Curriculum Vitae

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EDUCATION

University of Maryland Baltimore, MD
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Research Assistant to Dr. Mary Regan, Dr. Robin Newhouse, and Dr. Eun-Shim Nahm
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Columbia University New York, NY
MS, Nursing: Acute Care, 2009
Recognized by Columbia School of Nursing alumni newsletter as one of the most distinguished graduates of the last 5 years (May 2013).

Columbia University New York, NY
BS, Nursing, 2007

University of Maryland College Park, MD
BS, Cell Molecular Biology and Genetics
Certificate, Art History, 2005

EMPLOYMENT HISTORY AND TEACHING EXPERIENCE

Chamberlain College of Nursing Arlington, VA
Nursing Faculty
September 2012 - April 2014
Course Coordinator and head lecturer for Adult Health I/II in BSN program. Taught Pharmacology I/II. Organized and delivered didactic lectures, oversaw clinical instructors and clinical experience. Designed and facilitated SIM experience. Wrote and administered original exams in NCLEX format. Excellent student reviews, 3.8/4, active member of Test Review Committee. Currently serves as visiting faculty member.

Johns Hopkins Community Physicians Columbia, MD
Hospitalist, Howard County General Hospital
October 2010 - May 2013
Independently managed team of 10-12 patients in 400 bed community hospital. Managed wide range of illnesses from admission to discharge. Responsible for diagnosing, assessing, ordering and interpreting diagnostic tests and managing rapid response.

Member of RRT committee, trained new employees, proctored ACNP students from Hopkins. Triple credentialed as Hospitalist, ICU NP, and Emergency Room NP

New York Presbyterian Hospital New York, NY
CN I, Emergency Department
May 2007 - May 2010
Managed and triaged large patient volumes. Trained new employees, served as clinical instructor. Won employee-nominated and patient-nominated awards for providing outstanding care. Worked in largest stroke destination and cardiac destination hospital in NYC in an ER, which saw over 100,000 patients a year. Designed and implemented QI protocol to enhance efficiency and care of neutropenic fever patients and rapid cooling of post-MI patients.

Center for Advanced Research in Biotechnology Rockville, MD
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Performed research portion in direct support of study on protein affiliation, later published in 2010. Built and purified proteins using recombinant genetics. Optimized procedure and wrote results section of study.

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American Association for Nurse Practitioners
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PUBLICATIONS/PRESENTATIONS
Regan M, McElroy K, Chung S, *Heetderks E*, Friedmann E, Johantgen M. Place, provider and timing Factors influencing the overuse of cesarean in low-risk primigravid women. Journal of Nursing Education and Practice, 2014: 4(10).
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Panel Member "Online Education: A new reality", University of Maryland School of Nursing 35th Anniversary Celebration, Nov 8, 2014, Baltimore, MD.

Abstract

Neuroimaging in Headache Patients: The Sensitivity of Computerized Tomography (CT) in Missed Stroke Diagnoses

Elizabeth Claire Heetderks, Doctor of Philosophy, 2018

Dissertation Directed By: Meg Johantgen, PhD, University of Maryland School of Nursing

Background: Stroke is the leading cause of disability in the US, costing $34 billion a year and affecting 800,000 patients. Early detection and treatment is the best way to improve outcomes. Yet, 12.5% of strokes are discharged from the ED within the prior 30 days, with headache the most common diagnosis. Neuroimaging, ideally, would catch an impending stroke, but head CT has variable sensitivity based on onset of symptoms and there are both Federal and provider-led (including Choosing Wisely and the American College of Radiology Appropriateness Criteria (ACR-AC) initiatives to reduce overuse of imaging.

Purpose: This study examined variation in ED treatment for patients presenting with a headache, particularly focusing on use of neuroimaging. Potential missed strokes were identified to determine if CT or MRI could have captured stroke.

Methods: Using HCUP 2013 Maryland State Emergency Department Dataset, and State Inpatient Data, patients who were seen in the ED within 30 days of a stroke with a complaint of headache were identified. Generalized linear mixed modeling determined if neuroimaging predicted stroke bounce back while controlling for patient and hospital variables.

Results: Of the 63,942 headache visits in Maryland EDs, 337 patients presented with a stroke within 30 days of ED discharge. Half (54%) were seen in the ED the day of their stroke and 72% were seen within 7 days. A large majority of the stroke patients (82%) underwent CT for their ED headache visit. Patients who underwent CT for their headache were 2.5 times more likely to return with ischemic stroke, and 7.7 times more likely to return with hemorrhagic. Patients who underwent MRI were 1.7 times more likely to return with any stroke, and 2.8 times more likely to return with ischemic stroke.

Conclusions: Providers were concerned about pathology, given the large percentage of patients imaged; however, imaging did not catch active ischemia or bleeding. The negative predictive value of imaging for headache may need to be reconsidered. Patients with high suspicion of pathology should be placed in observation and have appropriate follow up testing. The ACR-AC should be incorporated into diagnostic pathways to optimize use.

Neuroimaging in Headache Patients: The Sensitivity of Computerized Tomography (CT) in Missed Stroke Diagnoses

by:
Elizabeth Heetderks

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ACA	Affordable Care Act
ACEP	American College of Emergency Physicians
ACR	American College of Radiology
ACR-AC	American College of Radiology-Appropriateness Criteria
AEM	Academic Emergency Medicine
AHA	American Hospital Association
AHRQ	Agency for Healthcare Research and Quality
AHS	American Headache Society
AMA	American Medical Association
AMS	Altered Mental Status
CDS	Clinical Decision Support
CMS	Centers for Medicare and Medicaid Services
CPT	Current Procedural Terminology
CT	Computed Tomography
CTA	Computed Tomography Angiography
CVA	Cerebral Vascular Accident
ED	Emergency Department
HCUP	Healthcare Cost and Utilization Project
HIE	Healthcare Information Exchange
ICD-9 CM	International Classification of Diseases, 9th Revision, Clinical Modification
IHI	Institute for Healthcare Improvement
IOM	Institute of Medicine

LOS	Length of Stay
MRA	Magnetic Resonance Angiography
MRI	Magnetic Resonance Imaging
NQF	National Quality Forum
OP	Outpatient
PDSA	Plan-Do-Study-Act
RAND	Research AND Development
RCT	Randomized Control Trial
SAH	Subarachnoid Hemorrhage
SEDD	State Emergency Department Data
SID	State Inpatient Data
TIA	Transient Ischemic Attack

CHAPTER 1 Introduction, Purpose, and Methods

This chapter represents an overview of the dissertation. It begins with an economic and theoretical perspective of overuse of health care, quickly narrowing to imaging use. The need for research that supports evidence-based clinical decision support in imaging is identified. Efforts to support provider decision-making are discussed including federal efforts to influence imaging use through measurement and oversight. The remainder of the chapter addresses the use of computerized tomography (CT) for diagnosing patients presenting to the emergency department with headache, the focus of the analyses. The methods are overviewed with a description of the three manuscripts included in Chapters 2, 3, and 4.

1.1 Healthcare Overuse and Economic Theory

Healthcare overuse is defined as medical care that is "inappropriate for a specified clinical indication, inappropriate for clinical indication in a specific population, excessive service intensity or sophistication given expected clinical benefit, and excessive frequency of service given expected clinical benefits [1]." Antibiotic use in upper respiratory infections, cervical cancer screening in elderly women, ear tubes for pediatric otitis media, and repeat imaging for chronic headaches are all examples of overuse. At a certain point, less is more. According to production theory, utility increases as consumption of medical care increases; however, utility is subject to the law of diminishing marginal productivity [2]. After a certain point, the slope of the curve approaches zero, and consumption no longer produces benefit. Health care is a durable good and therefore provides utility (in this case, health), albeit derived. Overuse of healthcare will eventually lead to disutility given the marginal productivity. For example, frequent imaging can lead to radiation exposure and increased cancer risk without detecting disease.

Empirical evidence has suggested that increased spending on health care and increased consumption of health care leads to marginal impact on both mortality and overall health to the point of almost zero slope among the non-geriatric population [3, 4]. Similar findings have been found with geriatric populations based on the RAND study and examinations of Medicare spending [5]. Health care is different than traditional durable goods in three ways: a lack of certainty of the product being sold as well as uncertainty of whether or when it will be needed; use of a third party payer; and asymmetry of information between consumer and seller in which the seller always knows more information that the buyer [2]. This unique relationship between consumer and seller as well as the unique nature of the "good" creates a complex view of the economics surrounding health. Utility is defined differently among the parties (patient, provider, insurers, and hospitals) involved, and incentives for reducing overuse vary in this complex system.

For a provider (note: when "physician" is used from here on, it refers to evidence that was only studied in physicans, "provider" is used to include advanced care nurse practitioners and physician assistants) utility is a combination of litigation protection, health of the patient, high-value low-cost medicine, and patient satisfaction. Unfortunately, these concepts conflict with each other. Often defensive medicine does not result in high-value, low-cost medicine, or keeping a patient satisfied may not be in the best health interest of the patient. Defensive medicine is not quality medicine and will inevitably lead to overuse [6]. Despite not always following it in practice, providers are invested in reduction of overuse, as evidenced by the formation of *Choosing Wisely*®. *Choosing Wisely*® (founded in 2010) is an initiative of over 80 provider specialty groups committed to increasing the conversations between patients and providers and, who create lists of evidence-based recommendations to reduce waste and unnecessary testing, treatments, and procedures in healthcare.

Studies have found that physicians have poor knowledge of radiation exposure [7], that fear of litigation increases the likelihood of them ordering imaging [6], and that there is a lack of communication between them and their patients about the risks associated with imaging [8]. Further alarming are physicians' attitude; only 36% believe that reducing cost (a facet of overuse) of healthcare is a responsibility of the provider [9]. Lack of provider knowledge about the risks associated with overuse, combined with the fear of litigation and an assumption that they have little responsibility to reduce this epidemic are all problematic and lead to overuse and thus disutility. The relationship between utility and overuse is paradoxical because from the provider perspective there are significant competing interests. Satisfaction and high-value, low-cost medicine often work against each other, and fear of litigation can result in high-cost, low-value medicine rather than the low-cost, high-value ideal.

For patients, there is a general belief that the more medical services are used the more health will ensue, or the greater the use of medical services the more utility is derived. The general patient population does not consider healthcare overuse (specifically diagnostic testing, but not medication) as a problem partially due to lack of understanding of risk associated with use, poor informed choice, and poor shared decision making with providers [10-12]. To these patients, endless use equates to endless utility, there is a so-called "therapeutic-illusion" [13]. If patients believe that health consumption is limitlessly beneficial, they will engage in consumption. In order for patients to change the behavior of consumption, they would have to recognize overuse as a threat to their health.

The healthcare system and hospitals have a more economic perspective on overuse and disutility. Healthcare is a durable good, which needs to be allocated efficiently. Allocation efficiency is subject to a law of increasing opportunity cost meaning that there is a give and take with resource allocation that is not always a 1:1: ratio [2]. That is, there will always be a loser and a winner, but as long as the winner "wins" more than the loser "loses", it is acceptable. The healthcare organization defines utility as profit in combination with quality and access; those three together are needed to maintain the system. The disutility of overuse results in poor balance of the three indicators of a good health economy: cost, access, and quality. However, the organizations are often at the mercy of the insurers, since most revenue comes from this third party system.

From the government perspective, utility is low-cost, high-quality medicine. This perspective is derived from both the public interest theory [2] and the special interest group theory [14]. The government has a clear desire to reduce overuse, not only to save money, but also from a public health perspective (public interest theory). Plus, having an efficient system will lead to re-election (special interest theory). Empirically, Centers for Medicare and Medicaid Services (CMS) data have demonstrated that areas in increased spending do not result in overall better care [5]. The obvious way to reduce overuse and thus increase utility is to cut reimbursement of providers and hospitals that overuse healthcare. CMS has enacted many outpatient and inpatient measures that do just that in its Hospital Outpatient Quality Data Reporting Program (HOP QDRP). In fact, these measures are used to determine hospital rankings and reimbursement. Another example is the 2008 Medicare reimbursement restructuring where hospitals would not be reimbursed when patients are readmitted with hospital-acquired conditions, such as infections from catheters or central lines [15].

A systematic review in 2012 found that there was an information gap in medical technology overuse and utilization, especially in neuroimaging, obstetrics, and abdominal imaging [17]. CT imaging is an example of all of the issues stated above: there is often patient self-referral, provider fear of litigation, poor provider and physician understanding of risk, lack of patient education, lack of shared decision making, and conflicting financial incentives for reduction, which all lead to overuse. It is a complex issue that needs research to support evidence and develop interventions to reduce overuse while maintaining safety of the patient. Proper dissemination and examining the role all parties play are essential to reduce overuse. Unless overuse is examined broadly and appropriate interventions are implemented, practice is unlikely to change.

1.2 Need for Evidence and Quality Improvement

Construction of evidence-based guidelines must be based on the highest quality evidence. This has been particularly evident since the Congressional Budget Testimony of 2008 which determined that increased spending did not result in better overall care [5], and the RAND study of 1982 and followed up in 2003 which determined that while cost sharing did not affect quality of care, quality care was only met 52-59% of the time depending on the healthcare plan [16]. Prior to the move towards evidence-based practice, clinicians relied on "physicians intuition" and it was demonstrated that practices varied widely among clinicians [17]. In fact, RAND also demonstrated that almost 20% of coronary angiography was used inappropriately, even by experts, which was high cause for concern about how medicine was being practiced [18]. In 2008, the Institute for Healthcare Improvement (IHI) designed a tool to promote and ensure this high-quality evidence-based protocol development which would eventually lead to reduced waste and overuse in healthcare. The Plan-Do-Study-Act (PDSA) Cycle is a model designed to accelerate quality improvements in healthcare. This model allowed for consistency in quality improvement efforts and protocol planning research and also included cost in an outcome that should be evaluated [19]. This dissertation addressed a first step towards creating the highest quality evidence that would be needed to create good evidence-based clinical decision support (CDS) regarding CT use in headache patients as the previous attempts (OP-15, discussed below) were not based on highest quality evidence and have been retracted and current options (The American College of Radiology Appropriateness Criteria, discussed at length in Chapter 4) are too complicated and relatively unknown among non-radiologists [20].

1.3 Federal Efforts to Reduce Imaging Overuse

CMS, reinforced by the Affordable Care Act (ACA), enacted measures to reduce overuse, increase appropriate use, and lower cost of healthcare. Diagnostic imaging is the most commonly referred service for Medicare patients [21] and data show that there are approximately 330.4 to 684 claims for imaging per 1000 beneficiaries depending on geographic variation [22]. Given the cost (both monetary and health-wise) of imaging without known benefit, diagnostic imaging was a target of newly proposed outpatient and inpatient standards published by CMS.

There was an overall increase of 330% in imaging in all populations from 1995-2012 [23] though there was a small decrease from 2010-2012 in the inpatient population (which does not include the Emergency Department (ED) [24]. While the frequency of CT use also varies among providers, there is no clear indication that more use is associated with better outcomes [23, 25]. CMS attempted to address the overuse of CT neuroimaging in headache patients. In 2012, an outpatient measure (OP-15) was enacted to measure frequency of head CT use in atraumatic headache [26], with the intent to use the measure as part of the pay-for-performance initiative. CMS enacted this initiative in spite of concerns that OP-15 was not a valid or reliable tool in measuring appropriate CT use as administrative data could not properly reflect what occurred in the ED in terms of patient presentation [27]. The measure was widely criticized by the American College of Emergency Physicians (ACEP) as being unduly restrictive [28, 29] and the National Quality Forum (NQF) found there was not enough scientific evidence and urged CMS to halt enactment of the measure [30]. *Choosing Wisely®* did not endorse the measure, despite having recommendations for less CT use in syncope and minor head injury [31]. In fact, many of the CMS measures were found to be poor indicators of hospital quality in general so that rankings based on outpatient and inpatient initiatives did not reflect overall hospital ratings [32]. In 2015, OP-15 was retracted due to this criticism [33] leaving the area surrounding CT use in headache patients even more murky.

1.4 CT Imaging Use and Risk

Computerized Tomography (CT) takes multiple X-Rays of the body from different angles in order to create a tomographic image of the area in question [34]. It can be done with or without contrast depending on whether the provider wants to be able to view vasculature. CT neuroimaging can be completed in under a minute and is good for viewing intracranial swelling and bleeding. Magnetic Resonance Imaging (MRI), while more expensive, carries the benefit of not exposing the patient to ionizing radiation, and is able to catch active ischemia and neoplasms, where CT is not as effective [35]. Virtually every ED in the United States has access to a CT scanner 24/7, making it a useful diagnostic tool, but at the same time the quick access makes it at risk for being overused. Not all hospitals, especially in rural areas, have access to MRI. A 2014 evaluation of *Choosing Wisely*®'s recommendations on CT neuroimaging found that alarmingly up to 80% of CT scans performed likely did not follow the recommendations and could be unnecessary [36].

The fact that CT uses ionizing radiation caries an inherent risk to the patient. Other risks include increased cost, increased length of stay, and the problems associated with incidental findings. The average cost of a head CT is $1200, ranging from $800-$8000 depending on location and insurance [37]. Undergoing imaging increases the length of stay (LOS) in the ED by approximately 36 minutes, which is 30% of the LOS of a discharged patient, and 17% of the LOS of an admitted patient [38]. It is estimated that CT scans increase lifetime risk of cancer by up to 6%, and there will be over 4000 future cancers from neuroimaging alone [39]. In fact, a quarter of the average persons' radiation exposure will come from CT [40]. Level of dose and the part of the body exposed change the associated risk; however, there is no known "threshold" to determine if a person will develop cancer as a result of exposure. A CT of the head is 1-2mSV which is the equivalent level of radiation that a person would be exposed to from radon in the atmosphere in a year [41]. What is known is that the risks for cancer development from imaging is more significant the younger the patient [40].

Having a CT scan also increases the risk for discovery of an incidental finding, which can cascade into even further radiation exposure. Incidental findings can lead to other consultations and diagnostic testing in which no clinical problem is ever discovered. It has been estimated that 40% of scans lead to incidental findings, and of those, only 6.2% likely need follow up [42]. It was estimated that 10% of MRIs of the brain turn up incidental findings [43] while CT scans of the abdomen have 40-70% incidental findings [42]. Not only is this problematic, it also raises the ethical issue of whether or not these incidental findings should be disclosed to the patient as the result will likely cascade into more tests, more radiation exposure, mounting costs, and likely no disease. Currently there are no guidelines to a threshold level of risk of when these findings should be disclosed [44].

1.5 What Drives Head CT Use and How Can It Be Reduced?

Multiple studies examined if physician risk aversion and fear of litigation drove CT ordering. One study found that physician characteristics were not an accurate predictor of CT ordering behavior in the case of minor head trauma [45]. Another larger and more comprehensive survey, however, found that physicians overestimated their risk of litigation in addition to overestimating how accurate CT was at diagnosis and its pre-test probability [46]. Findings from large surveys found that malpractice concerns were a serious driver in physician behavior, and that overall, physicians lacked good understanding of radiation and would welcome CDS as well in shared decision-making in CT ordering. Also, physicians thought that better patient education would ease some of their fears of litigation as well as promote less CT use [47-49].

Research has been done on effectiveness of reducing head CT in minor head injury patients; however, only the effect of health information exchange (HIE), (i.e., electronic medical records that are easily and readily shared among providers and with patients), has been examined for head CT use in headaches. There has been quite a bit of research done on effectiveness of measures in reducing head CT in minor head injury and imaging in general. HIE was found to be useful for reducing repeat imaging of headache patients, but no research has been done in reducing initial imaging of headache patients [50]. CDS combined with risk education was successful at lowering head CT use in low risk minor head injury patients but actually increased use overall; however, it did reduce bounce back to the ED [51]. Three studies examined use of CDS tools in reducing head CT in minor head injury. The researchers of one study determined that CDS could reduce imaging overall in this population [52], while another determined that it would only be reduced when using American College of Emergency Physicians (ACEP) guidelines [53]. The last study found that knowledge based CDS was ineffective at reducing CT use but did not examine electronic decision tools (those which automatically pop-up when ordering an exam) [54].

1.6 Appropriateness of CT for Headaches

Headaches account for almost 4.5% of ED visits and while the American Headache Society (AHS) via *Choosing Wisely*® and ACEP has been working to create treatment guidelines, there are no official set guidelines for management and diagnosis, which leads to inconsistency in treatment [55, 56]. The American College of Radiology (ACR) has developed Appropriateness Criteria (ACR-AC) for imaging in 187 clinical topics with over 875 variants [57]. For headache patients they advise based on 16 different specific clinical scenarios. Appropriateness of different imaging (CT, use of contrast and MRI, arteriography, etc) for persons presenting with headache with a variety of other symptoms are detailed. For example, the ACR-AC criteria are consistent with *Choosing Wisely*® that a person with chronic headache without new symptoms should not get CT imaging (ranked 3 out of 10 for appropriateness), whereas someone with a "thunderclap" headache has an appropriateness of 9 [20]. Despite the existence of these recommendations, research has shown that they are not well-known among non-radiologist physicians and Advance Practice Nurses (APN) and therefore likely not properly utilized [58-61].

Headache is the 5th most common ED complaint and represents more than 3 million visits every year. Women more commonly present with headache given the well-known link with headaches and hormones[62]. Primary headaches include migraines, tension headaches and cluster headaches; imaging is not recommended for these patients. Secondary headaches can be caused by many different primary diseases; however, the one of most concern in the ED is stroke, especially subarachnoid hemorrhage (SAH). Typically a headache patient will be examined to determine if the headache meets migraine criteria via a detailed patient history and neurological exam. Diagnosis is made purely on exam as there is no biomarker for pathology. Imaging is then used to rule out intracranial pathology if the provider feels it is appropriate [63].

It is well documented that imaging use varies significantly among providers, ranging from 11-35% of visits, specifically, head CT was ordered for the most percentage of visits and had the largest variability (3.7%-16.7%) [64]. Interestingly, high use of head CT also predicted high use of CT overall among providers [64]; however, that only accounts for slightly over 1% of overall variability in imaging use [65]. Age, presenting diagnosis, and hospital location predict variability in CT use; whereas teaching status, income, gender, payment method, and size have not been found to predict variability in use [66]. More than 97% of US hospitals have access to CT on site [67]. While head CT use has gone up, diagnosis of intracranial pathology has actually gone down [68]. While it is known imaging increases length of stay for all patients, in headache patients specifically, it increases the length of stay to 4.6h compared to 2.7h [68].

Abnormal findings on the neurological exam are the best predictor of intracranial pathology. Findings of pathology increase with increasing age, and sudden onset new headache in elderly people is a predictor of pathology. Also concerning is the "thunderclap" headache, or a headache that comes on suddenly and worsens with intensity quickly. This is the classic presentation of subarachnoid hemorrhage (SAH); however, it is not known if imaging in these patients is effective as once believed [69]. In fact, the utility in neuroimaging in non-focal headaches is not determined, and overall CT without other presenting symptoms has very low yield, as little as 4% for pathology [63, 70-72]. Yield is usually at its highest when a patient has other presenting symptoms, for example with altered mental status (AMS), 10.8% of cases were positive, and for focal neurological deficit, 31.5% of cases were positive [72].

1.7 Stroke and Missed Diagnosis

Some research has examined patient symptoms and ED visits prior to diagnosis of stroke. Headaches presented the most common diagnosis of the missed stroke patients after treat-and-release cerebral vascular accidents (usually transient ischemic attacks (TIA) [73]. Thunderclap headache is one of the most concerning primary presentations of hemorrhagic stroke, and can also be a presenting symptom in ischemic stroke, though it is typically accompanied by focal neurological deficit. A big reason a provider would order a CT in a headache patient is to rule out a possible stroke or neoplasm. Americans have almost 800,000 strokes a year, and of those, 165,000 people will die from their event [74]. Ischemic strokes make up 87% of cerebral vascular accidents (CVA). Stroke is the leading cause of disability in the United States and costs approximately $34 billion a year, with $17.4 billion in direct costs, including hospital stays, medication, long term care and $16 billion in indirect costs: work loss, mortality [74]. In fact, cardiovascular disease and stroke account for 15% of medical expenditures [75]. Certainly, prevention is ideal, but early detection and treatment often results in better outcomes. It is estimated that early and correct treatment can improve outcomes by up to 80% [76]. The NEJM recently published a study of a RCT demonstrating the efficacy of intra-arterial clot removal in ischemic stroke, in which patients with the intervention have significantly less disability and better outcomes [77]. This new approach would replace the former alteplase (i.e., clot-buster medication) treatment which, while effective, had many contraindications and a narrow therapeutic window of 4.5 hours after onset of symptoms [78]. The newer treatment needs to be used within 6 hours of onset of symptoms, so early recognition of stroke is still critical [77]. Hemorrhagic stroke is treated by relieving pressure on the brain and then eventual repair of the malformation. "Time is brain" is still a rallying cry for both types of stroke. Of course, early treatment requires correct early detection.

Despite our knowledge of early treatment, public health campaigns for education, and new treatments options, there are still missed diagnoses of stroke. A recent study by Newman-Toker found that 12.5% of persons admitted with stroke were seen in the ED within 30 days of their stroke admission [73]. Of these persons, and estimated more than 85% were seen the week prior to their admission with 5.13% of them having a treat-and-release visit for headache, with the highest rate being discharged within 24 hours of their stroke. Newman-Toker did not examine if these patients underwent neuroimaging in their ED visit. This dissertation examined the role imaging played in the missed diagnosis of stroke, and if imaging could have predicted the impending CVA.

Purpose and Methods

1.8 Purpose

There is a need for the following: better evidence-based clinical decision support on CT utilization for headaches that encompasses the ACR-AC and provides maximum yield; more research on effectiveness of methods in reducing imaging while maintaining safety; improved provider and patient education about radiation exposure from imaging; and better understanding of head CT utilization. Indeed, it has been demonstrated that CDS can significantly and effectively reduce wasteful imaging [79, 80]. This dissertation addressed neuroimaging in headache patients. Headache is an area without thorough consensus among stakeholders, in which research is needed to create evidence-based CDS. The purpose of this dissertation was to determine the relationship between CT and MRI imaging and missed diagnosis of stroke. The aims of the dissertation were to: 1) describe the patient demographics and hospital characteristics of adults presenting with headache in the ED; 2) determine if patient and hospital characteristics influence the likelihood of undergoing CT imaging for headache; 3) determine if CT or MRI neuroimaging is associated with a missed stroke diagnosis within 30 days of ED discharge for a headache; and 4) determine if neuroimaging in headache patients is being used per the ACR-AC. It was hypothesized that CT imaging would independently contribute to the likelihood of returning to the ED with an ischemic stroke, but not a hemorrhagic stroke. Furthermore, MRI would independently contribute to the likelihood of returning to the ED with a hemorrhagic stroke but not an ischemic stroke.

1.9 Methods

The methods for each aim of this dissertation are described in their respective manuscripts and chapters (Chapters 2-4). This was a retrospective cross-sectional design using secondary data from the Healthcare Cost and Utilization Project (HCUP). The Agency for Healthcare Research and Quality (AHRQ) compiles data from state data organizations, private data organizations and the Federal Government and makes them available to researchers via HCUP [81]. The 2013 Maryland HCUP State Emergency Department Database (SEDD), 2013 Maryland HCUP State Inpatient Database (SID), and the 2012 AHA Annual Hospital Survey were utilized [82-84]. The HCUP data has been reconfigured to allow linkage of persons over databases and time allowing this type of analysis. Demographic variables were obtained from the SEDD dataset, hospital level factors were determined from the AHA Survey, and stroke admissions were determined from the SID.

1.10 Overview of Manuscripts

This dissertation was completed as a manuscript option. Each manuscript coincides with one of the specific aims laid out above. Limitations and conclusions for each manuscript are within their specific chapter. Chapter 5 summarizes conclusions and discussed next steps and future research based on the findings. Chapter 2, "CT Utilization for Headache in the Adult Emergency Department (ED): What Influences Use?" (Aim 2) has been submitted for publication to the *Journal for Nurse Practitioners*. Chapters 3 (Aim 3) "Can Neuroimaging Predict Impending Stroke in Headache Patients Presenting to the Adult Emergency Department?" and 4 (Aim 4) "Following the American College of Radiology Appropriateness Criteria for Imaging for Headache in the Emergency Department: How Are We Doing? How Can We Improve?" will also be submitted to the *American Journal of Emergency Medicine* and the *Advanced Emergency Nursing Journal* respectively for consideration.

CHAPTER 2: CT Utilization for Headache in the Adult Emergency Department (ED): What Influences Use?[1]

2.1 Abstract

There are recommendations on Computerized Tomography (CT) utilization for headache, yet use ranges from 11-35% per physician. Headache is the 5th most common complaint in the Emergency Department. The variability of imaging is mostly due to patient level factors, though they have been examined on an outcome basis and not what drives patients to be imaged in the first place. Patient and hospital factors influencing undergoing CT scan for adult ED headache visits were examined using Maryland 2013 HCUP SEDD Data. There were 63,942 visits in 44 EDs. Visits were mostly female (69.5%), age 18-44 (62.6%), and 43.4% underwent CT. Age was positively associated with CT use; visits 75+ years old were 5x more likely than those in 18-44 year olds. Variability among hospitals (17-60%) in CT use was controlled for via clustering to account for physician group imaging practices. More co-morbidities need to be examined to determine factors of use and develop CDS to reduce overuse.

Keywords: head CT, emergency department, imaging, headache, overuse[1]

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[1] Heetderks, Elizabeth. Submitted and under revision for *The Journal for Nurse Practitioners*

2.2 Introduction

Complaints of headaches account for approximately 4.5% of visits to the Emergency Department (ED) [55]. This makes headache the 5th most common complaint to the ED, accounting for 3 million visits every year [55]. Chronic headaches, especially migraines, account for 61% of headache complaints in the ED, and cost an estimated $17.2 billion loss in work productivity [85, 86], as well as an estimated $11.4 billion in healthcare costs, including $700 million per year in ED costs in the US, with an average of $775 per patient visit [86, 87]. Headaches are common, with 12% of persons over the age of 12 meeting criteria for chronic migraine, and 65% of persons reporting any type of primary headache [88, 89]. Despite the frequency and costs, treatment and diagnostic guidelines vary. The American College of Radiology (ACR) outlines appropriateness criteria (ACR-AC) for imaging modality and use in different clinical headache scenarios; however, there is no clinical decision support (CDS) tool on when to use neuroimaging [20, 55, 90]. Computerized Tomography (CT) imaging overall has been rapidly rising in the past decade, with a 330% increase from 2008-2012 [23]. While it has decreased in the inpatient setting since 2012, it has not decreased in the ED [24]. Imaging for headache in the ED specifically has increased 17.4% to 33.3% from 1996-2014 [91]. While head CT use has gone up, diagnosis of intracranial pathology has actually gone down [68]. Use of any imaging comes with risks, from the exposure to radiation, to the increase in cost to the patient, to the problems associated with incidental findings [37-40, 42]. While it is known imaging increases length of stay for all ED patients, in headache patients specifically it increases the ED length of stay to 4.6 hours compared to 2.7 hours on average [68]. In one study it was estimated that 26% of head CTs yielded incidental findings and another study determined that less than 6% of head CT incidental findings actually need clinical follow up [70, 71].

To what extent ACR-AC guidelines are stringently followed is unknown, though studies suggest there is poor education about them in both undergraduate and graduate medical training, as well as advanced practice nurses (APN), and better awareness is needed [59, 61, 92, 93] . *Choosing Wisely*® and the American Headache Society (AHS) have recommended not to image patients with chronic headache or those that meet the diagnostic criteria for migraine, which is consistent with ACR's recommendations [31, 94]. Canada has developed recommendations for headache in the primary care setting, which are consistent with AHS, but not in the emergency setting [95]. More than 97% of US hospitals have access to CT on site [67]. Use of imaging varies considerably among physicians ranging from 11-35% of ED visits. In fact, high use of head CT predicts high use of all CT among physicians [64]. Age, presenting diagnosis, and hospital location predict variability in overall CT use; whereas teaching status, income, gender, payment method, and size have not been found to predict use [66]. Studies have been done to examine use of CT among physicians, descriptive studies on CT use by chief complaint and test done, and identifying factors that result in high yield of CT [23, 70, 72, 96], but there has not been research on what specifically predicts use of head CT in headache patients.

Research is needed to identify safe and cost-effective use of this powerful tool to develop clear evidence-based clinical decision support (CDS). This study examines the patient level and hospital level factors of undergoing head CT use for adult patients presenting to the ED with headache. With the pressures from Affordable Care Act (ACA), *Choosing Wisely*®, and ACR it is important to understand what drives imaging utilization.

2.3 Methods

This study was a retrospective observational design that used linear-mixed modeling with data from the Healthcare Cost and Utilization Project (HCUP). The HCUP compiles data from state data organizations, private data organizations, and the Federal government and makes them available to researchers [81]. The 2013 Maryland HCUP State Emergency Department Database (SEDD) was used for this analysis and represents visits to hospital-affiliated emergency departments that do not result in hospitalization[82]. Variables in the SEDD are typical of those in a hospital discharge abstract. A hospital identifier facilitates linkage to the 2012 American Hospital Association (AHA) Annual Hospital Survey, allowing examination of hospital level factors[84].

All adult (≥18 years) patients diagnosed and discharged with a headache in Maryland EDs in 2013 were included. Persons were identified as being treated in the ED for headache using International Classification of Diseases, Clinical Modification (ICD-9-CM) codes (found in Appendix A) based on the Primary_Visit_Dx variable in the SEDD dataset. The ICD-9 codes were identified from a similar study of stroke [73]. CT imaging is recorded as Current Procedural Terminology (CPT) codes. CPT codes identified for CT included those with and without contrast (Appendix A). As CPT codes are used for billing, the CPT data are considered reliable; this was also verified in personal communication with the HCUP help desk.

Demographic variables (age, sex, race, income, payer) are recorded in the HCUP data. Hospital characteristics examined include MRI availability, rural location, and residency program. Variables from the AHA can be found in Appendix B. Over 75% of hospitals participate in this annual survey. No hospitals in the SEDD dataset failed to respond to the survey. One hospital (n=165 visits) was removed as the hospital characteristics were unable to be independently verified and did not match the information on the AHA file due to ID discrepancy between the two datasets.

The data were cleaned and examined for missing variables. Less than 5% of values were missing for every variable with the exception of race, where there was 5.7% missing. Generalized linear mixed-modeling (GLMM) with a logit link function was used to determine factors for undergoing a head CT at the visit level (GENLINMIXED SPSS Statistics version 23). Clustering at the hospital level was included to account for possible hospital level care practice variability in imaging, as it was not possible to cluster at the provider level. The model was also clustered at the patient level to account for the fact that some patients were seen more than once. Odds ratios and 95% confidence intervals are used to describe influencers.

2.4 Results

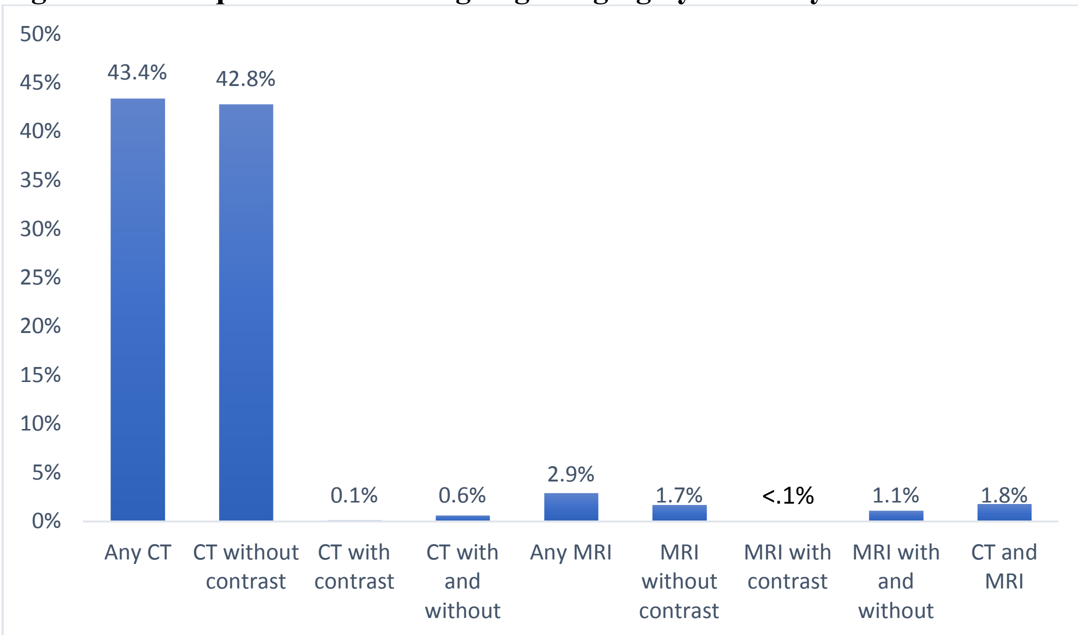
There were 63,942 adult patient visits who presented with headache in 44 Maryland EDs in 2013. Of all headache visits, 84% were single patient visits, and 16% were patients who were treated and released from the ED two or more times with a primary diagnosis of headache. There were 1,312 patients that were seen between 2-5 times and 327 patients that were seen 6-10 times. The most number of ED visits in one year for any individual was 32. Of adult patient visits to Maryland EDs with a primary diagnosis of headache, 69.5% were female (Table 2.1). Visits for 18-44 year olds were 62.6% of the visits, 28.5% were 45-64 years, 4.7% were 65-74 years, and 4.3% were 75 and older. Of visits with headache, a majority occurred in blacks (44.5%), followed closely by whites (40.9%); 4.9% were Hispanic, and 4.0% were other (Asian/Pacific Island, Native American). More than a third of the visits were covered by private insurance (37.1%), 27.5% were covered by Medicaid, 14.1% by Medicare, 17% were uninsured, and 4.3% were other. Almost half (44.2%) of visits were for people in the upper quartile (64K+) in income (quartiles are determined based on the national income, and patient income is based on zipcode). In the vast majority of visits (92%), patients were diagnosed with generalized headache (ICD-9 code 7340) as their primary visit reason. All of the hospitals had both MRI and CT available. The hospitals were mostly urban (86%), and almost two-thirds reported having at least one residency program (61%). Of the visits for headache, 43.4% included a CT scan of the head, 2.8% underwent an MRI, and 1.9% had both. More than half (51.9%) had neither (Figure 2.1). The demographics of the visits who underwent CT were mostly reflective of the total population being imaged (43.4%). Age was inversely increasing with CT use (37.8% 18-44, 47.1% 45-64, 63.5% 65-74, 78.7% 75 and older). Across race and gender and insurance, between 36%-55% of patients were imaged. African Americans and patients with Medicaid were imaged the least frequently.

Table 2.1: Patient and Hospital Characteristics for Headache Visits (n=63942)

	n	%	Underwent CT (n)	% CT
Patient Characteristics	63942		27765	43.4%
Age				
18-44	39954	62.6%	15096	37.8%
45-64	18192	28.5%	8568	47.1%
65-74	3037	4.7%	1928	63.5%
75 and older	2759	4.3%	2173	78.7%
Female	44441	69.5%	18290	41.2%
Race				
White	26096	40.9%	11809	45.3%
Black	28472	44.5%	11312	39.7%
Hispanic	3135	4.9%	1596	51.0%
Other	2556	4.0%	1281	50.1%
Payer				
Private	23732	37.1%	10970	46.2%
Medicaid	17538	27.5%	6029	34.4%
Medicare	9044	14.1%	5054	55.9%
Uninsured	10866	17.0%	4345	39.9%
Other	2728	4.3%	1352	49.6%
Income				
1-37,999	10669	16.8%	3872	36.3%
38K- 47,999	6977	11.2%	2866	41.1%
48K – 63,999	17283	27.0%	7318	42.3%
64K +	28322	44.2%	13430	47.4%
Type of Headache				
General	58825	92.0%	26742	45.5%
Migraine	4829	7.6%	877	18.2%
Other	288	0.5%	146	50.1%
Hospital Characteristics	44			
Location-Urban	38	86%		
Residency Program	27	61%		
MRI available	44	100%		
CT available	44	100%		

Note: Other in race includes Asian Pacific Islander, Native American, and those who identified as Other. There were 3683 missing cases for race, 34 missing for payer, 3 missing for gender, and 694 missing for income.

Figure 2.1: Frequencies of Undergoing Imaging by Modality for Headache



The GLMM included 59,551 visits; 6.9% were excluded due to listwise missing values. The most common missing variable was race (3683 missing). When the final model is run without race included, the results were relatively unchanged (results not shown). The final model was clustered by hospital with an ICC of 6.0% and clustered by visit level (for repeat visits) at 28%. Unsurprisingly, age was the strongest predictor of undergoing CT scan, with visits 75 years and older being almost seven times more likely to undergo a CT (OR=6.78 CI: 5.88, 7.81) compared to visits in 18-44 year olds (Table 2.2). Women were 32% less likely to undergo CT (OR= .688 CI: .657, .721). Visits for those reporting black race were 14% less likely to undergo CT (OR= .860, CI: .816, .908) as compared to whites, while Hispanics were 31% more likely (OR= 1.32, CI: 1.19, 1.46) compared to whites. Medicaid patients were 21% were less likely to undergo CT compared to Medicare patients, and privately insured patients were 10% more likely to undergo CT compared to Medicare. As income quartile increased from the lowest to the highest, likelihood of undergoing imaging increased by 20%. Having a primary diagnosis of migraine resulted in being 27% less likely to undergo CT compared to a primary diagnosis of general headache. Being in an urban hospital was only 18% more likely to undergo CT compared to rural, while being in a residency-affiliated hospital was 10% more likely to undergo CT. While the results were significant (likely due to the large patient size), they were small in effect size with the exception of age, which had a large effect size. The range among hospitals of CT scan use was 17%-60% per patient visit.

Table 2.2: Visit and Hospital Factors Associated with undergoing CT scan for Headache in the ED (n=59,551)

	OR, adjusted	CI	p
Patient Characteristics			
Age			
18-44	ref		
45-64	**1.63**	1.55, 1.71	<.001
65-74	**3.49**	3.09, 3.95	<.001
75 and older	**6.78**	5.88, 7.81	<.001
Female	**.688**	.657, .721	<.001
Race			
White	ref		
Black	**.860**	.816, .908	<.001
Hispanic	**1.32**	1.19, 1.46	<.001
Other	1.09	.985, 1.22	.091
Payer			
Medicare	ref		
Medicaid	**.797**	.727, .872	<.001
Private	1.09	1.00, 1.19	.005
Uninsured	.845	.769, .929	.228
Other	**1.19**	1.05, 1.35	.030
Income			
1-37,999	ref		
38K- 47,999	1.06	.964, 1.16	.228
48K – 63,999	**1.09**	1.01, 1.18	.030
64K +	**1.20**	1.11, 1.31	<.001
Diagnosis			
General Headache	ref		
Migraine	**.271**	.246, .298	<.001
Other HA	.926	.689, 1.24	.608
Hospital Characteristics			
Location-Urban	**1.187**	1.01, 1.30	<.001
Residency Program	**1.102**	1.05, 1.15	<.001

Note: GLMM with logit function was used and predictors were adjusted in the model, bold indicates p <.05

2.5 Discussion

While many variables were found to be significant, this was unsurprising given the large population being examined. Only age had a large effect size, with the rest of the significant factors having a small effect size. Age was unquestioningly the most important factor in head CT use which coincides with radiologist recommendations and increased risk of cardiovascular pathology. Gender had a small impact with women being 32% less likely to undergo CT yet comprising almost 70% of the population who presents with headache. This is likely do to the fact that women are perceived to have their pain taken less seriously, yet more likely to be prescribed analgesics in the ED [97, 98]. In addition, the link between hormones and headaches [62], and the fact that 18% of women experience migraines versus 6% of men[99] may contribute. These data suggest that it may be assumed that women are presenting with chronic headache and more likely to complain of a less severe headache that may warrant acute imaging. Given the worry of missing a stroke diagnosis in headache patients, it would be interesting to examine if women are more likely to bounce-back with a stroke diagnosis with men, given this finding. Headache, of course, is a self-reported symptom without a biomarker, that in combination with a good history and physician, may require imaging for diagnosis of cause.

Race, income, and payer had a small effect size on the model which was unsurprising given the nature of the ED. Interestingly, the demographics seen in the ED were not reflective of the state demographics according to the US Census Bureau. In Maryland, 59.3% of the population is white, 30.7% African-American, and 9.8% Hispanic, yet whites accounted for 40.9% of visits, African-Americans for 44.5% of visits, and Hispanics for only 4.9% of visits, though it is likely the true denominators of the population subgroups are not truly known. There was a step-wise increase of likelihood of being imaged as income increased, though still a small effect. This could be linked to education level, as patients with poorer education are less likely to have their pain taken seriously in the ED [100]. African Americans are also less likely to have their pain taken seriously in the ED, which was reflected in the frequencies of imaging. Residency hospitals visits were only 10% more likely to use CT; a previous national study found that residents used imaging in 28% of visits versus 21% among solo-attending physicians [101]. This could be a headache-specific finding versus radiology use overall, also the AHA does not designate which types of residents are in the hospitals in its survey. Given the very small effect size, it is a less significant finding.

Variation among physician use of radiology has been well documented, and has also been documented specifically in neuroimaging [64]. There was hospital level variation in CT use of 17-60% among ED visits; however, hospital level only explained 6.0% of this variability. The rest of the range could be described by physician level practice (years of experience, confidence, type of provider, radiologist in ED), as well as patient level factors that were uncaptured in the data (secondary symptoms). The repeated visitors accounted for 28% of the variability in the model, implying that patient level predictors are likely the biggest drivers of variation in imaging practice as opposed to physician level and hospital level. Previous research has found that within a 11-35% variability in physician to physician ordering of CT, only 1% of that variation is explained by physician level factors [64]. In order to truly capture physician and patient level variation, a study using medical record data would have to be used. This model could also be repeated with only first time visits captured and compared to frequent-flyer visits.

While the ACR-AC give scores of certain tests for specific patient scenarios, they do not take into account the wide number of comorbidities and secondary diagnoses that may warrant CT use for an ED provider, such as nausea, changes in vision, or diminished affect. Variation of imaging practice has to do with patient level comorbidities and would not be identifiable with administrative data. There is also evidence that the ACR recommendations need to be taught more in both undergraduate and graduate medical education, and that they are not necessarily used by non-radiologists [59, 92]. Detailed chart review determining comorbidities as well as which comorbidities have high yield could be integrated with the ACR-AC to create evidence-based CDS that is integrated within a radiology-ordering system. Determining yield based on comorbidity is crucial, as yield of head CT is 4-32% depending on secondary symptoms [70].

It is important to note that the SEDD data only encompasses visits who had treat-and-release visits from the ED. None of the visits included in this analysis were admitted to the hospital for their headache presentation, therefore 43% underwent CT imaging without any significant finding warranting admission to the hospital. Even more alarming is that almost 2% of the patients underwent both a CT and an MRI and were subsequently discharged. While this explains the lower average age of the patients who underwent imaging, it is still concerning to see almost half of patients undergo a test that could have been unnecessary. A comparison to inpatient samples to see if the percentage tested is similar would be needed to help determine predictive ability of CT.

2.6 Limitations

This study only examined hospitals in the state of Maryland. While it is likely generalizable to other similar states that have both urban and rural environments it is not globally generalizable. Practices may differ in states that are mostly rural, or in practices that utilize more mid-level providers. In Maryland, all the EDs had access to both CT and MRI; other states may not have that availability. It would be worth examining practice variation in states that do not have MRI as a resource.

While 17.4% had a migraine diagnosis listed among all their diagnoses, only 7.4% had it listed as their primary visit reason. There is always risk for error in administrative data as it is based on billing codes. The diagnosis of general headache disorder likely encompassed many specific migraines and other headache disorders that were not billed properly, which is unavoidable when using administrative data.

Research always includes bias, and observational research has more bias than experimental design. The researchers were unable to control for confounders and comorbidities. There are also physician and hospital factors that could be confounding that are impossible to control for (such as physician experience, whether there are on-call neurologists, if CT is available within the ED, if there is a radiologist in the ED etc.). Finally, there can be errors due to billing and it is possible data is entered incorrectly. The large dataset minimizes this error, but it still must be acknowledged.

2.7 Conclusions

Age has the overwhelmingly largest effect on whether or not CT is ordered in headache patients. There is a wide variability between hospitals of CT use from 17-60% that is not explained by this model and needs investigation, whether it be physician level or patient level. Given the high ICC due to the repeat visits, variability is likely mostly due to the patient level and less to do with hospital or physician level practice. There is still a high percentage of persons undergoing CT who are being discharged from the ED without significant clinical finding. It is important to do a chart review to determine comorbidities that create high yield, and integrate this with ACR-AC to create evidence-based CDS for CT use in headache patients.

CHAPTER 3: Can Neuroimaging Predict Impending Stroke in Headache Patients Presenting to the Adult Emergency Department?[1]

3.1 Abstract

Stroke is the leading cause of disability in the US, costing $34 billion a year and affecting 800,000 new patients a year. Early detection and treatment is the best way to improve outcomes and minimize disability. Despite this, 12.5% of patients are discharged from the ED within 30 days of a stroke; of these patients over 5% had a complaint of headache. Neuroimaging, ideally, would catch an impending stroke in a patient with headache. This study used the Healthcare Cost and Utilization Project's (HCUP), 2013 Maryland State Emergency Department Dataset (SEDD), and State Inpatient Data (SID), to identify patients who were seen in the ED within 30 days of a stroke with a complaint of headache and determine if neuroimaging use predicted their stroke bounceback using generalized mixed linear modeling. There were 63, 942 headache treat-and-release visits in Maryland EDs in 2013; among which 337 patients were seen within 30 days of their discharge with a stroke. Over half (54%) were seen the same day of their stroke and 72% were seen within 7 days. Of the strokes, 169 were hemorrhagic. Increasing age made persons more likely to bounceback with any type of stroke (OR 8.41; 95% CI: 4.64, 14.28). A vast majority of the stroke patients (80%) underwent CT for their ED headache visit. Patients who underwent CT for their headache were 2.5 times more likely to return with any type of stroke, 2.5 times more likely to return with ischemic stroke, and 7.7 times more likely to return with hemorrhagic stroke. Patients who underwent MRI were 1.7 times more likely to return with any stroke, and 2.8 times more likely to return with ischemic stroke

[1] Heetderks, Elizabeth. To be submitted to *The American Journal of Emergency Medicine*

than those who did not. Clearly the providers were concerned about pathology in these patients, given the large percentage that underwent imaging. The imaging, however, did not catch active ischemic or bleed. Perhaps sending person to observation and applying a wait-and-watch approach is better for persons with high suspicion of pathology, yet negative imaging. The negative predictive value of imaging in headache patients may need to be reconsidered.

Keywords: neuroimaging, missed diagnosis, stroke, headache, head CT

3.2 Introduction

Cardiovascular disease accounts for 15% of medical expenditures in the US [75]. There are over 800,000 strokes a year in the United States, with 165,000 being fatal. It is the leading cost of disability in the United States, costing $34 billion a year [74]. Of that, $17.4 billion include direct costs, and $16 billion are from indirect costs, especially work loss. Early detection of stroke is the best way to reduce disability and improve outcome. It has been shown that early detection and treatment can improve outcomes and quality of life by up to 80% [76]. Being seen within the first 6 hours of presentation for ischemic stroke, which accounts for 87% of strokes, allows for intra-arterial clot removal. This has demonstrated significantly less disability, which is an improvement from the previous 4.5 hour window [77, 78].

Despite this knowledge, a 2014 study found that 12.5% of persons admitted with stroke had been seen and discharged from the Emergency Department (ED) within 30 days prior to their stroke diagnosis [73]. In fact, more than 85% were seen in the week prior to their stroke. Headache was the most common diagnosis (5.13%) after a correctly identified treat-and-release (were not admitted to the hospital) transient cerebral vascular incident, typically a transient ischemic attack (TIA). The peak majority of persons who returned with a stroke after being discharged with a headache from the ED were seen the day before their hospital admission. It is possible that the headache was an early presentation of the stroke or a warning sign. Newman-Toker and colleagues examined predictors of missed stroke diagnosis, including demographic and hospital level predictors, but did not look at diagnostic level predictors [73]. Of particular interest is the use of neuroimaging.

Imaging and detailed neurological exam and history are currently the best ways to identify stroke patients, and imaging is necessary to categorize the cause and type of stroke a patient is experiencing. Undergoing Computerized Tomography (CT) neuroimaging is not without risk, including increased length of stay, increased cost, ionizing radiation exposure, and risks involving incidental findings [37-39, 41, 42, 68]. Headache is the 5th most common complaint in the ED, and represents more than 3 million visits a year [55], so headache alone is not indicative of stroke. Imaging is not recommended for primary headache disorders (such as migraine and cluster headaches), and of secondary headaches, it depends on the primary cause. The American Headache Society (AHS) through *Choosing Wisely®* has recommended that neuroimaging not be used in headache patients that meet the diagnostic criteria for migraine, but do recommend it to those who have abnormal neurological findings on exam. AHS was unable to give recommendations for persons with tension headache and headache in the absence of abnormal neurological exam as they did not have sufficient evidence [94].

CT varies widely among providers, ranging from 11-35% of ED visits for all imaging and head CT has the highest variability from 3.7-16.7% [64]. While head CT use has increased, intracranial pathology diagnoses have actually gone down [64]; in fact, imaging use for headache specifically has increased 17.4% to 33.3% from 1996-2014 [91]. While abnormal findings on the exam are the best predictor of intracranial pathology, it is not known if imaging in symptomatic patients is truly effective, especially in those with "thunderclap" headache [69]. CT positive yield ranges from 5 -31% in symptomatic headache patients (i.e: with altered mental status (AMS), focal deficit, or nausea/vomiting etc.), and for non-focal headache patients, yield is as low as 4% [63, 70-72]. CT is cheaper, quicker, and generally more readily available than Magnetic Resonance Imaging (MRI), with nearly every ED in the US having 24/7 access. CT is effective in detecting blood and swelling in the brain, but not as effective at detecting ischemia; MRI is superior in detecting ischemia, but not as effective in detecting blood [35].

This study aims to determine if neuroimaging (CT or MRI) for the index ED workup for headache is associated with a subsequent stroke (i.e., missed diagnosis). Knowing this information may help with the formulation of clinical decision support (CDS) for headache patients in the ED, as well as contributing to knowledge of ways to utilize neuroimaging more effectively. The ultimate significance is contributing to the knowledge of how strokes might be prevented or at least detected earlier to prevent catastrophic disability.

3.3 Methods

The study was a retrospective observational cross-sectional design that used generalized linear-mixed modeling (GLMM) from data obtained from the Healthcare Cost and Utilization Project (HCUP). The HCUP compiles data from state data organizations, private data organizations, and the Federal government and makes them available to researchers [81]. This study examined if CT and MRI predict bouncing back with a stroke within 30 days of an ED discharge for headache, while controlling for patient level and hospital level factors. Three datasets were used in this analysis: 2013 HCUP Maryland State Emergency Department Data (SEDD); the 2013 HCUP Maryland State Inpatient Database (SID); and the 2012 American Hospital Association (AHA) Annual Survey data[82-84]. The Agency for Healthcare Research and Quality (AHRQ) has reconfigured their HCUP database to allow for examination of readmission data within the state, for both

ED and inpatients. Only 12 states have this "linking" variable that allows for this type of manipulation and Maryland has the data elements needed to link emergency visits across time. The SEDD and SID datasets are representative of what would be found in a typical hospital discharge abstract and were used to determine patient demographic information. The AHA Annual Survey data was used to determine hospital level variables. AHA surveys hospitals annually about organizational structure, services, staffing, expenses, and geographic indicators.

All adult (≥18) patients diagnosed and discharged with a primary diagnosis of headache in Maryland EDs in 2013 were included. Persons were identified as being treated in the ED for headache using International Classification of Disease Clinical Modification (ICD-9-CM) codes (see Appendix C) based on the Primary_Visit_Dx variable in the SEDD dataset. The ICD-9 codes were identified from a similar study of strokes [73]. CT and MRI are recorded as Current Procedural Terminology (CPT) codes in the SEDD data. CPT codes identified for CT and MRI can be found in Appendix D. As CPT codes are used for billing, the CPT data are considered reliable; this was verified in speaking with the HCUP help desk. The second target population were patients who were admitted with a diagnosis of stroke (both hemorrhagic and ischemic) within 30 days of their headache visit; they were extracted from the SID dataset (see Appendix C). The datasets were merged and using the HCUP revisit variable, patients that were present in both datasets within 30 days were identified as bounce back or missed diagnosis patients. For patients who had multiple ED visits, only the visit nearest to the stroke admission was used.

Demographic characteristics (age, sex, race, income, payer) were from the SEDD data. Hospital characteristics examined include MRI and CT availability, rural location, and teaching. Location was defined as urban versus rural. The AHA does not specify the residency type, only that the hospital has one AMA accredited active residency program. Over 75% of hospitals typically participate in this annual survey. No Maryland hospitals in the dataset failed to respond to the survey. One hospital (n=165 headache visits) was removed from the analysis as there was ID discrepancy between the two datasets leading to a failure to merge, and the hospital characteristics were unable to be independently verified.

Data were cleaned and examined for missing data. Less than 5% of values were missing for every variable with the exception of race, where there was 5.7% missing. Generalized linear mixed-modeling (GLMM) was used with a logit link function to determine factors for having a bounce-back with a stroke at the visit level (GENLINMIXED SPSS Statistics Version 23). Chest X-Ray (CXR) was used as a parallel predictor to isolate specific versus general imaging, and also to isolate patients who were getting blanket imaging while searching for a diagnosis. All models included clustering at the hospital level to account for imaging practices that relate to care being clustered within the hospital level. Three models examined likelihood of any stroke, hemorrhagic stroke, and ischemic stroke.

3.4 Results

There were 63, 942 visits seen and discharged from Maryland EDs with a diagnosis of headache (see Table 3.1 for characteristics). A majority of the visits were for women (69.5%), aged 18-44 years (62.6%). Race was diverse with nearly equal proportions of white and black patients (40.9%, 44.5%). Nearly half of the visits were in patients with incomes greater than $64,000 (44.2%). Nearly all (92%) of the visits were for a general headache. A large majority (86%) of the hospitals were urban areas and 61% had a residency program. All hospitals had both MRI and CT available.

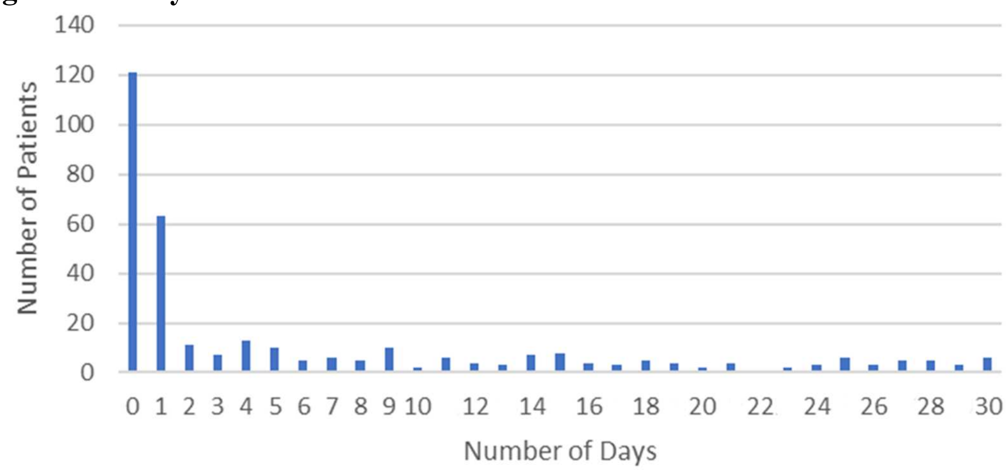
Table 3.1: Visit (n=63942) and Hospital Characteristics (n=44)

	n	frequency
Patient Characteristics		
Age		
18-44	39954	62.6%
45-64	18192	28.5%
65-74	3037	4.7%
75 and older	2759	4.3%
Female	44441	69.5%
Race		
White	26096	40.9%
Black	28472	44.5%
Hispanic	3135	4.9%
Other	2556	4.0%
Payer		
Private	23732	37.1%
Medicaid	17538	27.5%
Medicare	9044	37.1%
Uninsured	10866	17.0%
Other	2728	4.3%
Income		
1-37,999	10669	16.8%
38K- 47,999	6977	11.2%
48K – 63,999	17283	27.0%
64K +	28322	44.2%
Type of headache		
General	58825	92.0%
Migraine	4829	7.6%
Other	288	0.5%
Hospital Characteristics		
Location-Urban	38	86%
Residency	27	61%
MRI available	44	100%
CT available	44	100%

Note: Other in race includes Asian Pacific Islander, Native American, and those who identified as Other. There were 3683 missing cases for Race, 34 missing for Payer, 3 missing for gender, and 694 missing for income.

Of the 63,942 visits seen for headache in Maryland EDs in 2013, 337 (.53%) people were admitted for a stroke within 30 days after their ED visit. In fact, 70% of the bounce-backs were seen within 7 days of their ED visit. Over half (54%) were seen and discharged from the ED the same day of their stroke admission (Figure 3.1). Of the stroke admissions, 169 were hemorrhagic (50%), 209 were ischemic (62%), and 41 were diagnosed with both (12.4%) (see Table 3.2 for characteristics by stroke type). The majority of admissions who returned with any type of stroke were ages 45-65 years (45.7%) and female (62.3%). Of the ischemic group, 76% had a CT scan and 11% had an MRI during their ED visit. Of the hemorrhagic admissions, 90.5% had a CT during the ED visit and 4.7% had an MRI. Of all the stroke patients, only 5.0% were placed in observation prior to discharge from the ED.

Figure 3.1: Days until readmission for stroke after index ED headache discharge



Note: Total number of patients = 337

Table 3.2: Demographics and ED treatment aspects of bounce-back stroke patients by type of stroke

	Any stroke (337) n(%)	Ischemic (209) n(%)	Hemorrhagic (169) n(%)
Age (mean/range)	58.7 (18-97)	59.35 (18-97)	57.56 (19-92)
18-44	65 (19.3%)	42 (20.1%)	28 (16.6%)
45-64	154 (45.7%)	91 (43.5%)	89 (52.7%)
65-74	52 (15.4%)	34 (16.3%)	22 (13.0%)
75 and older	66 (19.6%)	42 (20.1%)	30 (17.8%)
Female	210 (62.3%)	133 (63.6%)	104 (61.5%)
Race			
White	168 (49.9%)	88 (42.1%)	97 (57.4%)
Black	123 (36.5%)	92 (44.0%)	49 (29.0%)
Hispanic	11 (3.3%)	8 (3.8%)	4 (2.4%)
Other	17 (5.0%)	10 (4.8%)	8 (4.7%)
Payer			
Private	125 (37.1%)	67 (32.1%)	80 (47.3%)
Medicaid	53 (15.7%)	39 (18.7%)	17 (10.1%)
Medicare	123 (36.5%)	83 (39.7%)	52 (30.8%)
Uninsured	30 (8.9%)	17 (8.1%)	17 (10.1%)
Other	6 (1.8%)	3 (1.4%)	3 (1.8%)
Income			
1-37,999	50 (14.8%)	34 (16.3%)	20 (11.8%)
38K- 47,999	35 (10.4%)	25 (12.0%)	13 (7.7%)
48K – 63,999	89 (26.4)	63 (30.1%)	39 (23.1%)
64K +	160 (47.5%)	86 (41.1%)	95 (56.2%)
Any CT	277 (82.2%)	160 (76.6%)	153 (90.5%)
CT without contrast	272 (80.7%)	155 (74.2%)	153 (90.5%)
CT with contrast	1 (0.3%)	1 (0.5%)	0 (0%)
With and without	2 (0.6%)	2 (1%)	0 (0%)
Any MRI	27 (8.0%)	23 (11.0%)	8 (4.7%)
MRI without contrast	12 (3.6%)	12 (5.7%)	1 (0.6%)
With and without	15 (4.5%)	11 (5.3%)	7 (4.1%)
CT and MRI	19 (5.6%)	16 (7.7%)	7 (4.1%)
CXR	104 (30.9%)	58 (27.8%)	60 (35.5%)
Placed in Observation	17 (5.0%)	16 (7.7%)	4 (2.4%)

In multivariable modeling, age, gender, and undergoing any imaging (CT, MRI, or CXR) were significant predictors for bounce-back for any type of stroke (Table 3.3). The effect of age is reflected in the increasing likelihood of any stroke as age increases. Women were 26% less likely to bounce-back for any type of stroke (OR .736; 95% CI: .571- .949). Patients who underwent a CT in the ED for their headache visit were 3.6 times more likely to bounce back with a stroke than those who did not (OR 3.64; 95% CI: 2.64-5.03), with patients 75 years and older being almost 8.5 times more likely to bounce-back with a stroke than those 18-44 (OR 8.41; 95% CI: 4.96, 14.28). Those who underwent MRI were 1.7 times more likely to be admitted for a stroke than those who did not undergo MRI in their ED visit (OR 1.72; 95% CI: 1.09, 2.69). Payer, income, race, hospital location, and residency program status were not significant but left in the model as control variables.

The model of bounce back with ischemic stroke showed that age and undergoing imaging during the ED visit were significant predictors of admission with an ischemic stroke with 30 days (Table 3.3). Age had the largest effect as was seen in any stroke. Imaging had a medium effect size; patients who underwent CT scan while in the ED for their headache visit were 2.5 times more likely to return with an ischemic stroke within 30 days (OR 2.54; 95% CI: 1.77- 3.64). Patients who had MRI during the ED admission were 2.8 times more likely to bounce back (OR 2.83; 95% CI: .76-5.57).

Table 3.3: Factors Associated with having a bounceback of stroke within 30 days of an ED visit for headache (n=337)

	Any Stroke (n=337)		Ischemic Stroke (n=209)		Hemorrhagic stroke (n=169)	
	OR,adj	CI	OR,adj	CI	OR,adj	CI
Patient Variables						
Age 18-44	ref		ref		ref	
45-64	**4.43**	**3.15, 6.23**	**4.03**	**2.67, 6.07**	**5.68**	3.73, 8.63
65-74	**7.07**	**4.24, 11.81**	**6.72**	**3.59, 12.56**	**6.75**	3.61, 12.59
75 and older	**8.41**	**4.96, 14.28**	**8.82**	**4.66, 16.68**	**7.57**	3.97, 14.44
Female	**.736**	**.571, .949**	.747	.547, 1.02	.751	.559, 1.01
Race White	ref		ref		ref	
Black	.838	.634, 1.11	1.18	.842, 1.66	**.620**	**.443, .866**
Hispanic	.833	.419, 1.65	1.18	.536, 2.59	.519	.206, 1.30
Other	1.146	.646, 2.03	1.43	.706, 2.89	.824	.407, 1.67
Payer Medicare	ref		ref		ref	
Medicaid	1.09	.675, 1.77	1.04	.592, 1.84	.925	.496, 1.73
Private	1.09	.736, 1.63	.858	.526, 1.39	1.541	.996, 2.46
Uninsured	.764	.438, 1.33	.635	.324, 1.24	1.028	.536, 1.97
Other	**.379**	**.136, 1.05**	.228	.050, 1.05	.489	.162, 1.48
Income 1-37,999	ref		ref		ref	
38K- 47,999	.894	.542, 1.47	1.10	.617, 1.97	.653	.340, 1.25
48K – 63,999	.841	.557, 1.27	1.06	.654, 1.71	.685	.407, 1.15
64K +	.744	.499, 1.11	.750	.461, 1.22	.762	.470, 1.24
Imaging in index ED visit						
CT	**3.64**	**2.64, 5.03**	**2.54**	**1.77, 3.64**	**7.71**	**4.72, 12.59**
MRI	**1.72**	**1.09, 2.69**	**2.84**	**1.76, 4.57**	.793	.411, 1.53
CXR	**1.89**	**1.44, 2.48**	**1.57**	**1.12, 2.22**	**2.34**	**1.72, 3.19**
Hospital Variable						
Location-Urban	.954	.579, 1.57	.981	.524, 1.84	.813	.475, 1.39
Residency Program	.996	.758, 1.31	1.09	.782, 1.52	.801	.574, 1.12

Note: GLMM with logit function and hospital cluster. Bold annotates p <.05 Any Stroke: ICC = 1.9%. , Ischemic and Hemorrhagic Stroke: ICC <1%, All factors were adjusted in the model.

For patients who bounced back with hemorrhagic stroke, age, race, undergoing CT and CXR had a significant effect size (Table 3.3). Age continued to have a strong effect. Interestingly, patients who were black were 38% less likely to return with a hemorrhagic stroke than white patients (OR .62; 95% CI: .44-.87). Patients who underwent a CT in the ED were 7.7 times more likely to be admitted with a hemorrhagic stroke than those who did not undergo a CT (OR 7.7; 95% CI: 4.72-12.59). MRI did not have a significant effect.

3.5 Discussion

For all types of stroke, CT was used in 82.2% of headache visits, a very high proportion. Patients were significantly more likely to bounce back with a stroke if they received CT imaging. The fact that such a high percentage of these visits underwent CT indicates that the provider likely had some suspicion of intra-cranial pathology, otherwise imaging would not have been ordered. Since these persons were discharged from the ED, it seems likely that the imaging was negative. This brings to question the ability for CT to identify impending strokes in headache patients. While it is known that CT is not as effective at capturing active ongoing ischemia, it should be able to capture blood, yet 90.5% of visits who returned with a hemorrhagic stroke underwent CT. The sensitivity and specificity, especially the negative predictive value, of CT in stroke patients should possibly be re-evaluated in this population.

Indeed, there was a high amount of bounce backs that were hemorrhagic. While globally, only 13% of strokes are hemorrhagic, 50% of the study populations had a hemorrhagic stroke. One possible explanation is that strokes are not properly diagnosed. There is some evidence that the epidemiologic measurements of stroke type is incorrect; as imaging techniques have improved and use of anticoagulants has increased, rates of hemorrhagic stroke are likely higher [102]. The high rate of hemorrhage could have two alternative explanations. First, headache is a more likely symptom in hemorrhagic strokes than ischemic strokes. Second, perhaps the sensitivity of CT in capturing active bleeding is not as effective as previously thought. Literature has suggested that in patients with a thunderclap headache (classic presentation of a subarachnoid hemorrhage), sensitivity of CT has a range of sensitivity with an average of 85.7% with peak sensitivity occurring within 6 hours of headache ictus. Essentially, timing of CT becomes important in correctly imaging hemorrhage; complicating this, individual machines have their own sensitivity. It was recommended that follow up of negative imaging may be needed in headache patients (whether it be repeat scanning or lumbar puncture) [69, 103]. Perhaps sensitivity of imaging based on timing of symptom onset needs to be taken into account when creating decision making trees for care of headache patients who are highly suspected of having intracranial pathology. Creating a time table of symptom onset in relation to imaging timing would maximize sensitivity of CT, but may require the patient to be placed in an Observation Unit. Only 5% of the patients were placed in Observation. It is possible that symptoms could have evolved and imaging would have captured stroke if more had been observed.

Another notable finding is that having MRI in index ED visit was not predictive of returning with hemorrhagic stroke. This supports literature of MRIs poorer sensitivity in capturing active bleeding, but better sensitivity in capturing active ischemia [35]. Notably in the ischemic group, MRI and CT almost had the same predictive value. In fact, 11.4% of admissions in the ischemic group had undergone MRI. The dataset could not differentiate if the subjects underwent diffusion-weighted (DWI) versus perfusion-weighted (PWI) MRI. DWI is considered significantly better at predicting acute ischemic stroke than CT imaging, and better at predicting severity than PWI [104] . The type of MRI used could have had a small effect in the MRI results, the effect however would have been small, as it is accepted that PWI is accurate at detecting ischemic, just not as good at detecting severity.

The high rates of imaging in both groups, it implies that sensitivity in capturing active of impending disease is variable. Of the patients who bounced back with stroke, over half were seen the same day. Many had imaging, and it is most likely the imaging was negative, or they would not have been discharged. Negative predictive value of CT and MRI are not 100%. Whether the negative imaging with a patient who in actuality was having a stroke is related to interpretation error (unlikely), machine user error, what type of machine is used, or timing of symptom onset, this study could not examine these issues. In the cases of high clinical suspicion of pathology, perhaps these patients should be placed in observation for clinical follow up. Which follow up is most appropriate, most economical, and most accurate would have to be determined in a subsequent study, but likely high-suspect stroke patients would be either repeat imaging, different imaging, lumbar puncture, or merely watchful waiting. Observation stay would allow for any or all of these follow up modalities, and would save money over having a bounce-back stroke. Observation could also allow for better timing of diagnostic imaging based on symptom onset, as mentioned above. A diagnostic pathway flowchart could be created and incorporated into imaging ordering as CDS that advises appropriate follow up for negative CT in highly suspected patients, as headache is a self-reported symptom. Detailed exam is also critical to identifying these highly suspected patients. This will also be especially useful as imaging reads move to artificial intelligence, leading to more stream-lined consistency [105, 106]. Stroke is an ideal candidate for automated diagnosis given its small window for treatment.

Other than imaging, age was the most significant predictor of a missed stroke diagnosis with a large effect size. Age was significant for either type of stroke. This coincides with cardiovascular pathology and was an expected finding. Other patient level predictors that were significant had a small effect size; for example African-Americans were 40% less likely to return with a hemorrhagic stroke diagnosis. Interestingly, research has shown that African-Americans and Hispanics are more likely than whites to have both hemorrhagic stroke as well as ischemic stroke, likely due to increased rates of hypertension, diabetes, and other comorbidities [107]. Perhaps the lower rates of bounce back could imply that their symptoms are taken seriously given the known increased risk and, therefore, there was a less likely bounce-back. Another alternative explanation is that the strokes in a population with more comorbidities are more debilitating and the patient is less likely to be admitted for a stroke because they do not survive the event. Given, that African-Americans first stroke is more likely to be debilitating and fatal than their Caucasian counterparts, the latter is the more likely scenario [107]. This study was not linked with medical examiner results, which could have allowed fatal ED stroke events to be accounted for.

It is important to note that some patients fell into both ischemic and hemorrhagic groups. It is likely that these were initially ischemic patients who had bleeding events secondary to their treatment for ischemic stroke. As there is no timing on the dataset, it is impossible to distinguish what happened first. In any case this is an interesting subgroup of patients for further analysis. Certain risk factors for bleeding after treatment for ischemic have been established [108], but as therapies evolve, especially with the increased use of clot removal, these factors will have to be re-examined.

This dataset could not capture comorbidities (hypertension, diabetes, sickle cell disease, obesity, smoking) or other symptoms that may be indicative of stroke (such as altered mental status, hemiparalysis, droop, aphasia, etc). A chart review to examine how comorbidities and other symptoms coincide with headache and relate to imaging, and if the presence of these comorbidities make it more likely to return with a stroke would be worth examining. It would also be worth examining patients with other primary neurological complaints (dizziness, syncope, etc) to examine their negative predictive value of CT imaging for stroke; headache was isolated for this study given that it was the most common missed diagnoses in a previous study of missed stroke [73].

3.6 Limitations

Observational research using administrative data has limitations. In addition to those identified above, patient level factors that could have an impact on the outcome could not be examine or controlled for, such as comorbidities and associated symptoms. Secondly, physician level factors could not be controlled for, such as years of experience, type of residents that are examining the patients, type of physicians who are manning the ED, if there was a radiologist within the ED, and if there are on-call neurologists available in the hospital. Administrative data can contain errors as it is designed for billing. It is possible there were missed cases due to administrative error in this design. Also, patients could be incorrectly entered or not properly tracked, so some bounce-acks may have been missed. Since only 2013 data was used, persons who bounced back 30 days after December 31 (January 2014) would not have been included in this data, additionally those who presented with a headache in December 2012 were not included, leading to a partial loss of data.

This study only examined hospitals in a single state. Results should be generalizable to states similar to Maryland with diversity of urban and rural environments, but it is not globally generalizable. Practices may differ in states that are mostly rural, or in practices that utilize more mid-level providers, or in states where EDs are staffed by non-ED physicians. In Maryland, all the EDs had access to both CT and MRI; other states may not have that availability. It would be worth examining practice variation in states that do not have MRI as a resource, as well as practice variability by physician specialty.

In billing, headache is not an acceptable ICD-9 code to justify a head CT. The clinical indication could not be identified based on this dataset, and could have given insight into the patient presentation. Finally, almost 16% of the patients with headache complaints had more than one visit. If these were the patients that returned with a stroke diagnosis was not examined. For future study it would be worth examining if frequent fliers for headache have an increased risk for stroke or negative imaging.

3.7 Conclusions

Given the large number of patients who underwent imaging and were still found to have a stroke after discharge from the ED, reconsideration on how headache patients with high suspicions of intra-cranial pathology in the ED are treated and diagnosed may be needed. Negative imaging is not enough to guarantee there is no pathology. Perhaps in high suspicion, a 24-hour observational stay with appropriate follow up would be warranted. As over 50% of the persons who return with a stroke were in the emergency department the same day as their stroke diagnosis, these patients perhaps would not have been missed had they been placed in observation and allowed evolution of symptoms or timing for positive imaging. Observation units, while not big revenue for the hospital, are emerging ways to capture these potential bounce-backs and monitor patients while unclogging the ED. It would also be cost-effective, given the economic burden of stroke, especially without properly timed treatment. Watchful waiting has been embraced by the pediatric emergency community and is starting to be used in head injury in adults, perhaps it can be a follow up method in imaging in high suspicion stroke patients presenting with non-specific neurological symptoms.

CHAPTER 4: Appropriateness Criteria for Neuroimaging of Adult Headache Patients in the ED: How Are We Doing?[1]

4.1 Abstract

The American College of Radiology (ACR) developed Appropriateness Criteria (ACR-AC) for diagnostic imaging, to reduce overuse and promote high-yield, cost-effective, evidence-based medicine. For adult headaches, there are 16 variants with specific recommendations. Headache accounts for 4.5% of Emergency Department (ED) visits, and 61% of the complaints are chronic. Imaging for headaches has increased in the past 2 decades, with intracranial pathology diagnosis going down. Evidence suggests that there is poor knowledge of the ACR-AC among Advanced Practice Nurses (APN) and non-radiologist physicians. ACR-AC recommendations were examined using the Health Care Cost and Utilization Project State Emergency Department Data (HCUP SEDD) from Maryland in 2013. Imaging proportions were examined, as well as differences between residency program hospitals and hospitals that have APNs in the ED. Of the 11,109 chronic headache visits, a quarter underwent CT (26.9%) and 3.6% underwent Magnetic Resonance Imaging (MRI); ACR-AC does not recommend the use of either of these in chronic headache patients. There were significant practice differences related to whether it was a teaching hospital and whether APNs were employed in the ED or not. For post-traumatic headache patients, there were not significant differences in practice. CT was used in 76.4% of post-traumatic headache visits. It was unknown if the ACR-AC is being

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used in the ED. Post-traumatic headache protocol is well established in the ED, but chronic headache continues to be a problem in imaging overuse despite recommendations. Radiological education, including the ACR-AC, as well as radiation dosing and exposure information should be part of APN, physician, and RN education, as well as mandatory post-graduate continuing education. Afterwards the ACR-AC should be integrated into CDS to promote best imaging practices, alone the recommendations are too complicated to be used without an integrative system.

Keywords**:** ACR-AC, imaging, emergency department, nurse practitioner, overuse

4.2 Introduction

Headaches account for almost 4.5% of adult Emergency Department (ED) visits in the United States. Chronic headaches have a significant burden for patients and hospitals, account for 61% of headache complaints in the ED, and cost $17.2 billion in lost work annually [85-87]. While the American Headache Society (AHS) through *Choosing Wisely®* has been working to create treatment and imaging advise, there are no clinical decision support (CDS) tools for management and diagnosis in the acute care setting, which leads to inconsistency in treatment [55, 56, 109]. Minimizing imaging, especially Computerized Tomography (CT) use, is a priority for providers especially given the effect imaging has on patient radiation exposure, cost, length-of-stay, and complications related to incidental findings [37-40, 68]. CT is also targeted given its ease of use, speed over Magnetic Resonance Imaging (MRI), and it is widely available in most US EDs 24/7 (97% of EDs have on site access), leading to overuse potential [67]. Despite desires to reduce overuse, CT use has seen a 330% increase in 2008-2012, with a slight decrease in the inpatient setting since 2010, but no decrease in the ED [23, 24]. Specifically, imaging for headache is the second most increased imaging use in the ED after urinary calculi, with an increase from 17.5% to 33.3% from 1996-2014 [91]. Despite this increase, diagnosis of intracranial pathology has actually gone down, bringing into question diagnostic yield capability [68].

The American College of Radiology (ACR) developed Appropriateness Criteria (ACR-AC) for imaging in 176 clinical topics with over 883 variants [57]. The criteria were developed in the 1990s and are reviewed annually. They utilize an expert panel and evidence-based medicine for creation and editing the criteria [57]. The goal of the ACR-AC is to reduce inappropriate and unnecessary imaging and increase diagnostic yield [110].

For adult headache patients, the criteria address 16 different specific clinical scenarios. Ranks of appropriateness of different imaging (CT, use of contrast, MRI, arteriography, etc.) for persons presenting with headache with a variety of other symptoms are specified. For example, the criteria indicate that a person with chronic headache without new symptoms should not get CT without contrast (ranked 3 out of 10 for appropriateness), whereas a patient with a "thunderclap" headache has an appropriateness of 9 [20]. An example of two of the headache variant's ACR-AC recommendations is seen in Figure 4.1 [20].

Figure 4.1: American College of Radiology Appropriateness Criteria for headache examples

Clinical Condition: Headache

Variant 1: Chronic headache. No new features. Normal neurologic examination.

Radiologic Procedure	Rating	Comments	RRL*
MRI head without and with IV contrast	4		O
MRI head without IV contrast	4		O
CT head without IV contrast	3		☢☢☢
CT head without and with IV contrast	3		☢☢☢
CT head with IV contrast	3		☢☢☢
MRA head without and with IV contrast	2		O
MRA head without IV contrast	2		O
Arteriography cervicocerebral	2		☢☢☢
CTA head with IV contrast	2		☢☢☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Clinical Condition: Headache

Variant 3: Sudden onset of severe headache ("Worst headache of my life", "thunderclap headache").

Radiologic Procedure	Rating	Comments	RRL*
CT head without IV contrast	9		☢☢☢
CTA head with IV contrast	8		☢☢☢
MRA head without and with IV contrast	7		O
MRA head without IV contrast	7		O
Arteriography cervicocerebral	7		☢☢☢
MRI head without IV contrast	7	This procedure may be helpful after CT depending on CT findings. Include FLAIR and GRE or SWI in this procedure.	O
MRI head without and with IV contrast	6	Include FLAIR and GRE or SWI in this procedure. This procedure may be helpful after CT depending on CT findings.	O
CT head without and with IV contrast	5		☢☢☢
CT head with IV contrast	3		☢☢☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Douglas, A et al. American College of Radiology Appropriateness Criteria for Headache. 2013 Taken from https://acsearch.acr.org/docs/69482/Narrative/

The ACR-AC have been around for over 2 decades, with an overall increase in imaging rather than a global decrease. Given this increase, it calls to question whether or not they are being used and if there is provider knowledge of them. A 2016 systematic review found that there was likely underutilization of ACR-AC guidelines likely linked to poor education among providers about their existence, especially in undergraduate and graduate medical education [59]. A small survey found that medical residents only got 50% of survey questions correct about appropriate thoracic imaging, versus 75% for radiologist residents [92]. Education in both graduate and post-graduate medical education seems to be a barrier for use of the ACR-AC. A survey of PGY-1 residents found that 81% had never heard of ACR-AC [60] Findings are similar among advanced practice nurses (APN); 75% had never heard of ACR-AC [61], but more education and years of experience were correlated with better knowledge of appropriate radiology. There is a dissemination gap between radiologists and practicing clinicians, both at the practice level and the education level. Radiology residents are aware of the ACR-AC, but they are not being taught by faculty and there is a failure to disseminate to clinicians [111].

Not only is there lack of knowledge about the ACR-AC among non-radiologists, knowledge about radiation exposure is poor; even among ED physicians. While they take into account number of CT scans in repeat imaging decisions, they have poor understanding of dose and risk [47]. Lack of knowledge about cumulative exposure to radiation and cancer risk has been found in both ED physicians as well as mid-level providers [112]. Systematic review shows that there are significant knowledge gaps among physicians about radiation dose and exposure [113].

Previous research into the ACR-AC focused more on medical residents and medical students rather than emergency room residents or ED APNs, where imaging choices often have to be made more quickly and the ACR-AC could be a useful reference tool. Research has also focused on education interventions and surveys, rather than examining gross usage in specific groups. There has not been research on the use of headache criteria specifically, where imaging is still increasing [91]. This study examines imaging use in the ED for headache patients presenting with two specific clinical scenarios covered by the ACR-AC: chronic headache without new symptoms, and post-traumatic headaches. This descriptive study examines the frequency of imaging use compared to the ACR-AC recommendations, as well as determines if there is a difference between hospitals that employ any residents or ED specific APNs.

4.3 Methods

This study used data obtained from the Health Care Cost and Utilization Project (HCUP). The HCUP compiles data from state data organizations, private data organizations, and the Federal government and makes them available to researchers [81]. The 2013 Maryland HCUP State Emergency Department Database (SEDD) represents visits to hospital-affiliated emergency departments that do not result in hospitalization [82]. Variables in the SEDD are typical of those in a hospital discharge abstract. The clinical data are majorly represented in diagnosis and procedure codes. A hospital identifier allows linkage to the 2012 American Hospital Association (AHA) Annual Hospital Survey, allowing examination of hospital level factors[84].

All adult (≥18 years) patients diagnosed and discharged with a chronic headache or a post-traumatic headache in Maryland EDs in 2013 were included. Chronic headaches with no new symptoms were defined as specific diagnosed chronic headache disorders (including migraines) without new symptoms, and post-traumatic headache are self-explanatory. International Classification of Disease Clinical Modification (ICD-9-CM) were used to select visits with a headache diagnosis (see Appendix E). Maryland SEDD has the potential for 50 diagnosis variables per case. CT imaging is recorded as Current

Procedural Terminology (CPT) codes. CPT codes identified for imaging diagnostic procedures are in Appendix A and include CT, MRI, Magnetic Resonance Arteriography (MRA), Computerized Tomography Arteriography (CTA), and Cerebrovascular Angiography (CA). As CPT codes are used for billing, the CPT data are considered reliable; this was also verified in personal communication with the HCUP help desk.

Demographic variables recorded in the HCUP data were examined including age, gender, and race. Hospital characteristics examined include MRI and CT availability, residency program, and APN availability in the ED. The AHA does not specify resident type, so the measure of teaching was having at least one active residency program. Over 75% of hospitals typically participate in this annual survey. No hospitals in the SEDD dataset failed to respond to the survey. All the hospitals had both MRI and CT available. Frequencies were reported with chi-square testing used to determine if there was a difference in practice between hospitals that employ residents versus those that do not and hospitals that employ APNs in the ED and those that do not.

4.4 Results

In 2013, there were 11,109 adult patients the ED with a complaint of chronic headache and 423 adult post-traumatic headache visits. Table 4.1 summarizes the hospital, patient, and imaging characteristics by the type of headache for those patients. Almost a third of the chronic headache patients were at a hospital with residency programs (30.6%) and a fifth were seen in a hospital that had an APN in the ED (20.1%). In the post traumatic group, almost half (40.9%) were seen in a hospital with a residency program and almost a third (31.4%) were seen at a hospital that employed APNs in the ED.

Table 4.1: Hospital, Patient, and Imaging Characteristics of Patients Complaining of Chronic Headache and Post-Traumatic Headache

	Chronic Headache (n=11109)	Post-traumatic headache (n=423)
Seen in Hospital with Residents	3399 (30.6%)	173 (40.9%)
Seen in Hospital with ED APNs	2240 (20.1%)	133 (31.4%)
Any CT	2992 (26.9%)	323 (76.4%)
CT without contrast	2964 (26.6%)	322 (76.2%)
CT with contrast	10 (0.1%)	0 (0%)
CT with and without	21 (0.2%)	1 (0.2%)
Any MRI	402 (3.6%)	9 (2.1%)
MRI with contrast	3 (0%)	0 (0%)
MRI without contrast	248 (2.2%)	5 (1.2%)
MRI with and without	159 (1.4%)	4 (0.9%)
CT and MRI	287 (2.6%)	6 (1.4%)
MRA without contrast	187 (1.7%)	4 (0.9%)
MRA with contrast	10 (0.1%)	0 (0%)
MRA with and without contrast	3 (0%)	0 (0%)
Age 18-44	2808 (70.3%)	284 (67.1%)
45-64	2946 (26.5%)	100 (23.6%)
65-74	291 (2.6%)	18 (4.3%)
75+	64 (0.6%)	21 (5.0%)
Female	9258 (84.2%)	257 (60.8%)
Race White	6284 (56.6%)	213 (50.4%)
Black	3628 (32.7%)	148 (35.0%)
Hispanic	488 (4.4%)	39 (9.2%)
Other	369 (3.3%)	14 (3.3%)

Any type CT (with or without contrast) was used in 26.9% of chronic headache visits and 76.4% of post-traumatic headache visits. Specifically, CT without contrast was used for 2964 chronic headache patients (26.6%), and 322 (76.2%) post-traumatic headache patients. The ACR-AC recommends a 3 (usually not appropriate) for non-contrast CT in chronic headache and an 8 (usually appropriate) for post-traumatic headache. Any type of MRI (with or without contrast) was used in 3.6% of chronic headache visits (2.2% without contrast, 1.4% with and without) and 2.1% of post-traumatic headache visits (1.2% without contrast, 0.9% with and without). The ACR-AC recommends MRI without contrast as 4 (may be appropriate) for chronic headache and 7 (usually appropriate) for post-traumatic headache. The highest recommended test by the

ACR-AC for chronic headache is for MRI with or without (4), but the highest percentage of patients underwent CT without contrast (ACR-AC 3). For the post-traumatic headache group, the highest percentage of patients underwent CT without contrast, which is also the highest recommended test (ACR-AC 8). Both CT and MRI were used in 2.6% of chronic headache patients and 1.4% of post-traumatic headache patients. The ACR-AC does not give a recommendation for combination testing.

For the chronic headache group, there was a significant practice difference between residency program hospitals versus not in ordering CT without contrast (χ^2: 45.21, <.001), as well as a significant difference between hospitals that employed ED APNs and those that did not (χ^2 :19.89, .001); 26.6% of persons got a CT without contrast, versus 29.7% in APN hospitals and 30.9% in residency hospitals (Table 4.2). There was a significant difference in MRI without contrast ordering in ED APN vs non-APN hospitals (χ^2: 9.51, .009) and residency vs non-resident hospitals (χ^2: 5.05, .025). There was not a significant difference in order practices in any category for the post-traumatic headache group (Table 4.3).

Table 4.2: Frequencies of undergoing neuroimaging for chronic headache with no new symptoms (n = 11109)

	ACR	n(%)	APNs in ED (n=2240)	χ^2, p	Residency Program (n=3399)	χ^2, p
CT without contrast	3	2964 (26.6%)	666 (29.7%)	**19.89, .001**	1051 (30.9%)	**45.21, .001**
MRI head without IV contrast	4	248 (2.2%)	31 (1.4%)	**9.51, .009**	92 (2.7%)	**5.05, .025**
MRA head without IV contrast	2	187 (1.7%)	51(2.3%)	6.89, .142	97 (2.8%)	**41.65, .001**
MRI with and without	none	159 (1.4%)	43 (1.9%)	5.60, .061	70 (2.1%)	**13.69, .001**
CTA head with IV contrast	2	46 (0.4%)	11 (0.5%)	2.46, .292	17 (0.5%)	.880, .348
CT with and without IV contrast	3	21 (0.2%)	6 (0.3%)	.007, .934	4 (0.1%)	1.32, .250
CT with IV contrast	3	10 (0.1%)	1 (0.0%)	4.25, .119	3 (0.1%)	.002, .967
MRA with IV contrast	none	10 (0.1%)	1 (0%)		1 (0%)	
MRI head with IV contrast	4	3 (0%)	0 (0%)		1 (0%)	
MRA head with and without	2	3 (0%)	2 (0.1%)	4.18, .124	2 (0.1%)	1.84, .175

note: ACR-AC is ranked 1-10 for appropriateness, 1-3 usually not appropriate, 4-6 May be appropriate, 7-10 usually appropriate. Chi-square used but not calculated in cases of small cell size

Table 4.3: Frequencies of undergoing neuroimaging for post-traumatic headache (n=423)

	ACR	n(%)	APNs in ED (n=133)	χ^2, p	Residency Program (n=173)	χ^2, p
CT without contrast	8	322 (76.1%)	109 (82.0%)	7.66, .105	140 (80.9%)	3.75, .153
MRI head without IV contrast	7	5 (1.2%)	1 (0.8%)	3.69, .158	3 (1.7%)	.764, .382
MRA head without IV contrast	5	4 (0.9%)	1 (0.8%)	2.45, .294	2 (1.2%)	.138, .710
MRI with and without	none	4 (0.9%)	2 (1.5%)	.687, .709	2 (1.2%)	.138, .710
CT with and without IV contrast	5	1 (0.2%)	0(0%)		0 (0%)	
CTA head with IV contrast	5	1 (0.2%)	0 (0%)		0 (0%)	

note: ACR-AC is ranked 1-10 for appropriateness, 1-3 usually not appropriate, 4-6 May be appropriate, 7-10 usually appropriate. Chi-square used but not calculated in cases of small cell size

4.5 Discussion

Previous research has indicated that there is variability in following the ACR-AC. Whether the criteria are followed based on knowledge of the ACR-AC versus previous knowledge of best practice could not be determined from this data. Certainly, the research indicates that there is a lack of knowledge about the recommendations among providers, both physician and APN [61, 109]. This is further complicated by a lack of understanding about the risks radiation exposure, especially cumulative dosing effect [47, 112, 113].

The results were mixed. Post-traumatic headache patients were imaged correctly according to criteria; however, that is not a surprising finding, given that post-acute injury CT is a normal part of protocol after trauma in order to examine for traumatic brain injury (TBI), especially when the patient is displaying symptoms (ie: headache) [114]. The fact that the percentage of patients imaged wasn't higher could be due to timing of the injury and timing onset of the headache. Female gender (which was 60.8% of the population) is a known risk factor for chronic post-traumatic headache, and the data were not differentiated into acute versus chronic cases [115]. Interestingly, post-traumatic headache was not related to finding or not finding evidence of TBI in CT imaging in a recent study [116].

Imaging is not generally recommended after mild pediatric concussion in the absence of other risk factors (nausea, vomiting, loss of consciousness etc.) [117] The ACR-AC includes recommendations for head trauma in children, but not pediatric post-traumatic headache [118]. This is an oversight, especially given the level of detail in the adult headache category, and given the global prevalence of pediatric TBI [119]. This particular study did not include pediatrics, nor was the data sufficient to examine the effect that secondary symptoms may have played on imaging practice.

In chronic headaches, an area where *Choosing Wisely®* has also recommended that patients not undergo imaging [109], 26.9% of patients underwent CT and 3.6% underwent MRI. CT without contrast is considered "usually not appropriate" by the ACR-AC for chronic headache, yet a quarter of patients underwent CT. MRI without contrast is considered "may be appropriate" according to the ACR-AC, but still ranked only 4 out of 10. The results also showed differences of practice in residency hospitals and centers that employed APNs. The residency designation in the AHA states that a hospital has a residency program if it has any single program, it is unknown from the dataset what specialty residents were seeing patients, which is important to note. Either way, previous research has made it clear that there needs to be better training about the ACR-AC among non-radiologists. The relatively high percentage of patients imaged for chronic headache, supports the literature that either recommendations aren't being followed, or are unknown.

As stated above, the dataset did not allow for evaluation of co-morbidities, which could have influenced imaging use.

The ACR-AC are evidence-based driven criteria that can be used to diminish overuse and promote cost-effective high-yield safe imaging. Yet, there is a failure in implementation and strategy for disseminating this critical information to non-radiologists. This dissemination gap is two-fold. First, is a lack of education among non-radiologist physicians, APNs, and registered nurses (RNs) during training and in continued education (CE). This could be solved by including radiology electives in all physician specialties, as well as in APN programs, as well as making mandatory CEs in the ACR-AC. It needs to be integrated into the education consistently, as single education intervention has been found to not be effective [120]. For example, it has already been demonstrated that teaching radiology as an elective in medical school increases medical student's ability to identify appropriate imaging [93]. APNs should be no different, especially as they continue to move in the primary care setting and will have many patients who have history of exposure to radiation. RNs working in acute care settings should be aware of the ACR-AC as well as radiation exposure, and could potentially act as a barrier and patient advocate to prevent inappropriate imaging. Both knowledge of the ACR-AC as well as training regarding radiation exposure and dosing needs to be promoted in all three of these provider populations, and needs to be targeted in pre-practice education, and mandatory continuing medical education credits.

The second issue relates to practice where, there is a lack of evidence-based clinical decision support (CDS) that incorporates the ACR-AC. As the recommendations are evolving, content learned in school may not be relevant years later in practice. When ordering imaging for a specific clinical condition, integrative CDS could be used to prompt the user and regurgitate prospective yield as well as recommendations. The ACR-AC on their own are too complicated and not user-friendly, and in the acute-care setting, especially the ED, a quick reference is more likely to be used. One study found that inserting ACR into a computer based ordering system slightly increased appropriating ordering among non-specialist physicians [121]. Such user-friendly systems should be common-place in order to promote best practice, lower cost, and enhance patient outcomes and safety.

This research was limited as it was based on observational administrative data. Future examination would be better done through chart review in order to examine co-morbidities and reduce measurement error. Administrative data can always have coding errors as it is primarily compiled for reasons other than research. Only 2 of the 16 headache recommendations were examined in this study, it would be worth examining the entire group of recommendations, and some of the methods in this study may be useful to at least describe the congruency of practice with the ACR-AC. This study only examined a single state ED data; practice may differ in more rural states where there is not as much access to MRI and there may be non-ED specialists staffing the ED. The study was also limited in that it was not a typical appropriateness study that has more extensive clinical data and expert reviewers. The purpose of this study was descriptive although it is recognized that more detailed analysis of patient data must be done to better study appropriate adoption of the ACR-AC. In any case, the ACR-AC needs to be better integrated into all levels of healthcare through a specific strategy and implementation outside of the specialization of radiology.

CHAPTER 5: Summary and Next Steps

This dissertation's aims were to examine overuse of head CT in adult headache patients in the Emergency Department (ED), determine characteristics of its use, determine if using neuroimaging is associated with missed diagnosis of stroke, and determine if the ACR-AC are being used in decision making for neuroimaging. This chapter summarizes the major findings, identifies limitations, and proposes implications for policy, research and clinical practice for each study objective.

5.1 CT Use in Headache Patients

When examining what patient and hospital factors drove head CT use, age was the only variable to have a large effect size, coinciding with cardiovascular pathology. As women are more likely to have chronic headaches given the link with hormones [62], and that 18% of women experience migraines versus 6% of men [99], 70% of the headache population being female was not a surprising result. Despite women being the large majority of headache visits, they were 30% less likely to be imaged. This could be due to the fact that their headaches are more commonly chronic, or the fact that women are less likely to have their pain taken less seriously, yet more likely to be prescribed analgesics in the ED [97, 98]. The results suggest that headache complaints in women are more likely to be perceived as chronic by a provider, and thus less likely to be imaged, which coincides with recommendations from *Choosing Wisely®* and the ACR-AC [20, 109].

There was between hospital variation in CT use of 17-60% among Maryland hospital-based EDs, hospital level only explained 6.0% of CT use variability. Clustering at the visit level accounted for 28% of the variability, there were 10,230 (out of 63,942) visits that were repeat patients with the same headache complaint to the ED in a single year. Despite the decent percentage (16%) of visits being non-single time users, there were only 1643 individuals that accounted for repeat visits. The cause of the high variability of CT use per visit likely lies in a small part due to physician level factors (years of experience, confidence, type of provider), and mostly due to patient level factors that were uncaptured in the data (secondary symptoms). Previous research has indicated that physician level factors account for less than 5% of the variation in all CT use, so patient level factors would be a next step in analysis [64]. In order to truly study physician and patient level variation in head CT use, medical record data would have to be used.

The dataset used to examine influencers of head CT included only visits in which a patient was discharged from the ED to home. It must be assumed that of the visits that underwent imaging, the imaging must have been negative, or else it would have warranted a hospital admission, or at the least an observation unit stay. If that had happened, these cases would not have been in the dataset, so this is a limitation to this study, as there is not an ability to compare positive finding groups and negative finding groups. Almost half (43%) of the visits that underwent CT likely had a negative finding and then were discharged, but it is unknown how many visits had positive findings and were admitted. This is concerning as the test may have been unnecessary and led to unneeded radiation exposure and cost. There needs to be more research into maximizing positive predictive value of imaging and yield in headache patients in order to better utilize CT. This would again require looking at patient level factors in a chart review. As evidence on patient, provider, and hospital characteristics that influence imaging use in headache patients increases, they can be linked to ACR-AC criteria to create evidence-based CDS.

5.2 Missed Diagnosis of Stroke

As was found in examining influencers for head CT use, age was the most significant predictor for bouncing-back with a missed diagnosis of stroke. For all types of stroke, CT was used in 82.2% of index visit for headache patients. Persons were significantly more likely to bounce back with any stroke if they received CT neuroimaging in their initial discharged-to-home ED visit. It is likely the provider had suspicion of intra-cranial pathology, if imaging was used, yet also likely the imaging was negative as these headache visits were discharged. Since more than half of the patients were seen in the 24 hours before their stroke diagnosis, imaging should have been able to detect pathology if CT had that capability. While it is known that CT is not as effective at capturing active ongoing ischemia, it should be able to capture blood, yet 90.5% of visits who returned with a hemorrhagic stroke underwent CT for their index headache visit. The sensitivity and specificity of CT in stroke patients should possibly be re-evaluated for negative predictive value for stroke.

Globally, only 13% of strokes are hemorrhagic, yet 50% of the study population had a hemorrhagic stroke. There already is some evidence that the previous epidemiologic data on stroke differentiation may be outdated. As imaging has improved and use of anticoagulants has increased, rates of hemorrhagic stroke are not only likely higher, but also more likely to be captured [102]. Headache is also more likely symptom in hemorrhagic strokes than ischemic strokes, which could have influenced the high percentage of hemorrhage in this dissertation. The results in any case bring into question the sensitivity of CT in capturing active bleeding. Previous literature has suggested that in patients with a thunderclap headache (classic presentation of a subarachnoid hemorrhage), CT sensitivity is variable and subject to timing of headache ictus. Further complicating this, different CT machines can also have differing sensitivities in capturing blood [69, 103]. Perhaps sensitivity of imaging based on timing of symptoms needs to be taken into account when creating decision making trees for care of headache patients who are highly suspected of having intracranial pathology. In any case, CT imaging cannot be completely relied upon for negative prediction of stroke in a headache patient.

Overall, given the high rates of imaging in both the ischemic and hemorrhagic groups, CT sensitivity is likely variable. Of the patients who bounced back with stroke, over half had been evaluated and discharged from the ED in the prior 24 hours. Negative predictive value of CT and MRI are not 100%. Whether the negative imaging in a patient who was actually having a stroke has to do with interpretation error, machine use error, the type of machine is used, or timing of symptom onset and imaging, none of these could be determined from this dataset. In the cases of high clinical suspicion of pathology, perhaps these patients should be placed in observation for clinical follow up. Which follow up is most appropriate, most economical, and most accurate would have to be determined in subsequent studies. Alternatives could include repeat imaging (based on symptom timing), different imaging, lumbar puncture, or watchful waiting. Efficacy of these techniques as well as a cost-effective-analyses should be done.

It is important to note that some patients had diagnoses of both ischemic and hemorrhagic stroke on their inpatient admission. It is likely that these were initially ischemic patients who had bleeding events secondary to their treatment for, or a complication of ischemic stroke. As there is no timing of diagnoses in the dataset, it was impossible to distinguish what happened first. In any case this is an interesting subgroup of patients for further analysis. Certain risk factors for bleeding after treatment for ischemic have been established [108], but as therapies evolve, especially with the increased use of intra-arterial clot removal, these factors will have to be re-examined.

Another limitation is related to comorbidities. The ED data do not consistently capture comorbidities (hypertension, diabetes, sickle cell disease, obesity, smoking) or other symptoms that may be indicative of stroke (such as altered mental status, hemiparalysis, droop, aphasia, etc.). Similar to the CT influencers of use study, there should be chart review to examine how comorbidities and other symptoms coincide with headache and relate to imaging yield, and if the presence of these comorbidities make it more likely to return with a stroke.

5.3 Use of the ACR-AC

While the ACR-AC have appropriateness scores of certain imaging for specific patient scenarios, they do not take into account the wide number of comorbidities and secondary diagnoses that may influence CT decisions for an ED provider (nausea, changes in vision, diminished affect, hypertension etc.). Further complicating the ACR-AC is the fact that it does not seem to be routinely used by non-radiologist, and there is an education gap in providers, both physicians and APNS. [59, 61, 92, 109]. In addition to not being educated about the ACR-AC, providers have a poor understanding of radiation exposure and dosing effect [47, 112, 113]. Detailed chart review determining high diagnostic yield comorbidities could further be integrated with the ACR-AC to create evidence-based CDS that is integrated within a radiology-ordering system. The ACR-AC on their own are somewhat complicated and not user-friendly for implementation in acute-care settings. Developing a quick reference or an electronic algorithm would be more useful. One study found that inserting ACR-AC into a computer based ordering system slightly increased appropriating ordering among non-specialist physicians [121]. Such user-friendly systems should be common-place in order to promote best practice, lower cost, and enhance patient outcomes and safety. In addition to improving the ACR-AC and making them more user-friendly, education about their existence as well as education about radiation exposure are needed.

Education intervention for non-radiologist practitioners about the ACR-AC and radiation exposure has to be continuously integrated into clinical education for RNs, APNs, and physicians. It also must be integrated into mandatory continuing education for practitioners. Single education interventions to increase ACR-AC use have been found to not be effective, so comprehensive education is warranted [120]. Integrating a radiology elective into medical education has been demonstrated to be effective at instructing physicians to choose correct diagnostic testing; a similar approach is needed for APNs [93]. As APNs assume increasing responsibility for primary care and also continue to work in acute care, understanding correct diagnostic testing and radiation exposure will become even more critical. The same training should also be given to RNs who work in acute care settings. RNs already act as a patient advocates, and understanding radiation exposure is another level they could act on this important role. Like physicians, RNs and APNs need to embrace the ACR-AC in order to promote patient safety.

The data only allowed for examination of 2 out of 16 of the recommendations for adult headache put forth by the ACR-AC. In addition, it is unknown which providers ordered testing on patients, or if when the provider correctly ordered testing it was due to knowledge of the ACR-AC. There should be further study into rates of ACR-AC compliance in headache patients and barriers to compliance. Headaches had not previously been studied specifically in relation to the ACR-AC. Practice differences by provider type (non-radiologist physician, ED physician, resident physician, attending physician, APN) could also be examined. This information would be useful in designing education interventions to promote the ACR-AC and considerate radiology use.

5.4 Limitations

Some limitations for each manuscript were discussed in their respective chapters as well as identified above. Related across all manuscripts, research always includes bias, and observational research has more bias than an experimental design. Using administrative data has several sources of bias, mostly related to lack of clinical detail and influences on what gets documented in a medical record. This made it difficult to isolate subgroups of headaches and adequately model confounders, especially comorbidities. There are also physician and hospital factors that could be confounding the relationships examined (such as physician experience and education, whether there are on-call neurologists, if CT is available directly within the ED, etc.). There is also potential for coding errors with this type of research. Overall, despite the limitations of administrative data, it still offers a rich database for studying some problems and settings [122].

Another limitation is the use of a single states dataset, which limits the generalizability of this research. Maryland is not representative of all other states, and all the EDs studied (n=44) had access to both CT and MRI on-site. Practice may differ in more rural states or where there is not quick access to diagnostic imaging or where there are non-ED physicians staffing EDs. While Maryland has a unique hospital reimbursement model, there are no reasons to think that this – or other regional practices - influenced diagnostic workup for headaches. Despite the limitations of using a single state's data, all

ED visits to the states' hospitals were included. Furthermore, the HCUP linkage variable to subsequent inpatient admissions allowed a population-based view of the study sample. Admittedly, it is possible that some stroke patients were seen in bordering states, so there was likely data loss. However, Maryland is one of 12 states that allows for this linkage over time and unit and HCUP provides invaluable information on utilization research.

5.5 Research and Clinical Implications

Five studies were identified that could advance the knowledge in this topic area: using chart review to determine patient and physician level predictors for maximum yield of head CT in headache patients; using chart review to determine patient level predictors in missed diagnosis of stroke in headache patients; examining timing of neuroimaging in terms of yield and negative predictive value for stroke, especially hemorrhagic; and, examining follow up of negative imaging with either lumbar puncture, repeat imaging, different imaging, or watchful waiting to prevent missed diagnosis of stroke, and cost-comparison, cost effectiveness, and cost benefit-analysis of appropriate imaging and follow up, specifically the cost of observation versus prevention of missed diagnosis.

From a clinical perspective, improving the ACR-AC to create interactive CDS may improve appropriate use of imaging. The importance of improving education about the ACR-AC and radiation exposure for non-radiologist physicians, APNs, and RNs was also highlighted, not only does the ACR-AC need to be integrated into pre-practice education for all groups, but also should be part of mandatory continuing education for providers. Education and proper dissemination will allow this powerful resource to be utilized. Placing patients with high-suspicion of stroke pathology into observation instead of discharge after negative imaging could be done on a pilot basis to determine efficacy. A decision-making tree that involves follow up while in observation would be established, possibilities would include lumbar puncture, timed imaging based on symptom ictus, watchful waiting, or different/repeat imaging. A cost-comparison should be performed as well, as the cost of missed stroke is so high and is not reimbursed by CMS. Clearly, changes need to be made to current practice regarding imaging in headache patients, radiological education among non-radiologist providers, and relying on negative predictive value of neuroimaging.

Appendices

Appendix A: ICD-9 and CPT codes used in Chapter 2

Headache Diagnosis	ICD-9-CM Diagnosis Code
Headache, Generalized	7840
Cluster headache syndromes	339 3390 33900 33901 33902 33903 33904
Migraines	3460 34600 34601 34602 34603 3461 34610 34611 34612 34613 3462 34620 34621 34622 34623 3464 34630 34631 34632 34633 3464 34640 34641 34642 34643 3465 34650 34651 34652 34653 3467 34670 34671 34672 34673 3468 34680 34681 34682 34683 3469 34690 34691 34692 34693
Short lasting unilateral neuraligform headache with conjunctival injection	33905
Other trigeminal autonomic cephalgias	33909
Tension type headaches	3391 33910 33911 33912
Post-traumatic headaches	3392 33920 33921 33922
Drug induced headache	3393
Complicated headache syndromes	3394 33941 33942 33943 33944
Other specified headache	3398 33981 33982 33983 33984 33985 33989
Diagnostic Imaging Procedure	CPT Code
Computerized Tomography (CT)	70460 70450 70470
Magnetic Resonance Imaging (MRI)	70551 70552 70553

Appendix B: Questions used from the AHA Annual Survey, Chapter 2

Question #	Hospital Level Variable
C44a	Emergency Department Classification
C44e	Trauma Center Classification
C83a	CT scanner
C83e	MRI available
A80	Residency Program Accredited by AMA

Appendix C: Definitions of diagnoses using ICD-9-CM Codes, Chapter 3

Headache Diagnosis	ICD-9-CM Diagnosis Code
Headache	7840
Cluster headache syndromes	339 3390 33900 33901 33902 33903 33904
Migraines	3460 34600 34601 34602 34603 3461 34610 34611 34612 34613 3462 34620 34621 34622 34623 3464 34630 34631 34632 34633 3464 34640 34641 34642 34643 3465 34650 34651 34652 34653 3467 34670 34671 34672 34673 3468 34680 34681 34682 34683 3469 34690 34691 34692 34693
Short lasting unilateral neuraligform headache with conjunctival injection	33905
Other trigeminal autonomic cephalgias	33909
Tension type headaches	3391 33910 33911 33912
Post-traumatic headaches	3392 33920 33921 33922
Drug induced headache	3393
Complicated headache syndromes	3394 33941 33942 33943 33944
Other specified headache	3398 33981 33982 33983 33984 33985 33989
Cerebrovascular Disease Diagnoses	ICD-9-CM Diagnosis Code
Acute cerebrovascular disease	34660 34661 34662 34663 430 431 4320 4321 4329 43301 43311 43321 43331 43381 43391 4340 43400 43401 4341 43410 43411 4349 43490 43491 436
Intracranial hemorrhage	430 431 4320 4321 4329
Occlusion of cerebral arteries	43301 43311 43321 43331 43381 43391 4340 43400 43401 4341 43410 43411 4349 43490 43491
Acute, but ill-defined cerebrovascular accident	34660 34661 34662 34663 436
Occlusion or stenosis of precerebral arteries	4330 4331 43310 4332 43320 4333 43330 4338 43380 4339 43390
Other and ill-defined cerebrovascular disease	4370 4371 4373 4374 4375 4376 4377 4378 4379
Transient cerebral ischemia	4350 4351 4352 4353 4358 4359

Appendix D: Definitions of procedural using Current Procedural Terminology (CPT) Codes, Chapter 3

Diagnostic Imaging Procedure	CPT Code
CT	70460 70450 70470
MRI	70551 70552 70553
MRA	70544 70545 70546
CTA	70496
Cerebrovascular Angiography	36221-36228

Appendix E: ICD-9-CM and CPT codes to represent diagnoses and procedures for Chapter 4

Headache Diagnosis	ICD-9-CM Diagnosis Code
Chronic headaches, including migraines	3460 34600 34601 34602 34603 3461 34610 34611 34612 34613 3462 34620 34621 34622 34623 3464 34630 34631 34632 34633 3464 34640 34641 34642 34643 3465 34650 34651 34652 34653 3467 34670 34671 34672 34673
Post-traumatic headaches	3392 33920 33921 33922
Diagnostic Imaging Procedure	CPT Code
Computerized Tomography (CT)	70460 70450 70470
Magnetic Resonance Imaging (MRI	70551 70552 70553
Magnetic Resonance Angiography (MRA)	70544 70545 70546
Computerized Tomography Angiography (CTA)	70496
Cerebrovascular Angiography	36221-36228

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