Original Article

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Trends of Computed Tomography Use in a Tertiary Emergency Department in Taiwan from 2010 to 2020

Hao-Ming Li[1,3,7,], Shi-Zuo Liu[1,*], Lee-Ren Yeh[1,3,4], Nan-Han Lu[1,4,8], Liang-Yi Wang[7], Hung-Yuan Su[2,5], Chih-Wei Hsu[2,6]*

Objective: To analyze the trends of computed tomography (CT) use and repeat CT imaging in a tertiary emergency department (ED) in Taiwan.

Methods: From 719,670 records of ED visits during 2010 – 2020, we calculated annual crude rates and age-standardized rates (ASRs) of any CT use (per 1,000 ED visits) with corresponding average annual percent changes (AAPCs) and 95% confidence intervals (95% CIs). We also calculated the above rates and AAPCs for repeat CT and each CT type. Using ASRs and AAPCs could minimize the confounding effect of aging and provide a stable comparison of trends.

Results: The ASR of any CT use increased from 107.7 (95% CI 105.2 – 110.3) in 2010 to 173.6 (95% CI 169.9 – 177.3) in 2020, with an AAPC of 3.9 (95% CI 3.4 – 4.5). Consistent results were found for repeat CT and each CT type, with the highest AAPC in spine CT (28.2, 95% CI 26.4 – 31.1), followed by extremity CT (19.6, 95% CI 16.2 – 24.2). Brain CT had the lowest AAPC (0.9, 95% CI 0.1 – 1.7). The increase in ASR was associated with older age, being male, more emergent acuity, and trauma. Upward trends of ASRs were observed in most subgroups, except for the pediatric and non-urgent subgroups.

Conclusions: Increasing trends of CT use and repeat CT imaging were found in a tertiary ED in Taiwan during 2010 – 2020, even after age standardization with the general population. Marked growth of spine and extremity CT use was also observed. Further investigation is needed to evaluate potential CT overuse in ED.

Key words: computed tomography, emergency radiology, epidemiology, health resources

Introduction

Computed tomography (CT) has played a vital role in the emergency department

From the [1]Department of Medical Imaging and [2]Department of Emergency Medicine, E-Da Hospital, I-Shou University; [3]Department of Medical Imaging and Radiological Sciences, College of Medicine, [4]School of Medicine, College of Medicine, [5]School of Chinese Medicine for Post Baccalaureate, College of Medicine and [6]School of Medicine for International Students, College of Medicine, I-Shou University, Kaohsiung; [7]Department of Public Health, College of Medicine, National Cheng Kung University, Tainan; [8]Department of Pharmacy, Tajen University, Pingtung, Taiwan.

(* Signifies equal contributions as corresponding authors)

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* Address reprint request and correspondence to: Hao-Ming Li and Shi-Zuo Liu, Department of Medical Imaging, E-Da Hospital, No. 1, Yida Road, Jiaosu Village, Yanchao District, Kaohsiung City 824005, Taiwan

Tel: +886-7-615-0011 ext. 2228, Fax: +886-7-615-0909, E-mail: lhm0323@gmail.com (HML)

Tel: +886-7-615-0011 ext. 251977, E-mail: ed106088@edah.org.tw (SZL)

(ED) for rapid patient diagnosis and triage. Although the use of brain CT in stroke and traumatic brain injury is well-known,[1,2] clinical guidelines have expanded the indications for CT in the last decade, such as polytrauma, major bleeding, cervical spine clearance, acute chest pain, peripheral artery disease (PAD), small bowel obstruction, urolithiasis, and therefore extended CT use in the ED.[3-9] In the United States of America (USA), the reported rates of CT use per ED visit increased nearly 5-fold between 1995 and 2007, from 2.8% to 13.9%.[10] Similar growth has been reported worldwide, raising concerns about CT overuse.[11-16] The universal coverage of National Health Insurance (NHI) in Taiwan facilitated the use of high-cost medical imaging such as CT and magnetic resonance imaging (MRI),[17] which may lead to possible CT overuse in ED patients causing excessive radiation exposure and healthcare cost.[13,18] However, there is no consensus on the definition and measurement of CT overuse. A systematic review of imaging overuse in ED described two definitions of CT overuse: repeat imaging and inappropriate imaging without sufficient justification.[19] The latter definition is subjectively evaluated and difficult to apply to large samples. In this study, we use repeat CT imaging as a surrogate of CT overuse, and the term of "CT use" refers to CT examinations in an ED visit, not including those in the subsequent hospitalization.

The growth magnitude and temporal trends of CT use vary depending on imaging types, study periods, patient characteristics, hospital settings, and countries.[10-16] Therefore, continuous and comprehensive monitoring CT use is crucial in identifying potential areas of overuse and implementing control measures. However, most trend reports of CT use are from Western countries, whereas Asian data are outdated and underreported. Additionally, the global aging population has resulted in increased healthcare utilization. Previous studies have shown the association between age and CT use,[10-16] but rarely used age-standardized rates (ASRs) in trend comparison to adjust for aging confounding.

We hypothesized that the population of ED visits in Taiwan would have aging effects. Therefore, this study aimed to assess the trends of CT use and repeat CT imaging in a tertiary ED in Taiwan using ASRs, which could minimize the confounding effect of aging, and make our results comparable to those from the general population. In addition, we compared differences in the trends of CT use by age, sex, triage score level, and trauma status stratification to explore factors associated with the trends. The present study will provide an update on the patterns of CT use and identify potential areas of CT overuse in Taiwan.

Materials and Methods

Study design and setting

This retrospective observational study was conducted during 2010 – 2020 at a 1,259-bed tertiary referral hospital in Taiwan, with the capabilities of a Level I Trauma Center and annual volume of 66,000 ED visits. The ED had full access to two multi-detector CT scanners located next door (Brightspeed Elite 16, GE Healthcare, USA; SOMATOM Sensation 16, Siemens, Germany). Board-certificated radiologists provided 24-hour reporting services with night shifts covering off-hours emergency reporting. This study follows the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (eTable 1 in the Supplement).[20]

Data source and selection of participants

Data were retrieved from the hospital's electronic health records, which were managed using Oracle database servers. We enrolled all patient records of ED visits during 2010 – 2020 but excluded visits with incomplete data (n = 473), visits for documentation or certification (n = 6,927), and visits involving patients who

were dead on arrival with unsuccessful resuscitation (n = 1,644). Figure 1 illustrates the patient selection diagram.

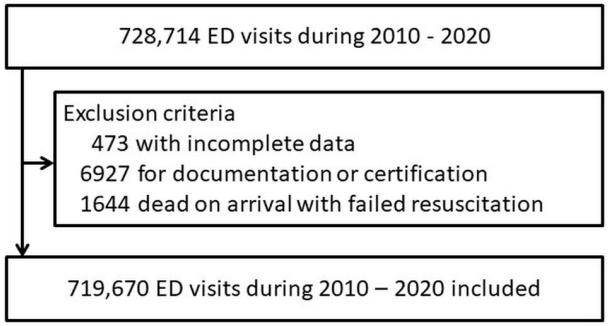

Fig. 1 Patient selection diagram.

Measurements of CT use

We used annual crude rates and ASRs of ED visits involving any CT use (per 1,000 ED visits) to assess the trends of CT use. The annual crude rates were calculated on a comparable basis to previous studies,[10-16] as the number of CT users divided by the number of total ED visits in each year. The annual ASRs were calculated from crude rates by applying direct standardization with the age distribution of Taiwan's population in 2010.[21] The reasons for using ASRs were to reduce the confounding effect of aging on the study population and to facilitate comparability of the results to the general population.

We also calculated the above rates of ED visits involving repeat CT imaging and each CT type. Repeat CT imaging was measured dichotomously as whether the patient was transferred with CT imaging in the previous hospital or had multiple CT scans during the same ED visit. CT types were grouped by anatomical sites applied for scanning as follows: brain (including the brain and sella turcica), neck (including the facial bone, temporal bone, nasopharynx, and neck), chest (including the chest, heart, aorta, and pulmonary artery), abdomen (including the abdomen and pelvis), extremity (including upper and lower limbs), and spine (including cervical, thoracic, lumbar, and sacral spine). All rates are presented with corresponding 95% confidence intervals (95% CIs).

Potential associated factors

To explore factors associated with trends of CT use, we collected patient demographics (age and sex) and characteristics of ED visits (triage score and trauma status). Patient ages were grouped into five categories: < 18 years, 18 – 34 years, 35 – 54 years, 55 – 74 years, and ≥ 75 years. Triage scores were evaluated by the Taiwan Triage and Acuity Scale,[22] then collapsed into three categories (emergent: triage score 1 or 2; urgent: triage score 3; non-urgent: triage score 4 or 5) to increase statistical power. Trauma status was categorized dichotomously as yes or no.

Statistical analysis

Descriptive statistics were used to summarize patient demographics, visit characteristics, and CT use in study periods. Continuous and categorical baseline variables were presented as mean (standard deviation) and number (percentage), respectively. Trend tests for variables of interest were performed using linear regression for parametric continuous variables, the Jonckheere-Terpstra Test for non-parametric continuous variables, the Cochran-Armitage Trend Test for binary categorical variables, and the Cochran-Mantel-Haenszel Test for multi-level categorical variables.[23]

To quantify the temporal trends of annual crude rates and ASRs, we estimated their average annual percent changes (AAPCs) with 95% CIs for the study period (i.e., 2010 – 2020). The AAPC, obtained from the joinpoint regression model with the best fit for the data, is a weighted average of the annual percent changes according to the length of each trend segment. AAPC has been proven to be a good summary measure of trends with minimal framing bias, especially when data are sparse and short trend segments are present.[24,25] It

could provide a stable comparison across different groups and time intervals. An AAPC with 95% CI above or below zero indicates an upward or downward trend, respectively, while an AAPC with 95% CI containing zero indicates a stable trend.[26] Subgroup analyses stratified by age, sex, triage, and trauma status were conducted to compare ASR and AAPCs.

Descriptive statistics and trend tests were performed using SAS (version 9.4, SAS Institute). The computation of annual crude rates, ASRs, and AAPCs was performed using the Joinpoint Regression Program (version 4.9.1.0, National Cancer Institute). Statistical significance was set at the alpha-level of 0.05.

Results

Characteristics of study subjects

A total of 716,970 ED visits were included in this study. Compared to 2010, the number of ED visits in 2020 decreased (53,300 vs. 69,513), whereas the number of CT users increased (11,079 vs. 8,165) (Table 1). ED patients in 2020 were significantly older (mean age 46.8 vs. 41.8), fewer males (54.3% vs. 55.4%), fewer emergent & non-urgent cases (15.2% vs. 20.5%; 10.9% vs. 14.2%), but more traumatic cases (18.2% vs. 16.5%). CT users showed similar trends as ED patients. Compared with all ED patients, all CT users were significantly older (mean age 57.5 vs. 43.8), more males (56.8% vs. 54.7%), more emergent cases (27.2% vs. 15%) and more traumatic cases (29.1% vs. 16.6%).

Trends of CT use

During 2010 – 2020, the annual crude rates of any CT use per 1,000 ED visits increased from 117.5 (95% CI 114.9 to 120) in 2010 to 207.9 (95% CI 204 to 211.7) in 2020, with an AAPC of 4.9 (95% CI 3.3 to 6.6). After age standardization, the results were consistent, showing steadily increasing trends (ASR from 107.7 to 173.6, AAPC = 3.9, 95% CI 3.4 to 4.5); meanwhile, significant increase in repeat CT imaging was also found (ASR from 6.9 to 22.9, AAPC = 11.9, 95% CI 11 to 13.1) (Table 2).

Among the various types of CT, brain CT accounted for the majority of CT use with the highest annual crude rates, but the proportion of brain CT in all CT studies decreased from 63% in 2010 to 45% in 2020 (eFig. 1 in the Supplement). Increasing trends in ASRs were

Table 1. Characteristics of all ED patients and the CT users during 2010 – 2020.

Variable Mean ± SD or n (%)	All ED patients				CT user			
	2010 (n = 69,513)	2020 (n = 53,300)	2010 – 2020 (n = 719,670)	*p* for trend	2010 (n = 8,165)	2020 (n = 11,079)	2010 – 2020 (n = 113,349)	*p* for trend
Age	41.8 ± 26.2	46.8 ± 25.9	43.8 ± 26.4	*	55.8 ± 20.7	58.8 ± 20.3	57.5 ± 20.6	*
< 18	15,525 (22.3)	8,126 (15.2)	146,165 (20.3)		297 (3.6)	218 (2)	3,092 (2.7)	
18 – 34	13,047 (18.8)	10,204 (19.1)	130,546 (18.1)		1,183 (14.5)	1,382 (12.5)	15,278 (13.5)	
35 – 54	16,272 (23.4)	11,758 (22.1)	160,727 (22.3)		2,183 (26.7)	2,677 (24.2)	28,603 (25.2)	
55 – 74	16,233 (23.4)	14,673 (27.5)	181,100 (25.2)		2,815 (34.5)	4,115 (37.1)	39,818 (35.1)	
≥ 75	8,436 (12.1)	8,539 (16)	101,132 (14.1)		1,687 (20.7)	2,687 (24.3)	26,558 (23.4)	
Male	38,491 (55.4)	28,917 (54.3)	393,834 (54.7)	*	4,655 (57)	6,168 (55.7)	64,435 (56.8)	*
Triage†				*				*
Emergent	14,235 (20.5)	8,095 (15.2)	108,262 (15)		3,084 (37.8)	2,801 (25.3)	30,849 (27.2)	
Urgent	45,424 (65.3)	39,382 (73.9)	528,537 (73.4)		4,664 (57.1)	8,043 (72.6)	79,265 (69.9)	
Nonurgent	9,854 (14.2)	5,823 (10.9)	82,871 (11.5)		417 (5.1)	235 (2.1)	3,235 (2.9)	
Trauma	11,437 (16.5)	9,690 (18.2)	119,286 (16.6)	*	2,408 (29.5)	3,048 (27.5)	33,009 (29.1)	*

* $p < 0.001$.

† Triage: emergent (triage score 1 or 2), urgent (triage score 3), and non-urgent (triage score 4 or 5).

CT: computed tomography; ED: emergency department; SD: standard deviation.

Table 2. Trends of CT use in the ED patients during 2010 – 2020.

CT type	2010	95% CI	2020	95% CI	Rate difference from 2010	Growth % from 2010	AAPC	95% CI
Annual crude rate per 1,000 ED visit								
Any CT	117.5	(114.9 – 120)	207.9	(204 – 211.7)	90.4	77%	4.9	(3.3 – 6.6)
Repeat CT	6.8	(6.2 – 7.4)	26.3	(24.9 – 27.6)	19.5	284%	13.4	(12.1 – 15.9)
Brain	79.2	(77.1 – 81.3)	109.6	(106.8 – 112.4)	30.4	38%	2.1	(1.1 – 3.1)
Abdomen	32.1	(30.7 – 33.4)	79	(76.6 – 81.4)	46.9	146%	9.2	(7.8 – 10.7)
Chest	6.1	(5.5 – 6.7)	23.4	(22.1 – 24.7)	17.3	286%	11.2	(9.5 – 13.4)
Neck	5.9	(5.3 – 6.4)	13.4	(12.4 – 14.3)	7.5	127%	8.1	(6.8 – 9.8)
Spine	0.8	(0.6 – 1)	9.4	(8.6 – 10.2)	8.6	1137%	28.6	(27.1 – 31.2)
Extremity	0.8	(0.6 – 1)	7.2	(6.5 – 7.9)	6.4	826%	20	(16.6 – 24.9)
Annual ASR per 1,000 ED visit								
Any CT	107.7	(105.2 – 110.3)	173.6	(169.9 – 177.3)	65.9	61%	3.9	(3.4 – 4.5)
Repeat CT	6.9	(6.3 – 7.6)	22.9	(21.6 – 24.3)	16	232%	11.9	(11 – 13.1)
Brain	71.6	(69.6 – 73.7)	88.7	(86.1 – 91.3)	17.1	24%	0.9	(0.1 – 1.7)
Abdomen	30.3	(28.9 – 31.6)	68.2	(65.8 – 70.5)	37.9	125%	8.4	(7.4 – 9.5)
Chest	5.2	(4.7 – 5.8)	17.9	(16.8 – 19)	12.7	244%	9.9	(8.3 – 11.8)
Neck	6.4	(5.8 – 7)	13.5	(12.4 – 14.5)	7.1	110%	7.9	(7.3 – 8.7)
Spine	0.9	(0.7 – 1.2)	8.9	(8 – 9.7)	8	873%	28.2	(26.4 – 31.1)
Extremity	0.8	(0.6 – 1)	7	(6.2 – 7.7)	6.2	771%	19.6	(16.2 – 24.2)

AAPC with 95% CI above zero indicating a significant increasing trend.
AAPC: average annual percentage changes; ASR: age-standardized rate; CI: confidence interval; CT: computed tomography; ED: emergency department.

consistently observed for all types of CT, with the highest percentage of growth for spine CT (growth of 873%, ASR from 0.9 to 8.9, AAPC = 28.2, 95% CI 26.4 to 31.1), followed by extremity CT (growth of 771%, ASR from 0.8 to 7, AAPC = 19.6, 95% CI 16.2 to 24.2). The lowest percentage of growth was seen for brain CT (growth of 24%, ASR from 71.6 to 88.7, AAPC = 0.9, 95% CI 0.1 to 1.7) (Table 2 & Fig. 2).

Factors associated with trends of CT use

In subgroup analyses of any CT use, most subgroups showed increasing trends of ASRs, except for the pediatric and non-urgent subgroups (pediatric: AAPC = 0.2, 95% CI –1.9 to 2.2; non-urgent: AAPC = –1.9, 95% CI –4 to 0.2) (Fig. 3 & eTable 2 in the Supplement). The increase in ASR of any CT use was associated with older age, male sex, higher emergent acuity and trauma. The subgroup analysis of repeat CT imaging showed consistent results as those of any CT use (eFig. 2 in the Supplement).

In subgroup analyses stratified by CT types (Fig. 4), increasing ASR trends were generally observed, with two exceptions: for brain CT, increasing trends were observed only in the subgroups with higher risk (age over 35, male, emergent, and traumatic); in the subgroup of non-urgent cases, all types of CT did not have an increasing trend, and brain CT had a decreasing trend (AAPC = –4.4, 95% CI –6.3 to –2.9).

Discussion

In this study, we found that the aging effect did exist in our study population, with the mean age of ED patients increasing by five years from 2010 to 2020. Therefore, using ASR for trend analysis and comparisons has made our results less confounded by the aging effects. After age standardization, we still observed the continued growth of CT use and repeat CT imaging in our ED, with trends differed by CT types (shown in Table 2 & Fig. 2). Spine and

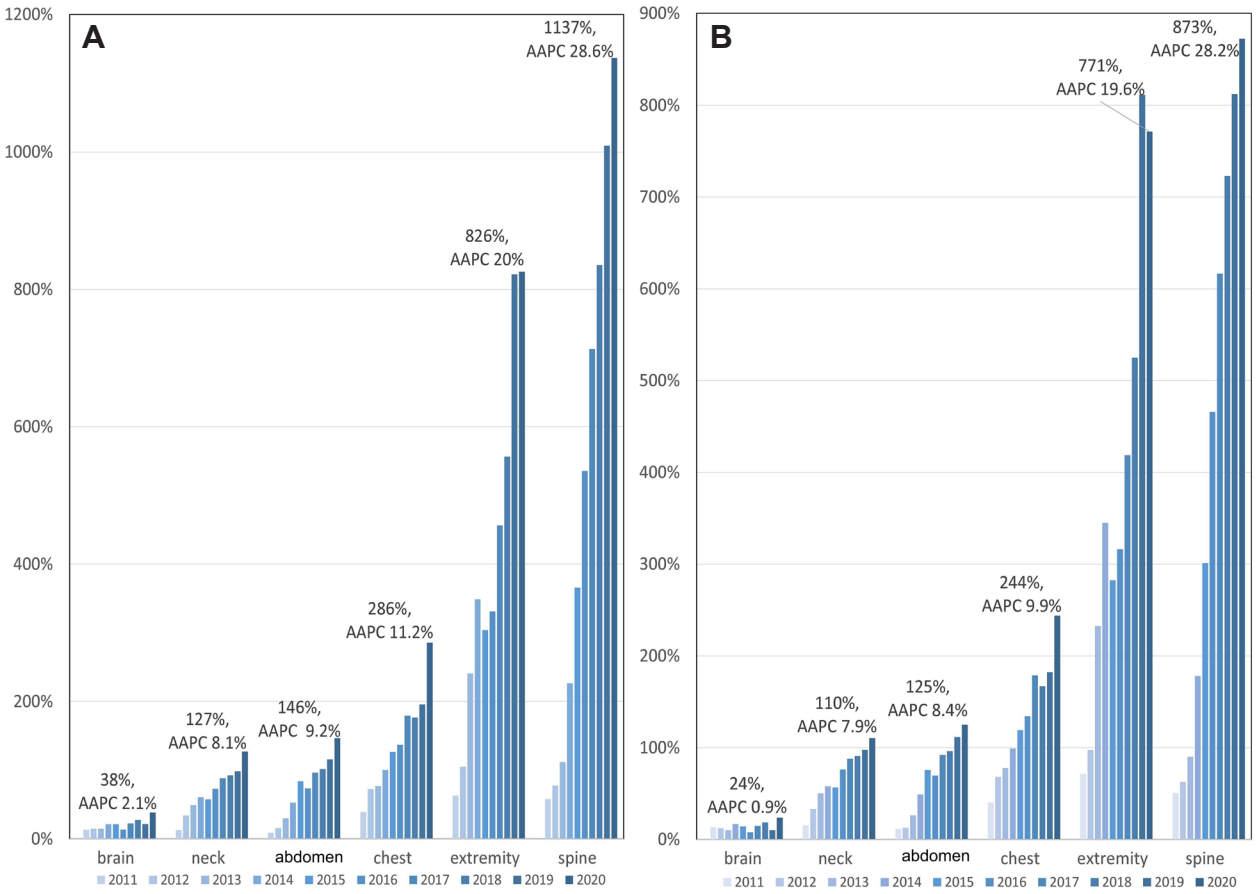

Fig. 2 Growth percentage of (A) annual crude rate and (B) age-standardized rate (ASR) in each type of computed tomography (CT), compared with 2010. The end of each curve labeled the corresponding growth percentage and average annual percent change (AAPC).

extremity CT had the most prominent growth trends, while brain CT had the least growth trend. Furthermore, the proportion of brain CT in the total emergent CT decreased between 2010 and 2020. These findings suggest that in Taiwan, the use of brain CT in the ED setting may reach a stable status, rather than continue to grow. In addition, this study showed a stable trend of CT use in non-urgent and pediatric patients.

Compared to previous related studies from Korea, Taiwan, and the USA,[14-16,18] our study showed similar results of increasing trends of overall CT use with minimal growth in brain CT use. Additionally, our study showed drastic growth in spine and extremity CT utilization, which may reflect the emerging need for imaging due to increased ED visits for trauma and diabetic foot complications in Taiwan.[27,28] However, the CT type with the highest growth differed among these studies, such as spine,[16] facial,[14] and chest/cardiac CT.[15,18] It is plausible that evidence-based guidelines for emergency brain CT were developed early and widely adopted,[1,2] resulting in the regular use of brain CT nowadays. Conversely, guidelines for other types of CT were developed later,[3-9] with varied rates of technology spread in different countries and patient settings. Starting in 2007, the European guideline began recommending whole-body CT scans for hemodynamically stable patients suspected of having internal bleeding from high-energy injuries.[3] In 2009, The Eastern Association for the Surgery of Trauma established the guideline that advocated for cervical spine CT as the primary imaging survey for patients with suspected cervical spine injuries, excluding those who had no neurologic deficit, neck pain or limited range of motion in the neck.[4]

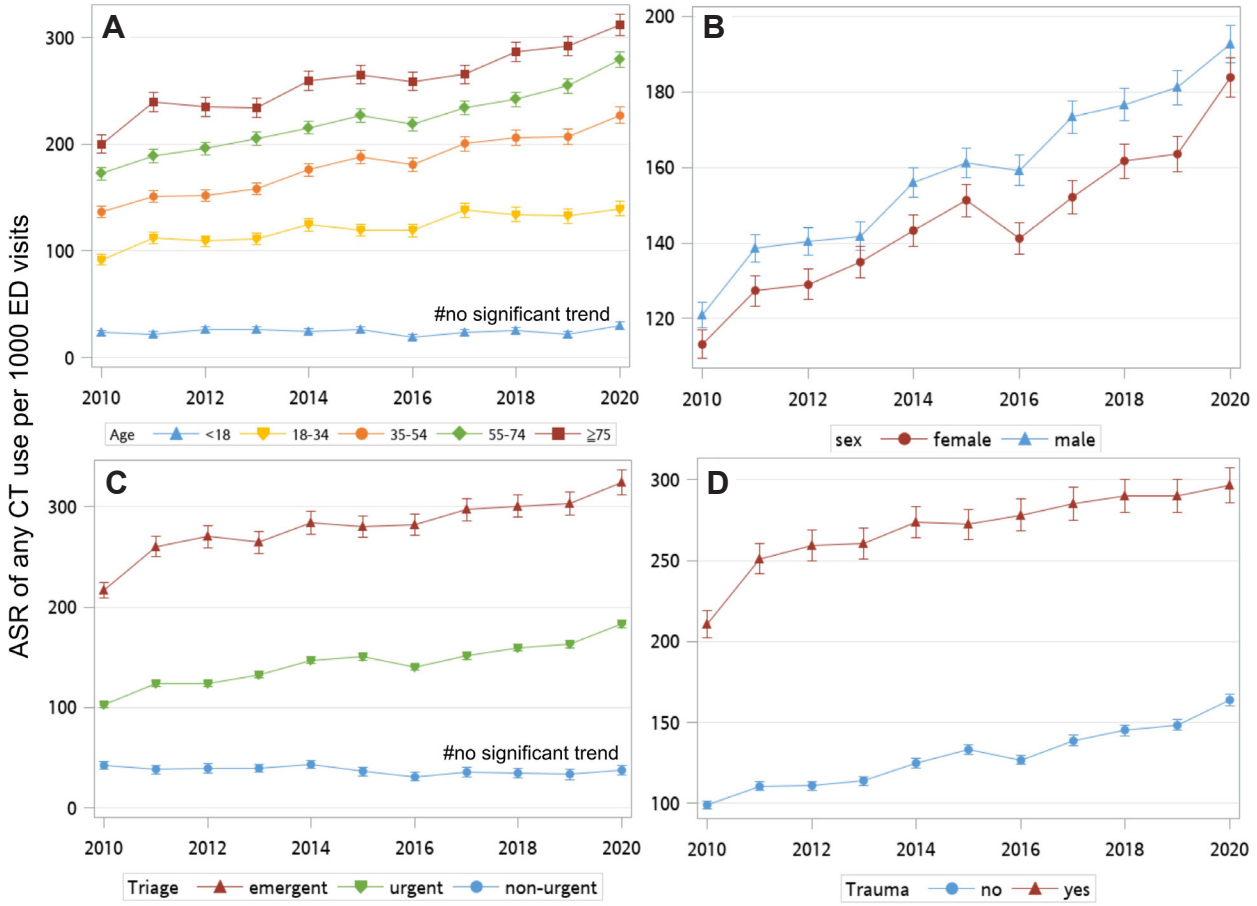

Fig. 3 Trends of age-standardized rate (ASR) in using any computed tomography (CT) per 1,000 emergency department (ED) visits, stratified by (A) age, (B) sex, (C) triage and (D) trauma subgroups. Increasing trends of ASR were observed in most subgroups, except for the pediatric and the non-urgent subgroups (# No significant trend – AAPC with 95% CI containing zero).

In 2011 and 2015, multisociety guidelines suggested CT angiography as an early assessment tool for symptomatic patients suggestive of PAD, acute coronary syndrome, pulmonary embolism, or acute aortic syndrome.[5,6] As of 2019, the National Institute for Health and Care Excellence of the United Kingdom recommended urgent low-dose non-contrast CT for adults with suspected renal colic, except for pregnant women.[8]

A unique finding of this study was a stable trend of CT use in pediatric and non-urgent patients, which indicates that ED physicians are careful to avoid using CT in these patients. Nevertheless, the constant growth of CT use and repeat CT imaging in other patient subgroups may suggest that ED physicians preferred to use more CT than before. It is unclear whether this increase was caused by unmet needs according to the guidelines,[1-4,6,7,9] or overuse from defensive medicine.[19,29] In Taiwan, emergency medicine is among the top three specialties involved in malpractice claims.[30] Besides, it has been reported that the practice of defensive medicine has been expanded by physicians due to the perception of malpractice liability.[30] Therefore, the possibility of CT overuse in ED needs to be investigated. The overutilization of CT has been linked to several adverse effects, including potential harm arising from invasive testing or treatment, as well as repeated radiation exposure leading to cancer development, particularly in children. Reported cumulative radiation doses to the red bone marrow and brain per CT scan were ranged from 5.9 – 10.1 mGy and 18.3 – 49.0 mGy, leading to an increase of 2.68% and 0.91% per mGy of dose over the

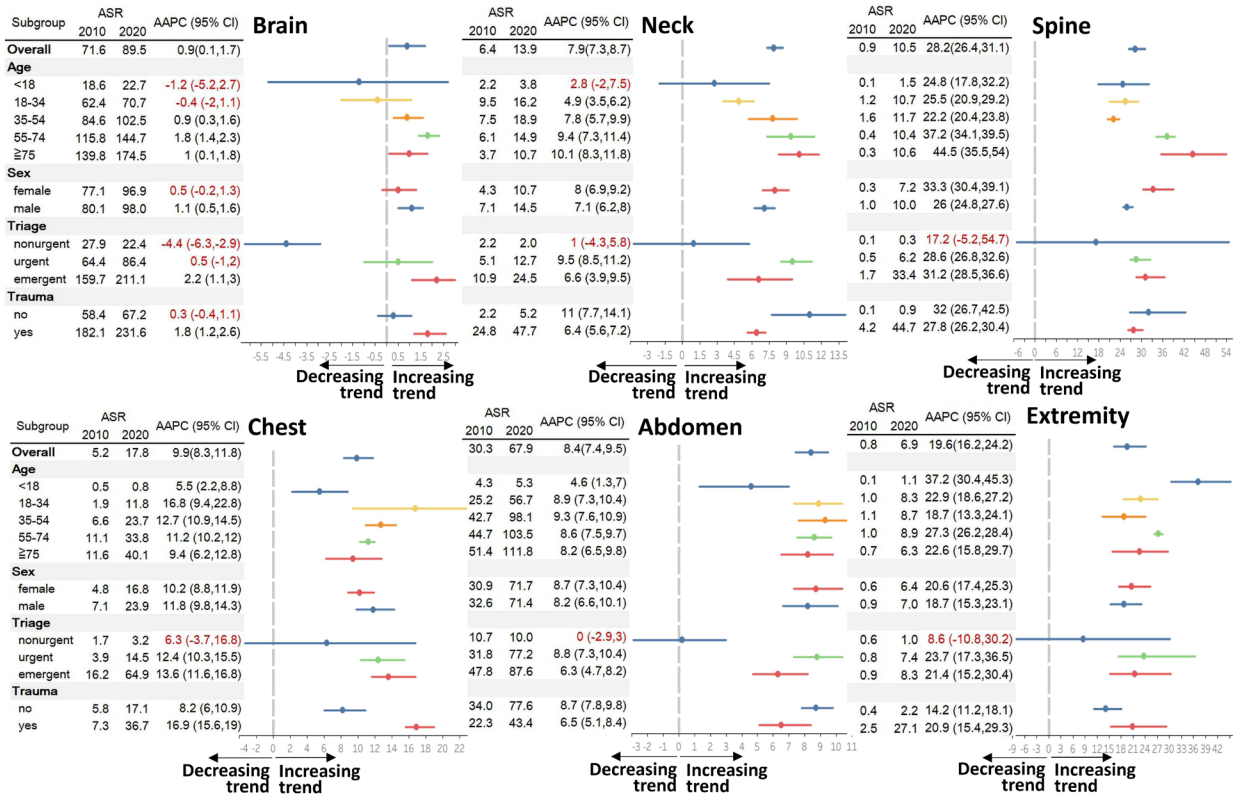

Fig. 4 Subgroup analyses of age-standardized rates (ASRs, per 1,000 emergency department visits) in using each type of computed tomography (CT), and average annual percent changes (AAPCs) with 95% confidence intervals (95% CIs), stratified by age, sex, triage, and trauma status. An AAPC with 95% CI above zero indicates a significant increasing trend. The subgroups without significantly increasing trends were marked with red AAPCs. The forest plots display the generally increasing trends of ASRs in each type of CT, except for brain CT. In addition, there is no increasing trend of ASR in the non-urgent subgroup.

background risk of cancer, respectively.[31] Furthermore, excessive use of CT incurs greater health care costs in a resource-constrained system, with limited benefits and cost-effectiveness for patient care. Thus, reducing the frequency of low-value CT scans is a pivotal priority in the healthcare system.[32] A systematic review summarized the effectiveness of interventions to reduce CT use in ED, including alternate test availability, specialist involvement, diagnostic pathways, clinical decision support, passive dissemination of guidelines, and others.[32] Their results demonstrated that specialist involvement, diagnostic pathways and increasing the availability of alternate tests were the most effective interventions to reduce CT use (by providing ED physicians with another test or opinion). Instead, passive dissemination of guidelines or clinical decision support were not as effective as the above interventions. They also showed the most potential of reducing use in spinal CT compared with other types of CT.[31] The present study may help identify possible targets of CT overuse and control measures for future studies.

The findings of this study should be interpreted cautiously due to the limited external generalizability from single-center data. To address this limitation, age standardization was applied using the age distribution of Taiwan's general population, which yielded consistent results. The risk of measurement bias was low in this study because of the scrutiny of reimbursement claims by Taiwan's Bureau of NHI and the hospital. Despite our efforts to reduce the aging effects and framing bias by using ASR and AAPC, there may be residual confounding factors, such as the unmeasured health status of the study population or physician preference for CT use, that could affect our

results. Finally, evaluating clinical outcomes and the appropriateness of CT use was beyond the scope of this study.

In conclusion, increasing trends of CT use and repeat CT imaging were found in a tertiary ED in Taiwan during 2010 – 2020, even after age standardization with the general population. Marked growth of spine and extremity CT use were also observed. Further investigation is needed to evaluate potential CT overuse in ED.

Supplementary Materials

eTable 1. STROBE Statement—checklist of items that should be included in reports of observational studies.

eTable 2. Trends of any CT use in the ED patients (presenting in annual ASR per 1,000 ED visit) during 2010 – 2020, with age, sex, triage, and trauma stratification.

eFig. 1 The proportion of each type of CT in all ED CT studies, 2010 – 2020.

eFig. 2 Trends of age-standardized rate (ASR) in repeat CT imaging per 1,000 ED visits, stratified by (A) age, (B) sex, (C) triage and (D) trauma subgroups.

Author Contributions

Guarantor of integrity of the entire study: Hao-Ming Li; Study concepts and design: Hao-Ming Li, Shi-Zuo Liu and Liang-Yi Wang; Literature research: Hao-Ming Li and Shi-Zuo Liu; Data acquisition: All the authors; Data analysis: Hao-Ming Li, Shi-Zuo Liu and Liang-Yi Wang; Statistical analysis: Hao-Ming Li, Shi-Zuo Liu and Liang-Yi Wang; Manuscript preparation: Hao-Ming Li and Shi-Zuo Liu; Manuscript editing: All the authors.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of E-Da Hospital (approval number: EMRP-110-181 and date of approval: 2021/12/24).

Informed Consent Statement

Patient consent was waived due to the retrospective nature of the study and the lack of patient interaction.

Data Availability Statement

The datasets generated or analyzed during the study are not publicly available due to the confidentiality policy of the study hospital.

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Conflicts of Interest

The authors declare no conflict of interest.

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