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ORIGINAL ARTICLE

Longitudinal changes in the US emergency department use of advanced neuroimaging in the mechanical thrombectomy era

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Abstract

Purpose To describe ED neuroimaging trends across the time-period spanning the early adoption of endovascular therapy for acute stroke (2013–2018).

Materials and methods We performed a retrospective, cross-sectional study of ED visits using the 2013–2018 National Emergency Department Sample, a 20% sample of ED encounters in the United States. Neuroimaging use was determined by Common Procedural Terminology (CPT) code for non-contrast head CT (NCCT), CT angiography head (CTA), CT perfusion (CTP), and MRI brain (MRI) in non-admitted ED patients. Data was analyzed according to sampling weights and imaging rates were calculated per 100,000 ED visits. Multivariate logistic regression analysis was performed to identify hospital-level factors associated with imaging utilization.

Results Study population comprised 571,935,906 weighted adult ED encounters. Image utilization increased between 2013 and 2018 for all modalities studied, although more pronounced in CTA (80.24/100,000 ED visits to 448.26/100,000 ED visits ($p < 0.001$)) and CTP (1.75/100,000 ED visits to 28.04/100,000 ED visits $p < 0.001$)). Regression analysis revealed that teaching hospitals were associated with higher odds of high CTA utilization (OR 1.88 for 2018, $p < 0.05$), while low-volume EDs and public hospitals showed the reverse (OR 0.39 in 2018, $p < 0.05$).

Conclusions We identified substantial increases in overall neuroimaging use in a national sample of non-admitted emergency department encounters between 2013 and 2018 with variability in utilization according to both patient and hospital properties. Further investigation into the appropriateness of this imaging is required to ensure that access to acute stroke treatment is balanced against the timing and cost of over-imaging.

Keywords Stroke · Advanced neuroimaging · CT perfusion · CT angiogram · MRI

Introduction

Emergency Department (ED) cross-sectional imaging use has dramatically increased in recent decades [1, 2]. ED CT utilization trends in the United States demonstrated exponential growth in the early 2000s, [3] with subsequent flattening between 2007 and 2017 [4]. Contributing to these overall trends has been the evolving emergency use of cross-sectional neuroimaging, specifically in the evaluation of patient presentations clinically suggestive of ischemic or hemorrhagic stroke and transient ischemic attack (TIA).

Thrombolytic therapy for acute ischemic stroke (AIS) - administered within the first 3–4.5 h after onset of symptoms - has been a treatment mainstay since 1995 [5]. Current recommendations promote a 30-minute ED arrival to treatment time target (door-to-drug time) [6]. Neuroimaging must be accomplished within this time window to exclude alternate, particularly hemorrhagic, causes of presenting clinical deficits. The compressed time for evaluation and treatment requires increased utilization of cross-sectional neuroimaging in a substantial population – accepting a lower specificity for neuroimaging to achieve greater sensitivity in early identification and treatment for AIS. Endovascular therapy (EVT) has further expanded this activity by providing treatment options for stroke patients out to 24 h from symptom

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onset. [7–11] Selection of appropriate patients for EVT, however, requires identification of a large vessel occlusion (LVO) and a high probability of salvageable penumbral tissue. This has expanded use of advanced neuroimaging techniques including CT angiogram (CTA), CT perfusion (CTP), and Magnetic Resonance Imaging (MRI) [8, 11–14].

Similarly, the evaluation of patients with hemorrhagic stroke has evolved towards greater reliance on CT angiography as part of initial evaluation, although professional society recommendations on this practice vary [15–17].

Complicating these testing patterns for acute stroke evaluation in the ED are less clear presentations such as TIA, a condition with resolution of neurologic symptoms which can create uncertainty regarding the optimal ED management particularly around the use of diagnostic neuroimaging and follow-up care [18]. Studies investigating ED imaging evaluation for TIA found that the majority of discharged patients do not receive guideline-compliant neuroimaging during their ED visit, and may not complete it in the subsequent outpatient setting [19, 20]. Evidence also suggests frequent redundant imaging, and professional-society level efforts in emergency medicine have attempted to streamline low-yield neuroimaging use [21, 22].

Therefore, understanding ED neuroimaging use and changes over time provides the potential for improvement in individual patient care and regional stroke systems of care by optimizing patient treatment opportunities and improving access and resource utilization. In this study, we evaluate national trends in advanced neuroimaging use between 2013 and 2018 in patients seen and discharged from the ED. We focus in particular on the discharged cohort as these patients are most likely to have experienced transient or resolving symptoms, but to have had stroke considered as part of their differential diagnosis, resulting in greater variation in care patterns. Furthermore, we examine patient- and hospital-level explanatory factors associated with differences in neuroimaging use in this population.

Materials and methods

Setting and selection of participants

This is a retrospective, cross-sectional study examining advanced neuroimaging use in the ED setting in the United States using the National Emergency Department Sample (NEDS) dataset, a sample of hospital-owned ED visits, part of the Healthcare Cost and Utilization Project [23]. This study was determined to be exempt and not regulated by our institutional IRB. The NEDS dataset represents a 20% sample of ED encounters in the US each year and utilizes a complex survey design to generate nationally representative results. For each of the years studied (2013–2018), the NEDS contains approximately 140,000,000 weighted encounters with an admission rate of about 14% [23]. Each encounter contains a unique identifier linking patient-level administrative data (e.g., age, gender, date of presentation, national quartile of median income by patient zip code); encounter event data (diagnosis, imaging, and testing patterns); and hospital-level data (e.g. teaching status, size, volume). Data from patients ≥ 18 years of age from January 2013 to December 2018 and not admitted to the same hospital were obtained from the NEDS data set. This time-period was selected to capture the most likely inflection point of imaging trends following thrombectomy study results and guideline changes [24]. Adult patients were selected because the most dynamic indication during this time-period for CTA and CTP imaging was acute ischemic stroke (AIS), which primarily affects an adult patient population. Only encounters in which the patient was not admitted to the same hospital (i.e., discharged, died, transferred, left AMA, or unknown) were included, as they retained original CPT coding, which is more precise for imaging modality, which was the subject of our study[10].

Study design

Pre-planned analyses examined: (1) changing frequency of neuroimaging use over time per 100,000 ED encounters; (2) association of patient-level variables with rate of advanced neuroimaging use; and (3) association of hospital-level variables with rate of advanced neuroimaging use. Neuroimaging modality use during each ED encounter was determined in the NEDS dataset using Common Procedural Terminology (CPT) codes for non-contrast head CT [NCCT], CPT 70450; CT angiography head [CTA], CPT 70496; CT perfusion [CTP], CPT 0042T, and MRI brain with and without contrast [MRI] CPT70553.

Outcomes

The primary outcome measure was change in rate per 100,000 ED visits for each imaging modality between 2013 and 2018. Secondary outcome measures include the change in rate per 100,000 ED visits for each modality between each of the intervening years. Exploratory outcomes included the rates of advanced imaging acquisition by different encounter properties, and determination of factors associated with hospital CTA utilization using regression analysis.

Missing Data

Because the sampling unit of the NEDS is the hospital, there were no missing data elements from the hospital

Table 1 Demographics of the studied encounters descriptive statistics of weighted study population of encounters across demographic properties

Study population properties:		
	Number of Encounters	% of study population
Study population	**571,935,906**	**100%**
Age 18–40	263566743	46.1%
Age 41–60	174850928	30.6%
Age 61–80	99694307	17.4%
Age > = 80	33823927	5.9%
Female	331731311	58.0%
Weekend	158975067	27.8%
Discharge	553465666	96.8%
Died in ED	1117486	0.2%
Transfer	10854916	1.9%
Unknown	8895646	1.6%
Income- top	88492200	15.5%
Income- 2nd	118953536	20.8%
Income – 3rd	153842244	26.9%
Income- Bottom	199315846	34.8%
Teaching	300898427	52.6%
Metropolitan	453202383	79.2%
Public	42801203	7.5%
ED Vol > 80k	151451352	26.5%
ED Vol 40-80k	216232944	37.8%
ED Vol 20-40k	125005856	21.9%
ED Vol < 20k	79245754	13.9%

characteristics evaluated. For the patient-level characteristics analyzed, missing data elements in the NEDS as a whole are infrequent. Age, gender, and day of the week had missing rates of less than 0.01% for both 2013 and 2018. There were no entries with missing information for “ED Disposition” from which the transfer status of a patient was derived. Income quartile for zip code for patients was missing in 2.2% of our encounters of interest in 2013 and 1.8% of encounters of interest in 2018 [23]. This low rate of missing income for zip code information was stable across each imaging subpopulation (NCCT, CTA, CTP, MRI) and therefore no corrections were made for missing values.

Statistical analysis

Data were analyzed according to weights, sampling units and strata defined by NEDS to allow national estimates. All analyses were conducted using domain analysis, applying the relevant survey weights to account for complex survey design (discharge weights for Tables 1, 2 and 3, and hospital weights for Table 4). Imaging rates for patient and hospital demographic properties of interest were calculated using domain analysis. Analyses were conducted using Stata, versions 16 and 17 (StataCorp, 2021).

Exploratory analyses were performed on available patient- and hospital-level characteristics, with ED encounter as the unit of analysis, with comparison to the national average, to identify characteristics associated with particularly large changes in imaging rate over the time-period studied.

In a separate analysis, we sought to identify hospital characteristics associated with high imaging utilization rates in 2013 and 2018. Due to the limited use of CTP in 2013, we intentionally restricted this analysis to CTA alone. Hospitals were stratified into tertiles based on CTA head rate per 100,000 ED visits and multivariable logistic regression analysis used to evaluate hospital characteristics associated with the highest tertile of CTA utilization in both 2013 and 2018. As above, all statistical significance tests were two-tailed with an alpha level of 0.05. Exploratory analyses were also conducted using Stata, versions 16 and 17 (StataCorp, 2021).

Results

Characteristics of study subjects

The NEDS population of patients meeting our criteria (patients at least 18 years of age seen in the ED and not admitted to the same hospital) included 166,161,224 patient encounters representing a weighted ED study population of

Table 2 Rate of imaging acquisition per 100,000 ED visits by type of imaging and by year for all non-admitted patients 18 years of age or over. Rates displayed along with 95% CI. Bottom row shows % change between 2013 and 2018 along with statistical significance as determined by z-test

	NCCT Rate/100k ED Visits (CI)	CTA Head Rate/100k ED Visits (CI)	CT Perfusion Rate/100k ED Visits (CI)	MRI Brain Rate/100k ED Visits (CI)
2013	5769.81 (5437.3-6023.5)	80.24 (60.87–99.6)	1.75 (0.831–2.67)	121.21 (102.4-140.02)
2014	6639.36 (6323.48-6955.24)	108.92 (83.31-134.53)	3.23 (0.698–5.77)	146.14 (125.94-166.34)
2015	7698.77 (7398.73-7998.82)	155.25 (137.6-172.9)	6.98 (3.21–10.75)	172.41 (154.67-190.14)
2016	7797.93 (7035.80-8092.28)	213.15 (191.02-235.28)	7.63 (4.14–11.13)	186.2 (159.47-201.78)
2017	8581.75 (8262.51-8901.09)	320.65 (282.11–359.20)	10.95 (6.67–15.23)	210.31 (187.16-233.47)
2018	8899.38 (8621.26-9177.51)	448.26 (407.9-488.62)	28.04 (17.20-38.87)	208.05 (184.48-231.63)
% Change (2013–2018)	54.24% $p < 0.001$	458.65% $p < 0.001$	1502.29% $p < 0.001$	71.64% $p < 0.001$

	2013 Rate Per 100k ED Visits		2018 Rate Per 100k ED Visits	
	CTA (CI)	CTP (CI)	CTA (CI)	CTP (CI)
Adults >18 years	80.2	1.8	448.26	28.04
Patient and Encounter Characteristics				
Age				
18-40 yr	44.1(32.7-55.4)	0.7(0.3-1.1)	192.4(170.5-214.3)	8.0(4.6-11.4)
41-60 yr	105.9(78.1-133.7)	2.3(1.1-3.4)	527.6(479.2-576.0)	33.4(20.5-46.3)
61-80 yr	135.8(105.8-165.8)	3.4(1.4-5.4)	810.3(741.9-878.7)	53.5(32.5-74.6)
>=80 yr	92.9(72.4-113.4)	3.5(1.6-5.4)	763.5(694.5-832.5)	65.7(40.4-90.9)
Male	77.6(60.2-95.0)	1.7(0.8-2.6)	453.6(413.4-493.7)	28.8(18.1-39.4)
Female	82.1(61.2-103.1)	1.8(0.8-2.8)	444.4(403.5-485.4)	27.5(16.5-38.6)
Weekday	83.8(63.3-104.2)	1.8(0.8-2.7)	462.4(420.7-504.1)	29.1(18.0-40.2)
Weekend	71.2(54.5-88.0)	1.6(0.8-2.4)	410.8(373.6-448.0)	25.2(15.0-35.4)
Income Quartile				
Top	111.9(84.9-139.0)	1.1(0.4-1.8)	647.4(566.8-728.0)	40.5(18.8-62.2)
2nd	87.6(69.4-105.9)	2.0(1.0-2.9)	566.1(499.3-633.0)	34.4(21.8-47.0)
3rd	68.2(52.6-83.9)	1.9(0.8-2.9)	427.0(385.8-468.1)	26.3(14.8-37.8)
Bottom	70.8(41.4-100.1)	1.8(0.6-3.0)	318.3(282.0-354.5)	20.7(11.11-30.2)
Transfer	190.1(140.1-240.1)	5.8(3.0-8.7)	1376.1(1268.8-1483.5)	87.4(58.5-11.6)
Hospital Characteristics				
Teaching	122.9(77.6-168.2)	2.7(0.8-4.7)	521.8(458.0-585.7)	41.5(23.4-59.6)
Nonteaching	50.3(40.8-59.9)	1.1(0.3-1.8)	343.6(306.0-381.2)	8.8(4.4-13.3)
Metropolitan	94.1(68.5-119.7)	2.2(1.0-3.4)	475.3(426.9-523.6)	33.3(20.1-46.5)
Non-metropolitan	38.2(29.7-46.7)	0.5(-0.3-1.4)	326.5(280.0-373.0)	4.3(-.09-8.7)
Public	40.8(22.2-59.5)	0.1(-0.04-0.2)	377.0(239.4-514.2)	30.1(1.1-59.1)
Private	83.0(62.3-103.8)	1.9(0.9-2.8)	459.2(417.5-500.8)	27.7(16.0-39.4)
ED Volume				
>=80,000	72.2(32.7-111.8)	2.0(-0.4-4.4)	517.4(406.3-628.4)	51.3(17.8-84.9)
40-80,000	115.6(72.3-158.5)	2.6(0.8-4.4)	484.9(417.3-552.5)	23.4(12.6-34.2)
20-40,000	57.9(41.9-73.9)	1.2(-0.1-2.4)	394.5(344.9-444.0)	16.1(5.1-27.0)
<=20,000	32.5(18.6-46.3)	0.1(-1.15-3.5)	281.9(232.7-331.2)	9.3(1.1-17.5)

Table 3 CTA and CTP rate per 100,000 ED visits in each category in 2013 and 2018. Left set of columns shows 2013 for each modality, right set of columns shows 2018 for each modality. As the rate of acquisition of all modalities increased between 2013 and 2018, color coding illustrates the relative magnitude of the % change in imaging modality for that characteristic. Color coding is as follows: *red*: minimum % change for that modality, *orange*: between the minimum and the first quartile % change, *yellow*: % change is between the first and third quartiles, *light green*: % change is between the third quartile and the maximum, *dark green*: maximum % change for that modality. Teaching, Metropolitan, and Public characteristics are obtained from the NEDS, with the following notes. Teaching hospitals are only designated in metropolitan areas, because teaching hospitals in nonmetropolitan areas are so infrequent (NEDS Introduction, 2018). Metropolitan category according to NEDS designation includes large and small metropolitan areas (> 1 million and < 1 million residents), nonmetropolitan includes all other designations. Public includes: government, non-federal public, and public hospitals, private includes: private, nonprofit, voluntary and private invest-own hospitals

571,935,906 encounters from 2013 to 2018, mean age 45.6 years (95% CI 45.5–45.7). The selection of the study population is outlined in Fig. 1. This weighted population was used for all analyses and contained 43,430,171 estimated ED encounters with an accompanying NCCT; 11,278,026 with a CTA head; 56,459 with CTP, and 995,173 with an MRI brain. Demographic characteristics of the study population are described in Table 1. Frequency of advanced neuroimaging acquisition in the study population by characteristics of both patient- and hospital-level properties are presented in Supplemental Table 1.

Main results

Temporal trends in ED imaging

All imaging rates increased between 2013 and 2018 (Table 2). Overall, NCCT use increased 54.24%; MRI Brain 71.64%; CTA head 458.65%; and CTP 1502.29%. Imaging rates by modality and year in our study population are presented in Fig. 2. Analysis of annual imaging rates identified increasing CTA use, with modest acceleration over time. Relative to other imaging modalities, CTP use gradually

Table 4 Logistic regression analysis results for factors associated with a hospital being in the top tertile of CTA Utilizers in 2013 and 2018. N designates the number of hospitals in each category in the top tertile of CTA utilizers in each year, CI the 95% confidence interval and OR designates the odds ratio of this category of hospital being in the high utilizing group. * indicates $p < 0.05$

	2013			2018		
	N	OR	CI	N	OR	CI
Total	1541			1522		
Teaching	483	1.54*	(1.03–2.31)	718	1.88*	(1.30–2.72)
Metropolitan	1099	1.14	(0.81–1.60)	1113	0.87	(0.60–1.26)
Public	127	0.65	(0.40–1.06)	137	0.39*	(0.26–0.60)
ED Volume >=80,000	144			223		
40–80,000	585	1.59	(0.87–2.90)	464	0.89	(0.53–1.51)
20–40,000	476	1.04	(0.55–1.95)	440	1.07	(0.61–1.87)
<=20,000	336	0.32*	(0.16–0.63)	395	0.40*	(0.22–0.72)

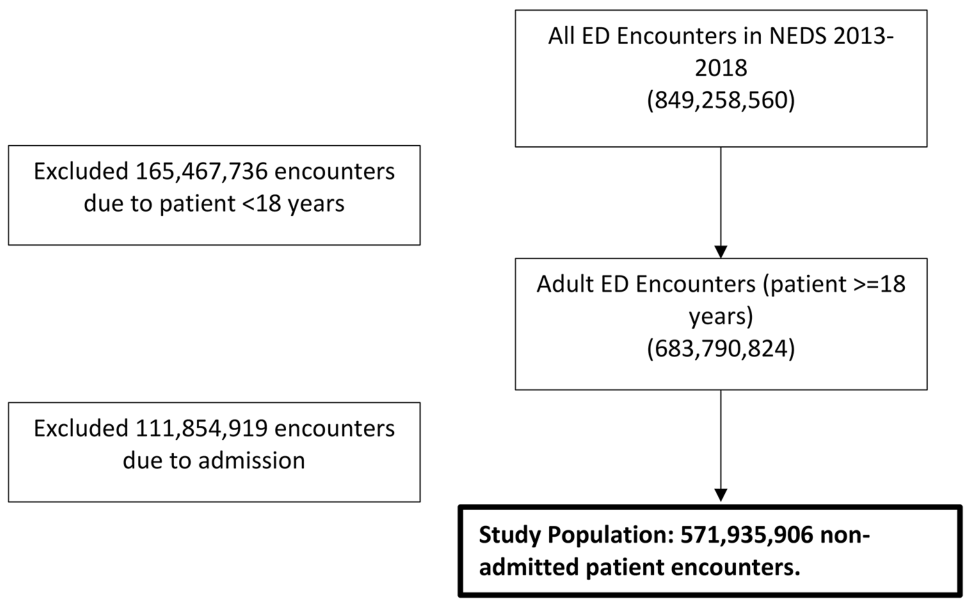

Fig. 1 Flow Diagram - Selection of studied encounters. Flow diagram of selection of encounters making up the study population for this analysis. Patients admitted to the same hospital made up a minority of encounters, and were not included in the imaging analysis because of the loss of precise imaging procedural information from coding of inpatient visits. *Discharge category includes the following non-admitted dispositions: routine discharge, transferred to another acute care hospital, against medical advice, other transfer including subacute nursing facility, unknown, home health, died in ED

increased between 2013 and 2017 and saw a substantial increase in 2018. By comparison, MRI showed larger increases early in the data set (2013–2015) with subsequent leveling. Acquisition of NCCT demonstrated modest yearly increases. In addition to total use, we evaluated for variation in advanced imaging use associated with specific encounter properties (age, income, type of hospital) (Table 3, and Supplementary Table 2).

CTP

CTP acquisition trends varied with income (as assigned by national income categorization of patient zip code), teaching status, metropolitan location, hospital ownership, and size. Among patient properties, the largest magnitude of increase of CTP use from 2013 to 2018 was observed in encounters associated with the top two income quartiles (increases of 3,483.2% and 1662.1%, respectively). Encounters at nonteaching hospitals had a lower rate of CTP in 2013 than teaching hospitals (1.1 per 100,000 vs. 2.7 per 100,000) and lagged behind the overall population in their rate of increase (734% increase in nonteaching hospitals compared with 1404% in all encounters). Encounters at metropolitan hospitals had higher rates of CTP acquisition in 2013 than nonmetropolitan hospitals (2.2 per 100,000 vs. 0.5 per 100,000 respectively) and this difference was even larger in 2018 (33.3 per 100,000 vs. 4.3 per 100,000). Hospitals categorized as public ownership had a lower rate of CTP acquisition in 2013 than privately-owned hospitals (0.1 per 100,000 vs. 1.9 per 100,000), but by 2018 the rate of CTP acquisition exceeded privately-owned hospitals (30.1 per 100,000 compared with 27.7 per 100,000). Despite increases in CTP acquisition at both ends of the ED volume spectrum, the trend toward larger volume ED's utilizing more CTP persisted in 2018.

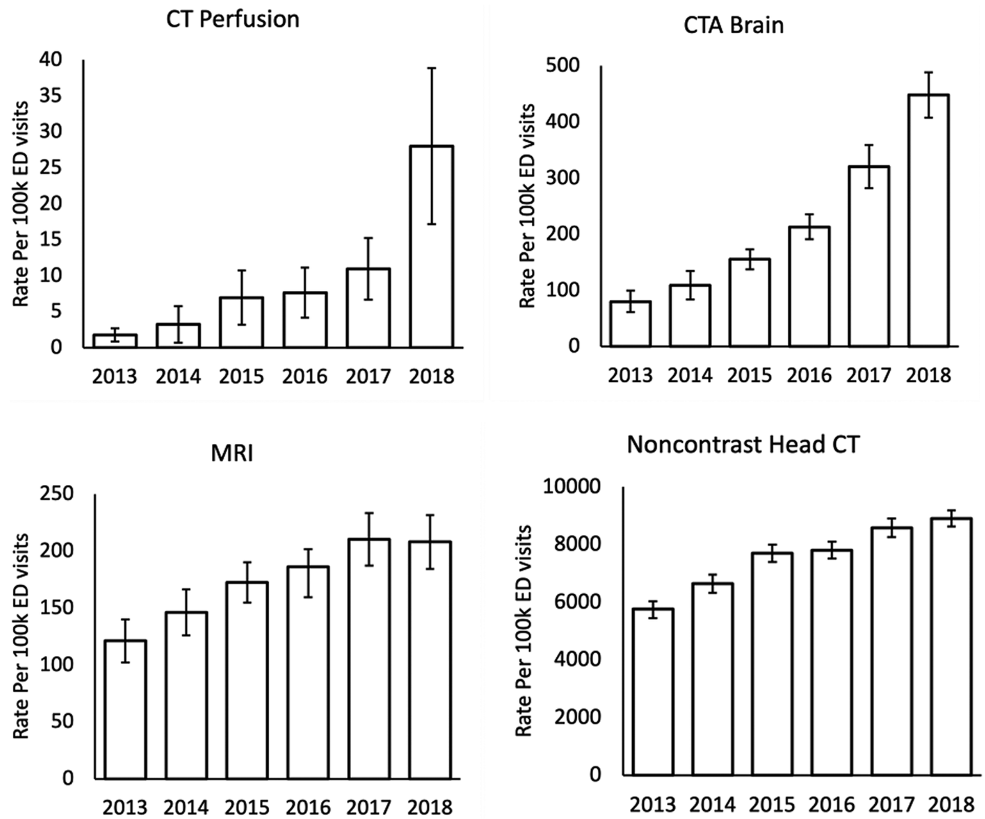

Fig. 2 Imaging rate per 100,000 ED visits for each modality studied from 2013 to 2018, error bars are 95% CI. All imaging modalities increased in use, although the scale of the increase is much more pronounced in CT Perfusion and CTA Brain as compared with MRI Brain and Noncontrast Head CT.

CTA

Trends in CTA use varied with income quartile as well as hospital teaching status, ownership, location and size. In 2018, the rate of CTA was higher in the top two quartiles of income than the bottom two quartiles and encounters in which a patient was transferred had a 3-fold higher rate of CTA acquisition than the overall study population. In 2013, encounters at teaching hospitals had the highest absolute rate of CTA per 100,000 ED visits of all hospital properties, over 2-fold higher than non-teaching hospitals, but by 2018, this gap had narrowed. Non-metropolitan and public hospitals showed large increases in CTA use over the study period (754.6% and 822.7%, respectively, compared with an increase in CTA of 458.7% for all adult encounters). Pronounced increases in CTA rate between 2013 and 2018 were seen in the largest volume emergency departments (≥ 80,000 annual ED visits) and the smallest (≤ 20,000 annual ED visits).

MRI

Substantial differences were identified in the rate of MRI acquisition between weekday and weekend encounters which narrowed only minimally by 2018. The rate of MRI imaging acquisition was also higher in teaching hospital encounters compared to nonteaching hospital encounters in 2013 (159.8 vs. 94.2 per 100,000). Over this period, across all variables examined, the greatest increase in the rate of MRI utilization occurred in public hospitals, with a 104.6% increase (see Supplementary Table 2 for additional detail).

Noncontrast Head CT

NCCT in adult encounters increased by 51.1% between 2013 and 2018. NCCT acquisition increased gradually across all hospital characteristics (See Supplementary Table 2). More pronounced increases were noted among teaching, non-metropolitan, and private hospitals (61.2%, 61.8%, and 56.6%, respectively). Encounters associated with hospitals with large ED volumes increased 89.6% and small volume hospitals increased 58.4%. Between 2013 and 2018, a smaller rate of increase in the use of NCCT was identified in public hospitals compared to the overall population (36.1% vs. 54.2%) (See Supplementary Table 2 for additional detail).

Hospital characteristics associated with high utilization of Advanced CT Imaging

Using logistic regression analysis, we examined factors contributing to a high rate of CTA (head and neck) acquisition (per 100,000 encounters) on a hospital basis (Table 4**).**

Teaching status in both 2013 and 2018 was associated with higher odds of being in the top tertile of CTA utilizing hospitals (odds ratios [OR] 1.54 (CI 1.03–2.31) and 1.88 (CI 1.30–2.72), respectively. Publicly owned hospitals were associated with significantly lower odds of top tertile CTA utilization in 2018 OR 0.39 (CI 0.26–0.60). Compared with the highest volume EDs (≥ 80,000 annual visits), the lowest volume EDs (≤ 20,000 ED visits) had lower odds of being in the high utilizing group in both 2013 and 2018 (OR 0.32 (CI 0.16–0.63) and 0.40 (CI 0.22–0.72).

CTP imaging in the emergency department is almost exclusive to the evaluation of acute stroke. However, its use is non-existent at many EDs and, where used, rates vary substantially making meaningful associations unreliable.

Discussion

In this study, we observed an increase in the use of all four cross-sectional neuroimaging modalities evaluated between 2013 and 2018, with nonlinear increases in the rates of CTA and CTP acquisition in the discharged ED patient population. Both CTA and CTP imaging rates show an inflection point around 2016, shortly after the publication of multiple trials supporting mechanical thrombectomy for confirmed LVO within 6–12 h [7, 8, 10, 25]. CTA imaging increased four-fold between 2013 and 2018, with CTP increasing fourteen-fold. These increases were more pronounced than NCCT and MRI. In the ED setting CTP imaging is essentially unused except for acute stroke evaluation and CTA head imaging is also predominantly used in evaluation for stroke, whether hemorrhagic or ischemic. The trends we observe parallel advances in endovascular treatment options for LVO strokes using CTA and CTP for patient selection. While the timing of these increases likely signals rapid incorporation of LVO-specific screening and treatment modalities into emergency acute stroke protocols [26], the fact that our analysis shows such striking trends in discharged patients may reflect a shift in the balance towards over-testing.

Our examination of imaging rates as associated with specific encounter properties reveals imaging utilization patterns with broader implications for EDs and systems of stroke care. Specifically, the top quartile of income, by zip code, had higher rates of CTA and CTP utilization in 2013 and larger percentage increases in CTA than the bottom quartile, effectively widening the gap in imaging utilization by the end of the time interval studied. CTP imaging was so rare in 2013, that imaging utilization does not segregate clearly by income for zip code, but by 2018, the CTP rate for patients in the highest income category was almost double the CTP rate for the lowest income category. While our dataset does not include outcomes, published studies have demonstrated lower rates of IV thrombolysis and worse stroke outcomes associated with lower socioeconomic status, which has been attributed to time to presentation to medical care after symptom onset [27, 28] and potentially to the stroke volume at the hospital of presentation [29]. A 2021 study showed a strong relationship between higher median income and proximity to certified stroke care, raising the question of whether physical proximity to specialized care may run parallel to income for zip code and underly some of the effects we observe [30]. Advanced neuroimaging rates may be related to these effects, as well as individual physician decision-making, institutional stroke protocols, and physical access to imaging capability at the presenting hospital [31].

Analysis of hospital-level factors identified important trends in advanced imaging rates associated with teaching status and ED annual volume. Teaching hospitals had a higher rate of advanced imaging at the start of the study period compared to non-teaching hospitals, potentially consistent with an early-adopter effect. Higher imaging rates across the study period in high ED volume hospitals may reflect greater access to new technologies and financial resources enabling new imaging modalities in larger institutions. Although small hospitals had the most substantial increases, they continued to use less imaging than all categories of larger hospitals in 2018, which may be related to the imaging modalities and specialist capabilities available at these sites [31]. It has been shown that rural and critical access hospitals are more likely to be lower-volume and less likely to be teaching hospitals, and are also associated with worse stroke mortality [32]. Regression analysis of high CTA utilizing hospitals demonstrated that hospital properties associated with high CTA utilization have been stable from 2013 to 2018, suggesting that opportunities remain for improving access to advanced imaging with a focus on small-volume centers and public hospitals.

Limitations

While our study has the advantage of leveraging a large representative database to describe national trends, there are some limitations. Because the NEDS is an administrative dataset, we lack granular clinical information such as illness severity, triage score, or comorbidities which might influence decisions to obtain neuroimaging. In addition, the imaging granularity available in the NEDS database is limited to patients seen in the ED and not admitted to the same hospital. This includes patients evaluated and discharged, transferred to another clinical setting, discharged against medical advice or with an unknown disposition. Our study population is likely to represent primarily evaluations in which a stroke or other serious pathology was not diagnosed, but still provides important information about emergency department imaging utilization. The NEDS was selected because of the ability to generate national estimates and the availability of very specific neuroimaging data using CPT codes for non-admitted patients. This allows us to compare CT Head, CTA head and neck, MRI brain and CT Perfusion use over time. Our results are consistent with estimates from other data sources such as NHAMCS [4].

In summary, our results demonstrate large increases in the rate of CTA and CTP utilization in the emergency department from 2013 to 2018 in discharged ED patients. These increases were greater than corresponding increases in NCCT and MRI. We identified differences in image acquisition by patient-level and hospital-level factors suggest potential areas for future improvement in access to advanced neuroimaging across hospital and patient demographic factors. Longitudinal evaluation of these trends will continue to be valuable in the development of stroke systems of care and ED resource utilization.

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Declarations

Disclosures None.

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