of fluids from the lungs)[75] **and jugular vein catheterization, which is commonly performed in critical care patients to support monitoring, administration of fluids, antibiotics, or nutritional preparations, and for hemodialysis.**[76, 77] Typically, catheterization is performed using anatomical landmarks as guides. However, a study of 900 patients determined that using ultrasound to guide catheter placement was superior to the landmark technique, which requires a certain amount of guesswork and carries the risk of carotid or subclavian artery puncture.[77]

Appendicitis

Over the past few decades, medical imaging has dramatically reduced reliance on exploratory surgery. Appendectomy care offers a clear example, with a number of peer-reviewed studies demonstrating that imaging can minimize unnecessary surgeries, which results in significant cost savings.[78-81] For example, a study published in the *New England Journal of Medicine* showed CT to reduce both the negative appendectomy rate (NAR—surgeries in which the patient turns out not to have had appendicitis) and the number of unnecessary admissions for observation, for an estimated savings of $3,540 per patient.[78] A similar study among women of reproductive age (16-49 years), reported a NAR of 42% without preoperative CT compared to 17% with CT ($p<0.038$), resulting in an average estimated savings from preoperative CT of $1,707 per patient.[80] In addition to decreases in NAR, the increased use of CT imaging has also shown correlation with decreases in appendiceal perforation, a previously common appendectomy complication,[82] as well as decreased hospital length of stay and reduced mortality among elderly patients with appendicitis undergoing laparoscopic surgery.[83]

"Over the past few decades, medical imaging has dramatically reduced reliance on exploratory surgery."

Orthopedics, Osteoporosis, and Arthritis

Knee Repair

The ability to better visualize the structure of bones and joints has also provided more options in orthopedic care, especially with the development of minimally invasive surgical techniques. Although in many ways these techniques are preferable to open surgeries, these procedures still carry risks and should be used selectively. MRI is a valuable tool for assessing lesions in the knee, illustrating imaging technologies' capacity to improve patient selection for minimally invasive surgeries. Crawford et al. conducted a systematic review of the literature to compare the "gold standard" of diagnostic arthroscopy to MRI in evaluating internal derangements of the knee. They found that MRI not only accurately identifies meniscal and anterior cruciate ligament (ACL) tears, but also avoids the risks associated with arthroscopy for those patients who do not ultimately require surgical knee repairs.[84]

Osteoporosis

In addition to improving the performance of orthopedic procedures, imaging can also help individuals avoid or reduce their risk for certain adverse health events. For example, advances in diagnostic imaging have made it possible to identify bone loss early, before an osteoporotic fracture occurs. A 2005 study published in *Osteoporosis International* estimated that bone mineral density scanning of an additional one million women in 2001, followed by appropriate osteoporosis therapy, would have averted 35,000 fractures and generated $119 million in Medicare savings by 2003.[85]

Arthritis

Imaging is also useful in the field of rheumatology. In one single-center RCT, a novel procedure using ultrasound-guided injection of corticosteroid drugs for the treatment of rheumatoid arthritis (RA) versus the traditional palpation-guided approach, ultrasound was associated with significantly improved patient outcomes. Ultrasound-guided injection resulted in 40% fewer patients with significant procedural pain and yielded significantly more responders to treatment (defined as asymptomatic joints at 2 weeks) (38% more responders, $p=.003$).[86] Additionally, the duration of therapeutic effect was significantly longer for ultrasound-guided vs. palpation-guided injection (increase of 1.2 months, $p<.001$) and the time to the next procedure was significantly longer (0.9 months, $p=.034$).[86] Ultrasound-guided

corticosteroid injection was estimated to provide a cost savings of $66 per responder per year vs. conventional palpation-guided care.[86] MRI has also been shown to improve treatment of patients with RA. With the introduction of disease-modifying antirheumatic drugs (DMARDs), which can prevent irreversible joint damage when treatment is initiated early, greater focus has been placed on early disease detection. MRI enables physicians to identify early stage erosions and synovitis or bone marrow edema. One retrospective analysis of patients with RA or suspected RA showed MRI changed the clinical management in half of all patients examined, with 80% of patients adding a DMARD therapy and subsequent improvement in symptoms.[87]

Trauma Care

Advanced imaging is an accurate and cost-saving tool for evaluating patients who arrive at the ED suffering from mild head injuries or torso trauma. For patients with mild head injury, CT during triage for admission generates cost savings over the conventional approach, which entails hospital observation. In a study of over 2,600 patients randomized to either CT or observation, the clinical outcomes were the same between groups; however, the initial costs per patient were 32% lower in the CT group ($806 vs. $1,183).[88, 89] The cost difference persisted for total related costs incurred over the 3 months post injury. Widespread implementation of this approach would require an additional 130 scans annually per 100,000 population, costs that would be offset by eliminating 165 hospital days.[89]

"Advanced imaging is an accurate and cost-saving tool for evaluating patients who arrive at the ED suffering from mild head injuries or torso trauma."

Another cost-saving strategy in the ED is the use of point-of-care limited ultrasonography (PLUS) to evaluate patients with torso trauma, which occurs annually in 5 million individuals. In a RCT, Melniker et al. found that PLUS shortened the time to operative care by 64% (57 minutes vs. 166 minutes).[90] In addition, the average length of hospital stay was 27% shorter for PLUS patients (6.2 vs. 10.2 days), with average total treatment costs for PLUS patients of $39,333 compared to $65,924 for patients undergoing conventional evaluation. In another retrospective study of patients admitted to the ED with penetrating thoracic trauma, use of a non-contrast chest CT at presentation was compared to observation with chest radiographs over a six-hour period to rule out injuries requiring invasive treatment. The immediate CT strategy provided a mean cost savings of $378 per patient through decreased time spent in the ED.[91]

Gastrointestinal Bleeding

Imaging technologies are expanding for use in a wider array of clinical areas beyond traditional oncologic, cardiac, and orthopedic applications. For example, Doppler ultrasound (DOP-US) improves outcomes in the treatment of gastrointestinal (GI) bleeding from peptic ulcer disease. Traditional care for bleeding from peptic ulcers includes thermal coagulation of ulcers through endoscopy. Despite advances in endoscopic procedures, mortality rates remain high and patients are at significant risk of recurrent bleeding. DOP-US identifies persistent blood flow in an ulcer after thermal treatment, allowing endoscopists to make more informed judgments concerning the need for additional therapy.[92] In an economic model comparing use of DOP-US vs. standard care with endoscopy alone among patients with upper GI hemorrhage, DOP-US provided a cost savings of $1,074 to $1,460 per patient by reducing rates of recurrent bleeding and need for urgent surgery.[92] GI bleeding is also common among patients with esophageal varices (dilated mucosal veins in the esophagus). In a prospective single-center comparison of screening for varices with CT imaging vs. standard upper GI endoscopy among patients with cirrhosis, CT as the initial screening option was the most cost-effective strategy. Screening with CT versus no screening cost $2,110 per bleeding event prevented, while screening with the traditional approach of upper GI endoscopy cost $2,337 per bleeding event prevented.[93]

Conclusion

In recent decades, the U.S. healthcare system has embraced evidence-based medicine in an effort to achieve the best patient outcomes efficiently. Medical imaging technologies carry the potential to reduce the burden of unnecessary and invasive procedures, and to improve patient outcomes by offering early detection and better informing treatment options. The evidence compiled in this review indicates that diagnostic imaging is an important resource for patients and clinicians, which provides both clinical and economic value.

Research is also emerging on the use of appropriateness criteria that identifies patients who will benefit from medical imaging. Clinical guidelines and appropriateness criteria, along with new technologies such as computerized radiology order entry and decision support systems will help physicians most effectively diagnose and treat patients, improving health and reducing costs.

Diagnostic imaging has proven effective across many disease states: cancer, heart disease, neurological disorders, and orthopedic conditions. Research continues to emerge that highlights the important clinical and economic benefits of medical imaging procedures, which will, in turn, prove to assist the medical community and policymakers in appropriate decision-making.

Reference List

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Appendix A: Summary of Key Findings for Select Studies Published January 2007 – June 2012

Disease Area	Imaging Strategy	Reference	Key Findings
Cardiac Disease / Coronary Artery Disease	CCTA (vs. no CCTA prior to invasive angiography)	Patel 2012[58]	• CCTA was cost saving through avoidance of unnecessary invasive angiography (total savings of $1,565 per patient).
Cardiac Disease / Acute low risk chest pain	CCTA (vs. standard care)	Goehler 2011[53]	• CCTA produced an average cost savings of $877 per patient in the ED compared to standard of care using SPECT, and savings of $476 per patient compared to standard of care using stress echocardiography. Savings were primarily driven by fewer angiographies and lower emergency department costs.
Cardiac Disease / Acute low risk chest pain	CCTA (vs. rest-stress MPI)	Goldstein 2011[2]	• Compared to MPI, CCTA was associated with a 54.0% reduction in time to diagnosis (CCTA median 2.9 h, MPI median 6.2 h, P<0.001). • Total ED costs per patient were reduced by 38.2% ($1,455) under the CCTA triaging scenario compared to MPI ($2,352 vs. $3,807).
Cardiac Disease / Acute low risk chest pain	Stress Cardiac MRI (vs. usual inpatient observational care)	Miller 2010[60]	• Initial testing with cardiac stress MRI in the ED observation unit avoided unnecessary inpatient admissions, providing a median cost savings of $647 per patient compared to inpatient usual care.
Cardiac Disease / Acute low risk chest pain	CCTA (with standard care vs. standard care alone)	Miller 2011[54]	• 28 of 30 (93%) of standard care + CCTA patients had a formal diagnosis of the presence of CAD at 90 days vs. 6 of 30 (20%) in the standard care group. • Mean total costs of care per patient in the 90 days post-ED presentation were lower for the standard care + CCTA group than for standard care alone ($10,810 vs. $17,685, P= 0.144); mean savings of $6,875.

Appendix A: Summary of Key Findings for Select Studies Published January 2007 – June 2012

Disease Area	Imaging Strategy	Reference	Key Findings
Cardiac Disease / Acute low risk chest pain	CCTA (vs. standard care)	Litt 2012[57]	• Patients receiving CCTA were more likely to be discharged from the ED rather than admitted (49.6% vs. 22.7%; 95% CI, 21.4 - 32.2), with shorter ED stays (median 18 hrs vs. 24.8 hrs, P<.001).
Cardiac Disease / Chest pain	MDCT (vs. stress echocardiography + observation unit or ECG + observation unit)	Khare 2008[55]	• MDCT provided a cost savings of per patient $667 vs. stress echocardiography and $892 vs. ECG.
Cardiac Disease / Stable angina	CCTA (vs. standard exercise stress testing)	Nielsen 2011[56]	• Use of CCTA vs. exercise stress testing significantly decreased subsequent test utilization (invasive coronary angiography, ICA, myocardial perfusion scintigraphy, and CTA) in the year following the initial test (32% vs. 21%, P<0.003).
Cardiac Disease	CCTA before cardiac catheterization (vs. catheterization in all patients)	Halpern 2010[59]	• Use of CCTA provides an average cost savings of $842 per patient under the base case assumption of a prevalence of CAD in 50% of patients; savings were obtained from cardiac catheterizations avoided.
Cancer / General (various cancer types)	Disease management strategy post-PET imaging vs. intended management prior to imaging	Hillner 2008[29]	• PET resulted in change of intended management (from treatment to no-treatment, or vice versa) in 38.0% of cases (95% CI: 37.6% - 38.5%).
Cancer / Thyroid Cancer Testing	Ultrasound-guided FNAB (vs. conventional palpation-guided biopsy for the detection of malignancies)	Khalid 2008[49]	• Ultrasound-guided FNAB results in correct malignancy classification in 98% of patients, vs. 92% with conventional biopsy. • Evaluation with ultrasound-guided FNAB vs. congenital biopsy is a cost-effective therapy option, costing $318 per additional cancer case correctly diagnosed.
Cancer / Lung	Integrated PDG PET-CT (vs. CT scan alone)	Subedi 2009[48]	• FDG-PET/CT was a significantly better predictor of overall TNM staging vs. CT alone, with PET/CT scans changing the initial treatment decisions in 41% of patients, specifically by avoiding thoracotomies and treatment instead with palliative care.

Appendix A: Summary of Key Findings for Select Studies Published January 2007 – June 2012

Disease Area	Imaging Strategy	Reference	Key Findings
Cancer / Lung	Low-dose CT screening (vs. chest radiography)	Aberle 2011[3]	• Lung cancer related mortality rate was significantly reduced by 20.0% with CT screening (95% CI: 6.8 - 26.7; P=0.004).
Cancer / Lung	Low-dose spiral CT screening (vs. no screening)	Pyenson 2012[47]	• Base case results estimate CT would lead to 130,000 additional lung cancer survivors in 2012 vs. no screening • Cost of CT - $18,862 per life-year saved
Cancer / Breast	HUG (vs. standard NLBB)	Thompson 2011[40]	• Use of HUG was more accurate in localizing non-palpable breast lesions, and eliminated the need for use of a needle with the NLBB procedure, thus reducing patient pain and discomfort from needle insertion.
Cancer / Breast	Axillary ultrasound (vs. standard care SLNB)	Lee 2011[1]	• Avoidance of unnecessary biopsies through use of ultrasound resulted in cost savings of approximately $4,682 per patient.
Cancer / Breast	Preoperative axillary ultrasound (vs. no ultrasound)	Turaga 2011[38]	• Preoperative axillary ultrasound provided cost savings of $747 per patient treated under a base case using ultrasound sensitivity of 86% and specificity of 40%.
Cancer / Breast	Ultrasound FNAB (vs. standard care)	Boughey 2010[39]	• In base case, use of ultrasound FNAB provided a cost savings of $41 per patient vs. no use. The additional costs of the test were balanced by the savings from SLNB procedures avoided.
Cancer / Colorectal	MRI (to determine the need for nRCT)	Strassburg 2011[44]	• Of 173 patients with stage II and III disease, 95 received nRCT after evaluation of MRI findings, thus avoiding nRCT therapy and its associated AEs and costs in 45% of patients.
Cancer / Colorectal	CT colonography	Johnson 2008[42]	• For detecting large lesions (≥ 10 mm), CT colonography had a mean sensitivity of .90 (±.031).

Appendix A: Summary of Key Findings for Select Studies Published January 2007 – June 2012

Disease Area	Imaging Strategy	Reference	Key Findings
Thoracic Trauma	CT (vs. serial chest radiographs)	Magnotti 2007[91]	• Use of CT upon presentation vs. serial chest radiographs has the potential to decrease charges by $378 per patient by saving ED time.
Arthritis	Sonographic image-guided injection (vs. conventional palpation-guided anatomic injection)	Sibbitt 2011[86]	• Ultrasound-guided injection resulted 40% fewer patients with significant procedural pain (VAS pain score of ≥ 5) relative to conventional palpation-guided methods. • Ultrasound-guided methods significantly reduced the cost per responder per year ($66; P < 0.001) vs. conventional care.
Arthritis	MRI	Fox 2012[87]	• Clinical management was changed in 50% (24/48) of patients due to MRI findings, with 80% (16/20) of patients adding DMARD therapy and demonstrating improvement in symptoms.
GI Hemorrhage	DOP-US (vs. conventional care)	Chen 2007[92]	• Initial evaluation with DOP-US provides a cost savings of $1,074 - $1,460 per patient compared to conventional visual assessment of peptic ulcer lesions by reducing rates of recurrent bleeding and emergency surgery.
Cirrhosis	CT imaging (vs. no screening)	Perri 2008[93]	• Use of CT as the initial screening tool was the most cost-effective strategy, with an ICER per bleeding event prevented of $2,110 compared to no screening, which is lower than the ICER when using the traditional approach of upper GI endoscopy vs. no screening ($2,377).

Note: This table contains recent literature published between January 2007 and June 2012.

CCTA – cardiac computed tomography angiography
MPI – myocardial perfusion imaging
FNAB – fine-needle aspiration biopsy
HUG – hematoma-directed ultrasound-guided technique
NLBB – needle localization breast biopsy
SLNB – sentinel lymph node biopsy
nRCT – neoadjuvant radiochemotherapy