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Cost-effective diagnostic cardiovascular imaging: when does it provide good value for the money?

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Abstract

To summarize the results of all original cost-utility analyses (CUAs) in diagnostic cardiovascular imaging (CVI) and characterize those technologies by estimates of their cost-effectiveness. We systematically searched the literature for original CVI CUAs published between 2000 and 2008. Studies were classified according to several variables including anatomy of interest (e.g. cerebrovascular, aorta, peripheral) and imaging modality under study (e.g. angiography, ultrasound). The results of each study, expressed as cost of the intervention to number of quality-adjusted life years saved ratio (cost/QALY) were additionally classified as favorable or not using \$20,000, \$50,000, and \$100,000 per QALY thresholds. The distribution of results was assessed with Chi Square or Fisher exact test, as indicated. Sixty-nine percent of all cardiovascular imaging CUAs were published between 2000 and 2008. Thirty-two studies reporting 82 cost/QALY ratios were included in the final sample. The most common vascular areas studied were cerebrovascular ($n = 9$) and cardiac ($n = 8$). Sixty-six percent (21/32) of studies focused on sonography, followed by conventional angiography and CT (25%, $n = 8$, each). Twenty-nine (35.4%), 42 (51.2%), and 53 (64.6%) ratios were favorable at WTP \$20,000/QALY, \$50,000/QALY, and \$100,000/QALY,

respectively. Thirty (36.6%) ratios compared one imaging test versus medical or surgical interventions; 26 (31.7%) ratios compared imaging to a different imaging test and another 26 (31.7%) to no intervention. Imaging interventions were more likely ($P < 0.01$) to be favorable when compared to observation, medical treatment or non-intervention than when compared to a different imaging test at WTP \$100,000/QALY. The diagnostic cardiovascular imaging literature has grown substantially. The studies available have, in general, favorable cost-effectiveness profiles with major determinants relating to being compared against observation, medical or no intervention instead of other imaging tests.

Keywords

Cost-effectiveness; Diagnostic cardiovascular imaging; QALY; Imaging technologies

Introduction

The costs of cardiovascular disease in the United States is estimated at \$475 billion for the year 2009 alone [1]. The high cost is largely attributed to expensive modern equipment, intensive use of diagnostic tests, and pharmaceutical and medical interventions. Imaging costs exceed \$100 billion per year in the US [2]. Cardiovascular imaging (CVI) represents 29% of all imaging workload [3], and at least a third of the several billion medical imaging examinations performed annually worldwide [4]. Moreover, between 1993 and 2002, cardiovascular imaging grew more than twice as rapidly as medical imaging for non-cardiovascular disease [3].

In an increasingly cost conscious environment, evidence-based medicine has been recognized as an essential tool for deciding on appropriate patient care. Greater emphasis is also being placed on cost-effectiveness analysis (CEA) to guide utilization of high-tech and often high-cost, diagnostic and therapeutic imaging resources. Many cardiovascular imaging studies fall into this category. Therefore, it is critically important to understand the body of evidence of cost-effectiveness, and more specifically cost-utility of medical imaging [5]. Cost-utility analysis (CUA) is a CEA subtype designed to incorporate the impact of the interventions on morbidity and patient preferences in addition to mortality [6,7]. CUAs use quality-adjusted life years (QALYs), a common metric that adjusts added life years by patients' quality of life and preferences. CUAs are increasingly used in health care and are considered to be the standard in economic analyses [8]. Thus, the purpose of this study was to identify all original CUAs in diagnostic cardiovascular imaging and systematically summarize the reported results and characteristics of those technologies reported to be cost-effective (i.e. provide good value for the resources expended).

Materials and methods

Tufts medical center CEA registry

This study is a part of a larger project to systematically review CUAs in healthcare. 2,033 original CUAs published in the medical literature through 2008 have been compiled into a publicly available registry (www.cearegistry.org) [9]. Briefly, the database was constructed through an extensive search for original CUAs using MEDLINE this database was searched for medical subject headings (MeSH) and/or text keywords: "quality-adjusted", "QALY", and "cost-utility". Then, all selected studies were independently audited by two expert readers and agreed upon consensus using a standardized form. More detail on the search, development, and contents of the registry is provided on the Website [9].

Diagnostic cardiovascular imaging CUAs

This study included all CUAs published between 2000 and 2008 that reported at least one cost utility ratio from a diagnostic cardiovascular imaging intervention. Studies were classified by disease category using the World Health Organization (WHO) classification system [10]. Studies were then grouped by anatomy of interest (cerebrovascular, peripheral, renal, aorta), by imaging modality, and by target population (low risk, high risk, or symptomatic). Low risk was defined as general, asymptomatic or healthy populations. High risk was defined as an asymptomatic population with multiple cardiovascular risk factors (e.g. men > 65 years old, previous history of transient ischemic attack) or referred for imaging after history, physical exam, and/or clinical signs raised suspicion. Additionally, studies were classified according to the continent of origin (Asia, North America, or Europe).

Each study reported one or more cost-utility ratio. Ratios are the incremental cost of an intervention to achieve one quality-adjusted life year (QALY), compared with an alternative intervention. The results were summarized with a table describing the intervention (proposed diagnostic imaging test), the comparator (the alternative diagnostic strategy or usual care), the target population (study sample or model input for base-case), and the cost-utility ratio (expressed in dollars per QALY). Because CUAs included in the review were conducted in different countries using different currencies, all ratios were converted into U.S. dollars, using the appropriate foreign exchange factor for the relevant year. All figures were then inflated to 2008 U.S. dollars using the medical care component of the consumer price index. All ratios were classified as favorable or not favorable at willingness-to-pay (WTP) thresholds of \$20,000, \$50,000, or \$100,000 per QALY, based on a well-recognized framework to interpret economic evaluations [11].

Statistical analysis

After descriptive analysis, we compared the distribution of favorable and unfavorable results among groups (e.g. cerebrovascular vs. peripheral, low risk vs. high risk vs. symptomatic, Asia vs. North America vs. Europe) with a two-tailed Chi square test for a 3×2 contingency table or Fisher exact test, when appropriate. All analyses were performed with Microsoft Excel 2007 for Windows (Microsoft) and STATA 9.0 for Windows (StataCorp LP) with statistical significance set at the 5% alpha-error level ($P < 0.05$).

Results

Sixty-nine percent of all (78/113) diagnostic cardiovascular imaging (CVI) cost-utility analyses published, were published between 2000 and 2008. More than doubling the number of studies published between 1975 and 2000 (Fig. 1). However, diagnostic CVI studies are only half of all CVI related CUAs published during the study period. The final sample was composed by 32 original diagnostic CVI studies that met the eligibility criteria [12–43].

The most common vascular territory studied was cerebrovascular ($n = 9$), cardiac ($n = 8$), aorta ($n = 7$), and peripheral vasculature ($n = 6$). Pulmonary and renal vasculatures were studied by one study each. The most common disease categories (WHO classification) were “arteries, and arterioles and capillaries” diseases with 11 studies and “cerebrovascular disease” with nine studies. Sixty-six percent (21/32) of studies included sonography as either an intervention or comparator, followed by conventional angiography and computed tomography (25% $n = 8$, each). Five studies targeted a low-risk, sixteen studies targeted high-risk, and eleven targeted symptomatic populations. Study characteristics are summarized in Table 1.

The studies that met the eligibility criteria reported 82 cost per QALY ratios (Fig. 2). Twenty-nine, 42, and 53 ratios were favorable at \$20,000/QALY, \$50,000/QALY, and \$100,000/QALY WTP threshold, respectively (Table 2). This includes 15 cost per QALY ratios that were dominant or cost saving, i.e. less costly and more or equally effective. The interventions deemed to be dominant or cost saving are summarized in Table 3.

Thirty ratios assessed one imaging technology or modality compared to medical or surgical intervention. Twenty-six compared imaging to non-intervention and the same number compared imaging to a different imaging modality or intervention. The distribution of ratios was not significantly different according to the type of comparison (versus other imaging modality, medical intervention, or no intervention) using the \$20,000/QALY and \$50,000/QALY WTP thresholds. At WTP \$100,000/QALY, imaging interventions were more likely ($P < 0.01$) to be favorable when compared to medical (or surgical) treatment or non-intervention than when compared to other imaging test. The distribution of ratios was not significantly different among low risk, high risk and symptomatic populations at any of the three WTP thresholds.

The distribution of ratios as favorable or not at any of the willingness-to-pay threshold was not significantly different according to the continent of origin of the study ($P = 0.07$, $P = 0.09$, and $P = 0.12$ for \$20,000/QALY, \$50,000/QALY, and \$100,000/QALY WTP thresholds, respectively).

All 6 studies at WTP \$100,000/QALY and 5 of 6 (83.3%) at WTP \$20,000/QALY evaluating sonography screening for abdominal aortic aneurysm found sonography to be cost-effective (range: from \$620 when men and women 50 years and older are screened in Canada to \$68,000/QALY when men 65–74 years old are screened in the United Kingdom). Similarly, three of 4 and all 4 studies evaluating sonography for deep venous thrombosis found it cost-effective at WTP \$20,000/QALY and WTP \$100,000/QALY, respectively. Four ratios in three different studies evaluating conventional catheter-based angiography versus MR angiography found conventional angiography to have adverse incremental cost-effectiveness ratios (ICERs, i.e.; incremental cost of intervention divided by incremental benefits) at all WTP thresholds. Two studies found CT to be cost saving for the evaluation of cerebral ischemia.

Discussion

We found that in spite of a steep increased in the number of published diagnostic CVI CUAs, the total number of studies remains relatively low. Given the importance of imaging for cardiovascular disease diagnosis and management as well as the workload that it represents, there is a need for additional analyses to identify evidence-based opportunities for more efficient delivery of health care in cardiovascular disease.

We also found that in general, cardiovascular imaging technologies have favorable cost-utility profiles proving to provide good value for money, in keeping with many current clinical evaluation strategies. Even more encouraging is that in our sample almost 20% of interventions were cost-saving. This number is relatively high because although numerous interventions are known to be cost-effective, few interventions have been shown to actually save money while improving patients' health [44]. The caveats for these very positive results are that there is evidence that favorable results are published more often in the economic research literature (publication bias) and that the quality of the studies is highly variable [45,46].

The increment in number and positive cost-utility profiles may be due to advances in computed tomography, magnetic resonance imaging, and other high end imaging

technologies that allow better noninvasive cardiovascular diagnosis. These modalities have begun to replace conventional angiography as the gold standard in many vascular territories while minimizing patient risks and discomfort [47,48]. Even more, during this period there has been a near total adoption of noninvasive technology for vascular diagnostic workups [49]. An underlying principle is to replace more invasive technologies (e.g. surgical exploration or conventional angiography) with the implicit caveat of increased utilization [50,51]. When considering the added value per cardiovascular imaging dollar, we must recognize that each test represents a cost and a risk. Very small individual costs and risks could become significant when multiplied by the large number of tests performed worldwide annually [4].

In that sense, from the perspective of actual decision makers cost-utility analyses does not fully address questions on how to approach appropriate use of technology. Both the American College of Cardiology Foundations (ACCF) and the American College of Radiology (ACR) have developed and implemented methods to evaluate the appropriateness of cardiovascular imaging procedures aimed at helping clinicians decide which test to use and more importantly helping them to curb improper utilization in an increasingly cost conscious environment [52,53]. To our knowledge, studies to date have not incorporated the potential risk of radiation induced cancer. This lack of acknowledgement is probably twofold. First, radiation risks were underestimated and largely neglected in relation to more tangible benefits. However, this preconception is rapidly changing [54,55] despite the controversy and lack of human epidemiologic data for radiation doses delivered by routine medical imaging. Moreover, a report from The National Council on Radiation Protection and Measurements found that by 2006 in the United States the per capita dose of radiation from medical imaging has increased by a factor of nearly six since the early 1980s [56]. Since early reports of radiation induced cancer risks [57], estimates have slowly been incorporated into the cardiovascular literature [58]. Second, basic simulation models were unable to incorporate these variables with such infrequent incidence. For example, samples for simulation models are often limited to 1,000 patients; some models lack the sensitivity to capture risks on the order of 1 per 100,000 cases. More data is likely to increase recognition that results in closer monitoring and regulation by the stakeholders.

There is little doubt that newer technologies bring new useful information to cardiovascular diagnoses; however, expanded economic analyses have the potential to help determine optimum resource allocation and to guide policy makers' coverage decisions. However, it is unclear how reallocation of resources based on cost-effectiveness will change the overall costs of cardiovascular care.

Cardiovascular imaging technologies appear to be cost-effective when compared to extended observation and natural history of disease (no intervention). This is important because many imaging technologies limit both the expense related to an extended stay in more costly settings (e.g. the emergency department) as well as disability and mortality related to catastrophic diseases (e.g. timely diagnosis of ruptured abdominal aortic aneurysm with ultrasound, or stroke with computed tomography). In such cases imaging is cost-effective when compared against a base line of observation or non-intervention.

One limitation of our study is that only a 9-year period 2000–2008 was considered. However, (1) studies prior to 2000 are sparse and (2) the exclusion of the year 2009 allow us to being comprehensive in terms of assuring that studies are audited, reviewed, and double checked by expert readers before incorporating them to the database. We also excluded studies with results not expressed in cost per QALY, further limiting the size of our sample. However, cost-effectiveness analyses using other metrics would have limited our ability to compare interventions. CUAs are increasingly used in health care and are considered by

many authorities to be the gold standard in economic analyses [8]. Finally, the inclusion of studies from different countries (and thus different costs and delivery structure) might also be considered a limitation. Although we found no significant difference in the distribution of ratios among different continents, there are major variations from country to country that we could not study because of our small sample size. However, the positive findings of our observations indicate that generalizations across different systems and perspectives are possible.

In conclusion, the diagnostic cardiovascular imaging literature has growth substantially. The studies available have, in general, favorable cost-effectiveness profiles with major determinants relating to being compared against observation, medical or no intervention instead of other imaging tests.

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Fig. 1.

Flowchart of eligible studies. *Other clinical domains mainly pharmaceutical and surgical procedures. †Including Stents placing, embolization and others. **Cardiovascular studies published before year 2000

Fig. 2.
Summary table of all included imaging interventions by cost-effectiveness ratio (cost per additional QALY expressed in 2008 US\$)

Table 1**Studies classification**

	Number of studies
WHO disease category	
Diseases of arteries, arterioles	11 (34.4%)
Cerebrovascular disease	9 (28.1%)
Ischemic heart disease	6 (18.8%)
Diseases of veins and lymphatics	3 (9.4%)
Other forms of heart disease	1 (3.1%)
Diseases of pulmonary circulation	1 (3.1%)
Hypertensive disease	1 (3.1%)
Vascular territory of interest	
Cerebrovascular	9 (28.1%)
Coronaries	8 (25%)
Aorta	7 (21.9%)
Peripheral vasculature	6 (18.8%)
Pulmonary circulation	1 (4.2%)
Renovascular	1 (4.2%)
Modalities under study*	
Ultrasound	21(65.6%)
Conventional angiography	8 (25%)
Computed tomography	8 (25%)
MR angiography	7 (21.9%)
Single photon emission CT	3 (9.4%)
Positron emission tomography	1 (3.1%)
Population type	
Low risk	5 (15.6%)
High risk	16 (50%)
Symptomatic	11 (34.4%)

* Each publication can consider one or more imaging modalities, therefore, adding up to more than 32 or 100%

Table 2

Distribution of incremental cost-effectiveness ratios according to results at three different willingness-to-pay thresholds

	Willingness-to-pay threshold		
	\$20,000	\$50,000	\$100,000
Favorable	29	42	53
Total	82	82	82

Table 3

Selected examples of diagnostic cardiovascular imaging interventions found to be cost saving or dominant (less costly and more QALY saved)

1	Bilateral examination of the common femoral and popliteal veins, followed by bilateral limited examination of the common femoral and popliteal veins within 5 days VERSUS Any strategy involving complete bilateral examination IN 65-year-old male patients presenting with unilateral symptoms of deep vein thrombosis and no contraindication to anticoagulant therapy [12]
2	Exclusion arteriography VERSUS Surgical exploration IN Patients with penetrating or blunt trauma [16]
3	MR angiography VERSUS Natural history of medication-resistant hypertension IN Patients with medication-resistant hypertension [20]
4	Measuring myocardial fraction flow reserve (FFR) at the time of angiography to help guide the decision or percutaneous coronary intervention (PCI) VERSUS Stenting intermediate lesions in all patients IN Patients with an intermediate coronary lesion and no prior functional study [22]
5	CT scan all patients immediately VERSUS CT scan all patients within 48 h of admission to hospital IN Cohort of 1,000 patients presenting with suspected stroke-age 60–64, 70–74, 80–84 [26]
6	CT angiography (CTA) VERSUS Catheter angiography IN Symptomatic patients with a screening examination consistent with internal carotid artery occlusion [40]
7	Multidetector CT VERSUS Echocardiogram IN United States patients in emergency room, with low risk (6%) coronary artery disease [42]
8	64 detector, Multi-detector CT angiography (CTA) diagnosis VERSUS Standard care IN US female patients at least 55 years old presenting with acute coronary syndrome [43]