

ORIGINAL RESEARCH



Computed tomography utilization in South Korean Emergency Medical Centers: national trends from 2014 to 2021

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Abstract

Background: The global use of computed tomography (CT) scans in emergency settings is rapidly increasing; however, nationwide data from South Korean Emergency Medical Centers (EMCs) remain limited. **Methods:** We conducted a retrospective cross-sectional analysis using nationwide data from the National Emergency Department Information System, which collects real-time emergency medical information from EMCs across South Korea. Approximately 11 million emergency department (ED) visits involving CT scans at EMCs between 2014 and 2021 were analyzed to evaluate annual trends in CT utilization, as well as trends by EMC level, age group, Korean Triage and Acuity Scale (KTAS), CT scan region, and scan type. **Results:** From 2014 to 2021, the total number of CT scans performed at EMCs increased by 96.97%. The proportion of ED visits involving CT scans (CT utilization proportion) increased from 10.23% in 2014 to 25.67% in 2021 ($p < 0.001$). Subgroups with high CT utilization included patients aged ≥ 80 years, Level I EMC patients, and KTAS Level I cases. The largest increases were observed in patients aged ≥ 80 years (160.34%), Level III EMCs (246.61%), and KTAS Level I cases (98.59%). Among patients aged ≤ 9 years, CT utilization increased by 133.42%. The most common CT scan types were non-contrast brain CT, contrast-enhanced abdominal CT, and non-contrast chest CT, with non-contrast chest CT increasing sharply after 2020. Discrepancies between scanned regions and presenting symptoms have also increased, particularly in chest and abdominal CT scans. **Conclusions:** CT utilization has substantially increased in South Korean EMCs, particularly among subgroups with high-utilization and those vulnerable to radiation exposure. Medical and ethical considerations regarding unnecessary radiation exposure and potential low-value diagnostic imaging (LVDI) should be carefully evaluated. We propose that continuous monitoring and systematic evaluation are essential to ensure appropriate imaging practices and minimize unnecessary radiation exposure.

Keywords

Computed tomography; Emergency medical centers; Diagnostic imaging; Healthcare utilization; Radiation exposure

1. Introduction

As emergency department (ED) visits continue to increase worldwide, ED overcrowding has become an intractable and challenging problem, further intensifying the need for rapid and accurate decision-making [1, 2]. Computed tomography (CT), owing to its speed, high spatial resolution, and broad availability, is widely used in emergency care and can substantially influence physicians' diagnostic impressions and management decisions [3, 4]. However, CT use carries significant risks, including radiation exposure, contrast-related adverse effects, and increased healthcare costs [5–7]. These concerns have led to ongoing efforts to promote appropriate utilization and reduce unnecessary CT imaging [8]. Although CT use has

declined in inpatient and outpatient settings [9], it has steadily increased in EDs [10]. Moreover, CT is now applied to a broad range of clinical scenarios and has become increasingly integrated into routine emergency care [4, 11].

Given these trends, it is essential to understand patterns of CT utilization and identify relevant factors to ensure appropriate and efficient imaging while minimizing unnecessary radiation exposure. Although the substantial increase in emergency CT utilization and its associated risks have prompted the publication of global data, nationwide data on CT utilization in Emergency Medical Centers (EMCs) in Korea remain limited. Therefore, this study aims to investigate nationwide trends and factors associated with CT utilization in EMCs, using comprehensive national emergency medical data from South

Korea.

2. Materials and methods

2.1 Study design and population

This study conducted a retrospective analysis of large data from the National Emergency Medical Information System (NEDIS), a nationwide real-time database of EMCs in South Korea. Among approximately 78 million ED visits recorded from 2014 to 2021, the analysis included 11 million cases with CT scans. Cases with incomplete or missing CT-related data were excluded.

2.2 Data source and collection

NEDIS (National Emergency Department Information System) is a nationwide emergency patient information network established in 2003 by the National Emergency Medical Center (NEMC) and the Ministry of Health and Welfare of South Korea. It collects real-time data on emergency medical services from designated emergency medical centers (EMCs) across the country, aiming to support the development of an advanced emergency medical care system and provide foundational data for research and policy development in emergency medicine. The transmitted data include demographic characteristics, including age and sex, visit details, *e.g.*, time from symptom onset to EMC visit, reason for visit, insurance status, transportation method, chief complaint, Korean Triage and

Acuity Scale (KTAS) scores, treatment resource utilization, and clinical outcomes *e.g.*, discharge status, length of stay. KTAS is a nationwide emergency triage system introduced in 2016 that classifies patient acuity from Level I (most urgent) to Level V (least urgent) based on chief complaints, vital signs, and clinical presentation.

According to the Emergency Medical Care Act, EMCs in South Korea are categorized into Level I, II, and III based on their clinical capabilities and regional responsibilities. Level I EMCs are equipped with specialized personnel and advanced medical resources to provide 24-hour care for critically ill or life-threatening emergency patients and represent the highest level of emergency care. In contrast, Level II and III EMCs provide intermediate and basic emergency care services, respectively, within their local communities. The number of EMCs participating in NEDIS increased from 401 in 2002 (15 Level I, 106 Level II, and 280 Level III) to 422 in 2014 (20 Level I, 121 Level II, and 281 Level III). As of 2021, 404 EMCs were included in NEDIS, comprising 38 Level I, 128 Level II, and 238 Level III centers. During the study period (2014–2021), NEDIS recorded approximately 78.77 million emergency department visits from over 400 participating EMCs across South Korea. Detailed information on the number of EMCs and annual patient visits by EMC level is presented in Table 1. NEMC, under the auspices of the Ministry of Health and Welfare, manages the NEDIS database, and the CT utilization data used in this study were extracted with approval from the NEMC.

TABLE 1. Annual distribution of emergency department visits to Emergency Medical Centers nationwide, 2014–2021.

Year	2014	2015	2016	2017	2018	2019	2020	2021	<i>p</i> -value	95% CI
Total visits (thousands)	10,389	10,314	10,726	10,401	10,609	10,238	7936	8155	0.033	−0.95 to −0.09
EMC (n)	422	418	413	416	404	402	403	404	NA	NA
Level I EMC	20	20	31	36	38	38	38	38	NA	NA
Level II EMC	121	124	120	119	118	124	129	128	NA	NA
Level III EMC	281	274	262	261	248	240	236	238	NA	NA
Age group (thousands)										
≤9	1741	1621	1737	1495	1436	1341	689	654	0.002	−0.98 to −0.56
10–19	915	906	904	819	809	753	475	504	0.002	−0.98 to −0.56
20–29	1173	1182	1211	1185	1205	1180	1006	1054	0.060	−0.94 to 0.04
30–39	1362	1324	1351	1272	1250	1170	942	948	0.001	−0.99 to −0.61
40–49	1397	1376	1392	1350	1345	1258	1016	1029	0.004	−0.98 to −0.45
50–59	1503	1512	1564	1573	1619	1547	1240	1234	0.095	−0.92 to 0.14
60–69	954	1000	1085	1142	1229	1249	1074	1172	0.058	−0.03 to 0.94
70–79	843	850	879	908	974	968	812	837	0.910	−0.68 to 0.73
≥80	500	543	604	657	743	773	681	723	0.007	0.37 to 0.97
Gender (thousands)										
Male	5422	5375	5542	5352	5416	5222	4093	4095	0.017	−0.96 to −0.22
Female	4967	4939	5184	5049	5193	5016	3843	4060	0.064	−0.94 to 0.05

EMC: Emergency Medical Center; CI: confidence interval; NA: Not Available.

Values for patient visits are presented in thousands.

2.3 Statistical analysis

All statistical analyses were performed using R software (version 4.2.2; R Foundation for Statistical Computing, Vienna, Austria) and MedCalc (version 19.4.1; MedCalc Software, Ostend, Belgium). Cases with missing values were excluded from the analysis. The primary outcomes were the total number of CT scans and CT utilization, defined as the proportion of ED visits involving CT. Data were stratified by EMC level, patient demographics, Korean Triage and Acuity Scale (KTAS) level, anatomical scan region, and CT scan type.

Temporal trends were assessed using linear regression for continuous variables and the Cochran-Armitage trend test for categorical variables. Chi-square tests were used to compare proportions across EMC levels, demographic subgroups, and KTAS levels, while Analysis of Variance (ANOVA) or Kruskal-Wallis tests were applied to continuous variables, as appropriate. Statistical significance was defined as $p < 0.05$. All estimates are reported with corresponding p -values and 95% confidence intervals (CIs).

3. Results

3.1 Patient demographics and trends in Emergency Medical Center visits (2014–2021)

The annual number ED visits to EMCs across South Korea remained stable at approximately 10.38 million per year from 2014 to 2019. This trend was followed by a notable decline to 7.94 million visits in 2020, with a partial recovery to 8.16 million visits in 2021 (Table 1). Age-specific distribution data revealed that in 2014, patients aged ≤ 9 years accounted for

the highest number of visits, whereas those aged ≥ 80 years accounted for the fewest. However, visit volumes among the ≤ 9 -year-old group declined steadily over the study period, becoming the second lowest volume age group by 2021, with only the 10–19-year-old group having fewer visits. By 2021, the highest visit volumes were observed among individuals in their 50s, 60s, and 20s. Throughout the study period, male patients consistently outnumbered female patients; however, the difference between male and female patients gradually narrowed, with the proportion of male patients declining from 52.19% in 2014 to 50.22% in 2021 ($p = 0.017$, 95% CI: -0.96 to -0.22).

The distribution of visit volumes by EMC level and institution showed that in 2014, approximately 0.97, 4.40, and 3.83 million visits occurred at Level I, II, and III EMCs, respectively (Supplementary Fig. 1). By 2021, visits to Level I EMCs increased to 1.54 million, while those to Level II and III EMCs decreased to 3.40 million and 2.45 million, respectively. The average number of visits per EMC remained stable from 2014 to 2019 but declined across all levels beginning in 2020. Level I EMCs consistently recorded the highest number of visits per institution, whereas Level III EMCs had the lowest.

3.2 Trends in annual CT utilization in nationwide EMCs (2014–2021)

From 2014 to 2019, the total number of CT scans performed in EMCs increased by 87.47%, rising from approximately 1.06 million to 1.99 million (Fig. 1). Although the upward trend was temporarily reversed in 2020, with the number of scans decreasing to 1.88 million, it rebounded to 2.09 million in

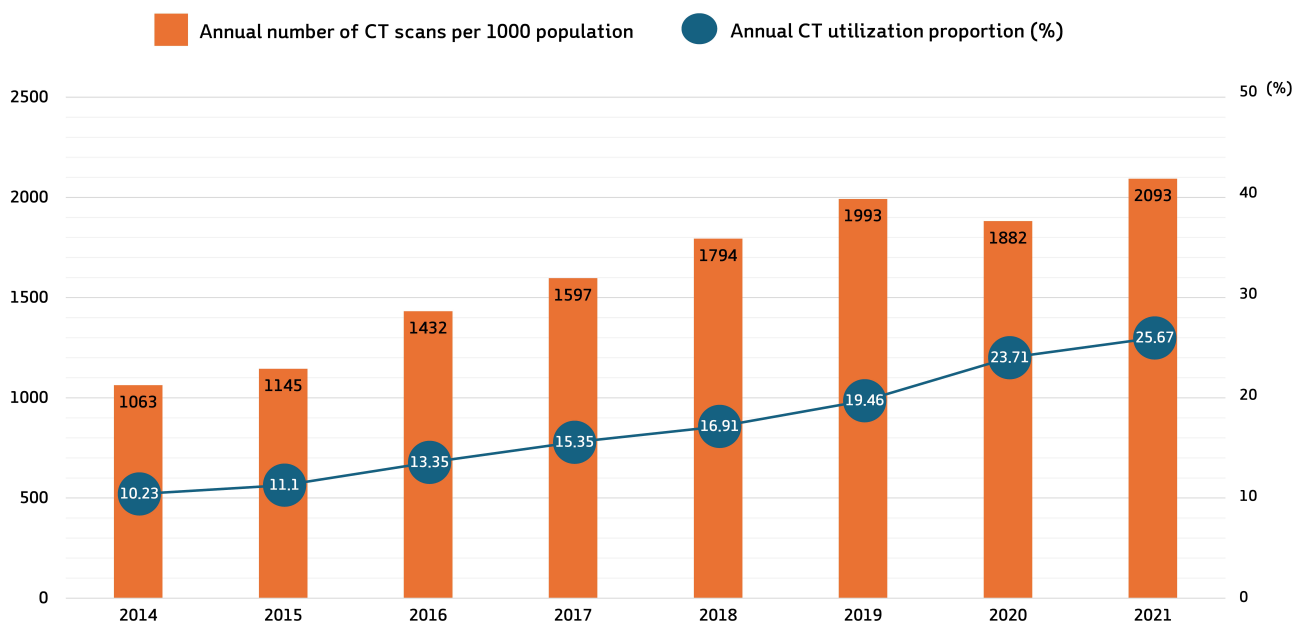


FIGURE 1. Annual number of computed tomography (CT) scans and CT utilization proportion at Emergency Medical Centers (EMCs) in South Korea, 2014–2021. From 2014 to 2019, the total number of CT scans (bar graph) increased by 87.47%, from approximately 1.06 million to 1.99 million. Although this number declined to 1.88 million in 2020, it rebounded to 2.09 million in 2021, representing a 96.97% increase from 2014. The CT utilization proportion (line graph) followed a similar upward trend until 2019 but continued to rise to 23.71% in 2020 despite a temporary decrease in scan volume. In 2021, both total CT scans and CT utilization proportion increased in parallel.

2021, marking a 96.97% increase compared with 2014.

The CT utilization proportion also showed a consistent upward trend, increasing from 10.23% in 2014 to 25.67% in 2021 ($p < 0.001$, 95% CI: 0.93–0.99). While both the total scan volume and CT utilization proportion increased in parallel until 2019, CT utilization continued to rise in 2020, reaching 23.71%, despite a temporary decline in total scan volume. By 2021, both indicators resumed their upward trends.

In terms of gender, the CT utilization proportion was 10.75% for males and 9.66% for females in 2014 (**Supplementary Fig. 2**). By 2021, these figures had increased to 26.69% ($p < 0.001$, 95% CI: 0.93–1.00) for males and 24.64% ($p < 0.001$, 95% CI: 0.93–1.00) for females. Throughout the study period, males consistently exhibited higher CT utilization than females.

3.3 Trends in annual CT utilization by age group (2014–2021)

From 2014 to 2021, the number of CT scans increased across most age groups, except for patients aged ≤ 9 years (Table 2). Although scan volumes declined markedly in 2020 across all age groups except among patients aged ≥ 80 years, they rebounded in 2021.

In 2014, the highest number of CT scans was observed among patients in their 50s, 70s, and 40s, whereas by 2021, patients aged ≥ 80 years accounted for the largest number of scans, followed by those in their 60s and 70s. Patients aged ≤ 9 years consistently had the lowest number of scans throughout the study period. Between 2014 and 2021, the annual number of CT scans decreased by 15.50% ($p = 0.218$, 95% CI: -0.89 to 0.33) in patients aged ≤ 9 years but increased by 284.81% ($p < 0.001$, 95% CI: 0.97–0.99) in those aged ≥ 80 years.

CT utilization showed a consistent upward trend across all age groups (Fig. 2; **Supplementary Table 1**). In 2021, the highest CT utilization was observed among patients aged ≥ 80 years (57.38%), followed by those aged 70–79 years (47.07%) and 60–69 years (35.80%). The largest relative increase in CT utilization over the study period was observed in patients aged ≥ 80 years (160.34%; $p < 0.001$, 95% CI: 0.97 to 0.99), followed by those aged ≤ 9 years (133.42%; $p = 0.003$, 95% CI: 0.48 to 0.98).

3.4 Trends in annual CT utilization by EMC level and institution (2014–2021)

CT utilization across EMC levels showed a consistent upward trend from 2014 to 2021, despite a temporary decline in 2020 (Fig. 3A). The number of CT scans performed in Level I, II, and III EMCs increased from approximately 201,000, 690,000, and 168,000 in 2014 to 596,000, 1,122,000, and 374,000 in 2021, respectively. These changes correspond to relative increases of 196.03% ($p < 0.001$, 95% CI: 0.65–0.99) for Level I, 62.49% ($p < 0.001$, 95% CI: 0.87–0.99) for Level II, and 122.01% ($p < 0.001$, 95% CI: 0.69–0.99) for Level III EMCs, respectively.

CT utilization also increased across all EMC levels, with the highest utilization consistently observed in Level I EMCs (Fig. 3B). Between 2014 and 2021, CT utilization increased from 21.0%, 15.0%, and 4.0% to 39.0%, 33.0%, and 15.0% for Level I, II, and III EMCs, respectively. These represent relative increases of 87.00% ($p < 0.001$, 95% CI: 0.87–0.99) for Level I, 110.18% ($p < 0.001$, 95% CI: 0.95–0.99) for Level II, and 246.61% ($p < 0.001$, 95% CI: 0.93–0.99) for Level III.

The average number of CT scans per EMC institution also increased across all levels (**Supplementary Fig. 3**). Level I EMCs consistently recorded the highest numbers of scans per institution, while Level III EMCs recorded the lowest. By 2021, the average number of scans per institution reached 15,700 for Level I, 8800 for Level II, and 1600 for Level III, corresponding to increases of 55.81%, 53.61%, and 162.13%, respectively.

3.5 Trends in annual CT utilization by triage severity (KTAS, 2016–2021)

According to KTAS data, which were introduced in 2016, the highest numbers of CT scans between 2016 and 2021 were performed in KTAS Levels III, IV, and II, whereas Levels I and V consistently recorded the lowest numbers of scans (Fig. 4A).

CT utilization steadily increased in KTAS levels I, II, and III from 2016 to 2021, with the highest utilization observed in KTAS level I ($p = 0.002$, 95% CI: 0.69–1.00) (Fig. 4B). The most pronounced increase occurred in KTAS level I (98.59%), whereas KTAS level V exhibited a 10.45% decline over the same period.

TABLE 2. Annual distribution of CT scans by age group, 2014–2021(thousands).

Year	2014	2015	2016	2017	2018	2019	2020	2021	<i>p</i> -value	95% CI
Age group (thousands)										
≤ 9	45.31	41.97	49.15	44.64	44.24	49.18	36.29	38.29	0.218	-0.89 to 0.33
10–19	71.61	71.66	82.71	82.83	83.86	88.30	67.22	77.76	0.719	-0.62 to 0.77
20–29	94.47	102.15	124.90	133.63	143.26	158.11	152.57	174.05	<0.001	0.87 to 1.00
30–39	113.37	118.01	144.25	150.54	159.52	172.76	156.17	167.18	0.003	0.49 to 0.98
40–49	147.16	152.16	183.55	198.54	211.21	227.14	206.30	218.53	0.003	0.51 to 0.98
50–59	185.85	197.49	244.93	271.36	299.34	326.14	296.95	310.51	0.002	0.58 to 0.98
60–69	143.03	160.01	210.63	244.27	283.25	323.50	317.73	367.45	<0.001	0.93 to 0.99
70–79	163.14	180.59	225.94	261.64	305.03	335.34	323.68	359.09	<0.001	0.87 to 0.99
≥ 80	98.91	121.06	166.39	209.38	264.22	312.07	324.71	380.63	<0.001	0.97 to 0.99

CT: computed tomography; CI: confidence interval.

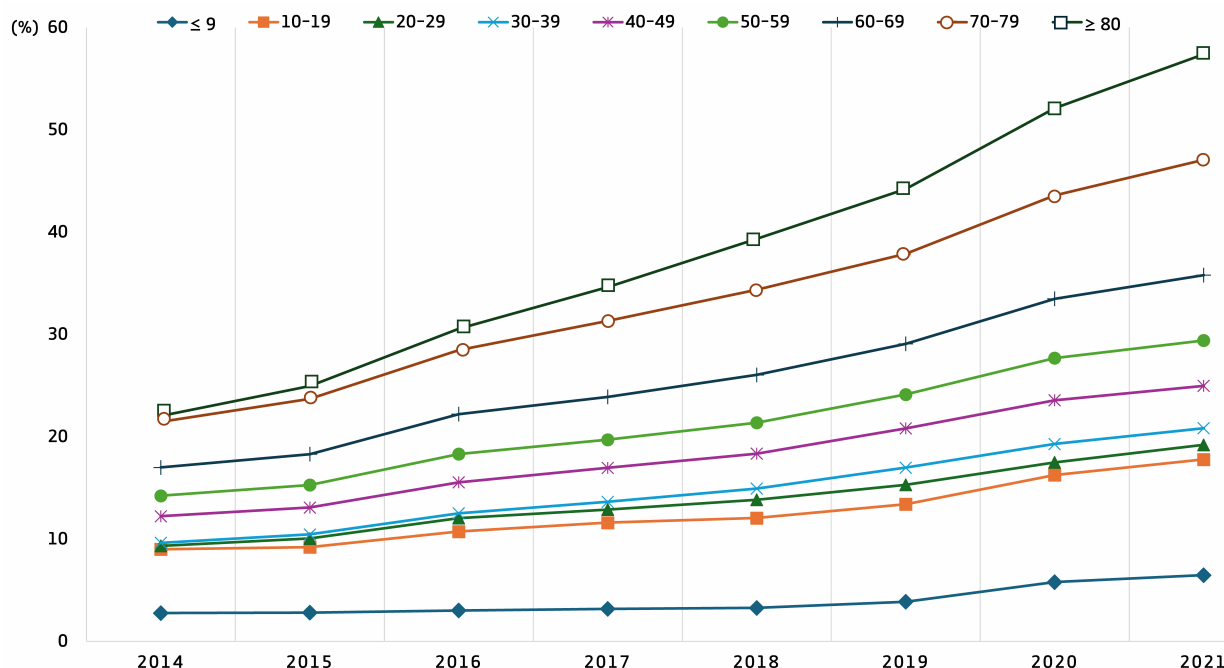


FIGURE 2. Annual CT utilization proportion by age group at Emergency Medical Centers (EMCs), 2014–2021. From 2014 to 2021, the CT utilization proportion increased across all age groups, although the magnitude of increase varied. In 2021, CT utilization was highest among patients aged ≥ 80 years (57.38%), followed by those aged 70–79 years (47.07%) and 60–69 years (35.80%), and lowest among those aged ≤ 9 years (6.48%). Compared with 2014, CT utilization increased by 160.34% in patients aged ≥ 80 years ($p < 0.001$, 95% CI: 0.97–0.99), 119.00% in those aged 70–79 years ($p < 0.001$, 95% CI: 0.97–0.99), 110.59% in those aged 60–69 years ($p < 0.001$, 95% CI: 0.96–0.99), and 133.42% in those aged ≤ 9 years ($p = 0.003$, 95% CI: 0.48–0.98).

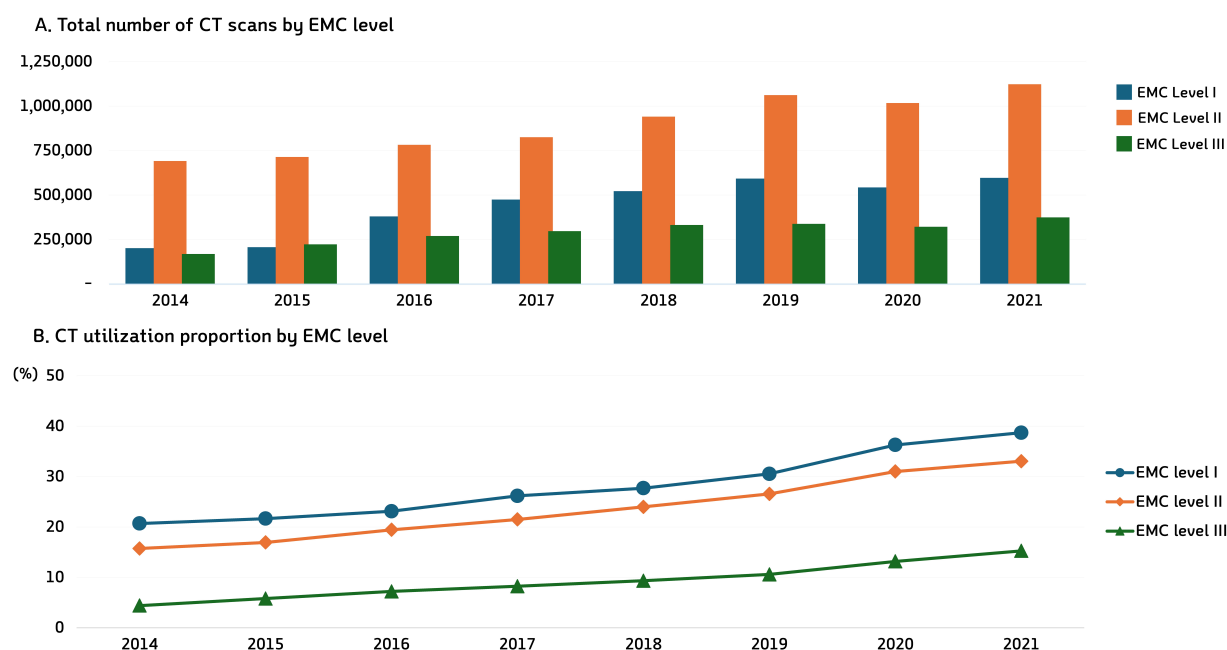
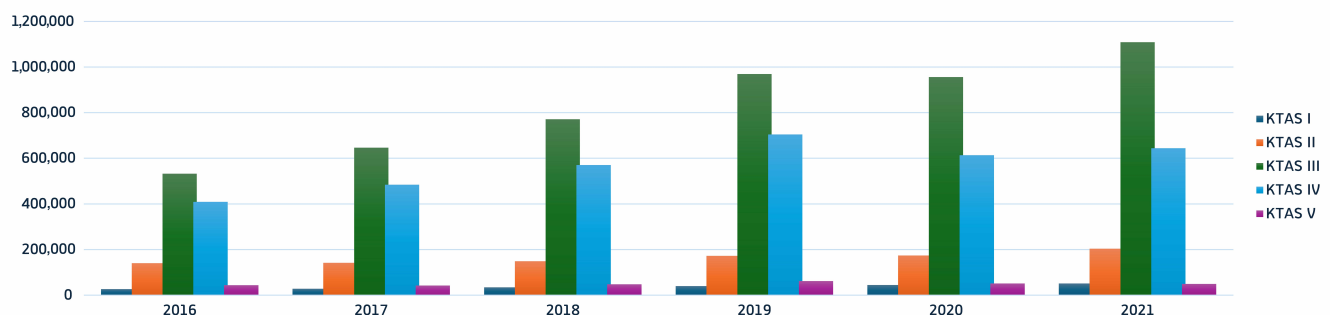


FIGURE 3. Annual number of computed tomography (CT) scans and CT utilization proportion by Emergency Medical Center (EMC) level, 2014–2021. (A) Total number of CT scans by EMC level (bar chart). From 2014 to 2019, CT scan volumes steadily increased across all EMC levels, followed by a decline in 2020 and a rebound in 2021. In 2021, Level II EMCs performed the highest total number of CT scans, while Level III EMCs had the lowest volume but showed the largest relative increase. (B) CT utilization by EMC level (line chart). CT utilization proportion was highest in Level I EMCs and increased across all levels during the study period. Between 2014 and 2021, it rose by 86.98%, 110.21%, and 246.61% in Level I, II, and III EMCs, respectively. The difference in CT utilization between Level I and II EMCs narrowed until 2019 but widened to 5.65% in 2021.

(A) Total number of CT scans by KTAS level



(B) CT utilization proportion by KTAS level

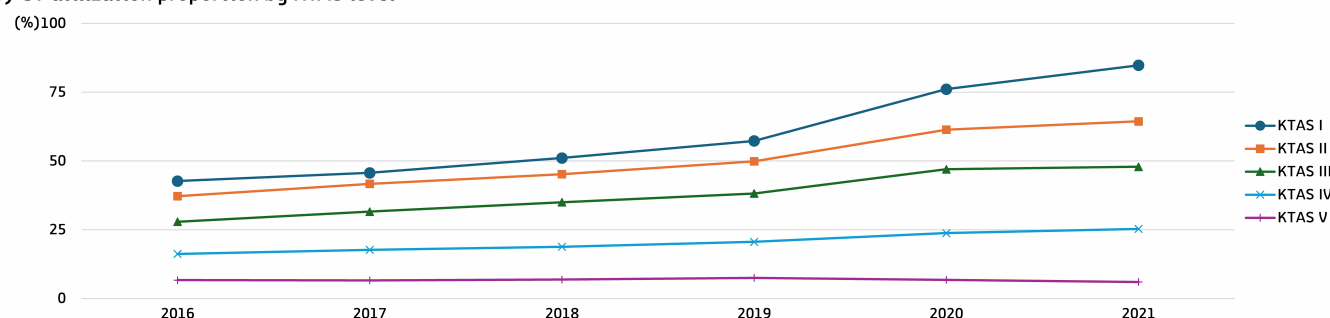


FIGURE 4. Annual number of computed tomography (CT) scans and CT utilization proportion by Korean Triage and Acuity Scale (KTAS) level at Emergency Medical Centers, 2016–2021. (A) Total number of CT scans by KTAS level (bar chart). From 2016 to 2021, the highest CT scan volumes were recorded in KTAS levels III, IV, and II, whereas levels I and V accounted for the lowest volumes. (B) CT utilization by KTAS level (line chart). CT utilization was highest in KTAS levels I, II, and III and demonstrated a continuous upward trend during the study period ($p = 0.002$, 95% CI: 0.69–1.00 for KTAS I; $p < 0.001$, 0.82–1.00 for KTAS II; $p < 0.001$, 0.83–1.00 for KTAS III). Over these six years, the most substantial increases in CT utilization proportion were observed in KTAS level I (98.59%) and level II (73.12%), whereas KTAS level V showed a 10.45% decrease.

3.6 Trends in annual CT utilization by scan region (2014–2021)

In 2014, non-contrast brain CT (49.98%), contrast-enhanced abdominal CT (23.11%), and contrast-enhanced chest CT (8.02%) were the most frequently performed CT scans in Korean EMCs (Table 3). Although non-contrast brain CT remained the most commonly performed scan throughout the study period, its utilization proportion declined by 23.17% during this period ($p < 0.001$, 95% CI: -0.99 to -0.91). In contrast, non-contrast chest CT utilization increased significantly, particularly in 2020, showing a 159.73% rise from 2014 to 2021 ($p < 0.001$, 95% CI: 0.88–0.99). By 2021, the top three most frequently performed CT scans were non-contrast brain CT (38.40%), contrast-enhanced abdominal CT (22.73%), and non-contrast chest CT (11.74%).

3.7 Distribution of primary presenting symptoms associated with CT scans (2014–2021)

Headache, dizziness, and syncope were consistently the most common presenting symptoms associated with non-contrast brain CT scans throughout the study period (Table 4 and Supplementary Table 2). Brain CT scans performed for fever were relatively rare; however, the proportion increased from 1.67% in 2018 to 1.92% in 2021 ($p < 0.001$, 95%

CI: 0.62–0.99). For contrast-enhanced abdominal CT scans, abdominal pain and fever were the leading presenting symptoms, followed by localized abdominal pain. Notably, the proportion of abdominal CT scans performed for dyspnea increased significantly from 1.50% in 2014 to 3.80% in 2021 ($p < 0.001$, 95% CI: 0.82–0.99). Moreover, in 2021, the most common symptoms associated with non-contrast chest CT scans were dyspnea, fever, and abdominal pain. Notably, the proportion of non-contrast chest CT scans performed for abdominal pain increased sharply to 6.13% in 2020, and abdominal pain remained the third most common presenting symptom for this imaging modality in 2021 ($p = 0.020$, 95% CI: 0.16–0.96).

4. Discussion

Analyzing nationwide data from EMCs spanning 2014 to 2021, this study identified a continuous increase in the proportion of ED visits involving CT, rising from 10.23% to 25.67%, respectively, representing an overall growth of 150.91%, despite relatively stable EMC visit volumes during the same period. CT use was particularly prominent among Level I EMCs, patients aged ≥ 80 years, and those classified as KTAS Level I. The most frequently performed CT scan types were non-contrast brain CT, contrast-enhanced abdominal CT, and non-contrast chest CT, with the latter showing the largest increase

TABLE 3. Annual distribution of computed tomography scans by scanning region (2014–2021).

Year	2014	2015	2016	2017	2018	2019	2020	2021	p-value	95% CI
Total CT scans (thousands)	1062	1145	1432	1596	1793	1992	1881	2093	<0.001	0.84 to 0.99
CT type (%)										
Brain, non-contrast	49.98	48.27	46.75	45.51	43.87	42.72	38.47	38.40	<0.001	−0.99 to −0.91
Abdomen, contrast-enhanced	23.11	22.47	22.76	23.05	23.50	24.02	23.16	22.73	0.468	−0.53 to 0.83
Chest, contrast-enhanced	8.02	8.24	8.30	8.80	9.59	10.06	10.50	11.34	<0.001	0.88 to 0.99
Abdomen, non-contrast	5.36	6.06	6.31	6.56	6.86	6.99	7.73	7.88	<0.001	0.91 to 0.99
Chest, non-contrast	4.52	5.65	6.53	7.00	7.82	8.13	12.24	11.74	<0.001	0.88 to 0.99
Face, non-contrast	3.67	3.64	3.76	3.51	3.20	2.92	2.50	2.23	<0.001	−0.98 to −0.69
Spine, non-contrast	1.96	2.08	2.06	2.10	2.03	2.10	2.34	2.39	0.009	0.33 to 0.97
Brain, contrast-enhanced	1.21	1.13	0.99	0.90	0.79	0.63	0.54	0.59	<0.001	−0.99 to −0.91
Neck, contrast-enhanced	0.88	0.80	0.85	0.88	0.84	0.85	0.75	0.79	0.129	−0.91 to 0.20
Extremity, non-contrast	0.70	1.02	1.08	1.08	0.95	1.02	1.23	1.37	0.016	−0.49 to 0.84
Neck, non-contrast	0.23	0.24	0.21	0.22	0.17	0.19	0.21	0.21	0.177	−0.89 to 0.27
Face, contrast-enhanced	0.16	0.16	0.18	0.19	0.18	0.18	0.15	0.14	0.420	−0.84 to 0.48
Spine, contrast-enhanced	0.10	0.13	0.11	0.11	0.08	0.08	0.08	0.07	0.013	−0.96 to −0.26
Extremity, contrast-enhanced	0.10	0.12	0.10	0.12	0.12	0.13	0.10	0.12	0.441	−0.49 to 0.84

CT: computed tomography; CI: confidence interval.

TABLE 4. Annual distribution of the top 5 presenting symptoms associated with selected CT scans types 2014–2021 (%).

2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)	2019 (%)	2020 (%)	2021 (%)
Non-contrast brain CT							
Headache (18.4)	Headache (18.73)	Headache (19.02)	Headache (18.63)	Headache (18.44)	Headache (18.64)	Headache (16.45)	Headache (17.17)
Dizziness (12.26)	Dizziness (12.97)	Dizziness (14.02)	Dizziness (14.66)	Dizziness (15.22)	Dizziness (15.48)	Dizziness (15.10)	Dizziness (16.54)
Syncope (3.29)	Syncope (3.37)	Syncope (3.79)	Syncope (3.95)	Syncope (4.11)	Syncope (4.11)	Syncope (3.91)	Syncope (3.86)
CC trauma (2.81)	Scalp laceration (2.53)	Scalp laceration (2.28)	CC trauma (2.44)	CC trauma (2.59)	CC trauma (3.04)	CC trauma (3.49)	CC trauma (3.40)
Contrast-enhanced abdominal CT							
Abd pain (37.69)	Abd pain (35.77)	Abd pain (36.87)	Abd pain (36.21)	Abd pain (35.69)	Abd pain (35.44)	Abd pain (35.21)	Abd pain (34.06)
Fever (7.38)	Fever (8.42)	Fever (9.11)	Fever (9.77)	Fever (10.38)	Fever (11.18)	Fever (10.83)	Fever (10.39)
RLQ pain (5.10)	RLQ pain (4.87)	RLQ pain (4.53)	RLQ pain (4.13)	Epi pain (4.06)	Epi pain (4.11)	Epi pain (4.33)	Epi pain (4.27)
Epi pain (3.99)	Epi pain (4.21)	Epi pain (3.82)	Epi pain (3.99)	RLQ pain (3.83)	RLQ pain (3.52)	RLQ pain (3.50)	Dyspnea (3.81)
Flank pain (2.06)	Flank pain (2.06)	Rt Flank pain (2.16)	Rt Flank pain (2.23)	Dyspnea (2.54)	Dyspnea (2.64)	Dyspnea (3.07)	RLQ pain (3.64)
Non-contrast chest CT							
Dyspnea (21.63)	Dyspnea (22.57)	Dyspnea (23.78)	Dyspnea (23.81)	Dyspnea (23.44)	Dyspnea (21.77)	Dyspnea (15.99)	Dyspnea (17.10)
Fever (12.88)	Fever (14.54)	Fever (15.94)	Fever (15.92)	Fever (16.54)	Fever (16.98)	Fever (13.56)	Fever (11.38)
Mastodynia (5.26)	Mastodynia (5.01)	Mastodynia (4.56)	Chest wall pain (4.79)	Asthenia (5.04)	Chest wall pain (5.17)	Abd pain (6.13)	Abd pain (5.81)
Chest wall pain (4.89)	Asthenia (4.43)	Chest wall pain (4.49)	Asthenia (4.60)	Chest wall pain (4.76)	Asthenia (4.85)	Asthenia (4.81)	Asthenia (5.35)
Asthenia (3.97)	Chest wall pain (4.26)	Asthenia (4.46)	Mastodynia (4.44)	Mastodynia (4.27)	Cough (4.21)	Chest wall pain (3.73)	Mastodynia (4.01)

Abd pain: abdominal pain; CT: computed tomography; RLQ pain: right lower quadrant pain; Epi pain: epigastric pain; Rt: right; CC trauma: Craniocerebral Trauma.

during the latter part of the study period, particularly after the onset of the COVID-19 pandemic.

Even without a marked increase in overall EMC visits, CT utilization in South Korean EMCs increased continuously, indicating a growing reliance on CT imaging in recent years. In 2020 and 2021, decreases in both ED visits and total CT scan numbers coincided with the COVID-19 pandemic, which began spreading nationwide in Korea in January 2020. Despite the reduced number of patient visits during the pandemic, the annual CT utilization rate per ED visit continued to rise, consistent with previous studies reporting increased CT utilization during the pandemic [12–14]. One explanation for the increased use of chest CT during this period is its higher diagnostic sensitivity for detecting pulmonary lesions at a time when physical examinations, such as auscultation, were limited [15, 16]. Several studies have suggested that even after the pandemic, the continued decline in chest radiography and sustained increase in chest CT utilization may reflect an evolving shift in imaging practice patterns, particularly in emergency care [13, 14]. In the present study, chest CT utilization demonstrated a more rapid increase than utilization of CT scans of other anatomical regions through 2021, even as the acute phase of the pandemic began to subside. This observation may signal an emerging change in chest CT utilization in Korea; however, additional post-pandemic data will be needed to confirm and further elucidate this trend.

Older adults account for a substantial proportion of ED visits, with previous studies reporting that they comprise approximately 12%–24% of all ED visits [17]. This proportion is expected to increase further with ongoing population aging. Our nationwide analysis of Korean EMC data similarly revealed a sustained increase in EMC visits among elderly patients. Notably, the utilization rate of CT scans in this age group, particularly those aged 80 years or older, has increased to exceed the increase in visit volume, a trend consistent with findings from other studies [18]. The increased use of CT scans in elderly patients likely reflects emergency physicians' assessment that the benefits of CT scans in terms of accessibility and diagnostic utility outweigh the risks of radiation exposure [3, 19, 20]. CT utilization in EMCs may facilitate reduction in ED length of stay and improve both the timeliness and appropriateness of triage to definitive care pathways for elderly patients. However, imaging that does not align with professional standards or clinical guidelines, is used inappropriately, or offers limited clinical value may be classified as low-value diagnostic imaging (LVDI) [21]. CT scans categorized as LVDI offer minimal or no clinical benefit while exposing patients to unnecessary risks from ionizing radiation and contrast agents, and also contribute to increased healthcare costs. Studies have estimated that broader wasteful healthcare spending accounts for 10% to 34% of total healthcare expenditure, and 20% to 50% of diagnostic imaging may be classified as low-value [21, 22]. As CT utilization continues to rise among elderly patients in emergency settings, there is a growing need to evaluate the potential for LVDI within this population. However, due to the diversity of clinical symptoms and the complexity of clinical decision-making in EMCs, determining the appropriateness of CT scans and identifying instances of LVDI remains challenging. With

ongoing population aging and increasing CT utilization among elderly patients, continuous monitoring and targeted research are essential to better understand patterns of CT use and evaluate the balance between the diagnostic benefits and potential risks in this elderly patient population.

Recognizing the imperative to minimize unnecessary radiation exposure in the pediatric population, Korean clinical studies have evaluated low-dose CT protocols, and age-based diagnostic reference levels for pediatric CT have been established in Korea [23–25]. In this study, patients aged ≤ 9 years recorded the lowest total CT scan volume among all age groups, with a 15.5% decrease observed between 2014 and 2021. However, this decline in scan volume occurred alongside a 2.33-fold increase in CT utilization, indicating that the lower volume may have been driven primarily by a reduction in pediatric EMC visits than reduction in CT use per ED visit. Because CT radiation exposure in pediatric patients primarily occurs in the ED, systematic interventions are warranted to reduce potentially unnecessary CT utilization corresponding to LVDI in EMCs [26, 27]. To maintain appropriate CT use while minimizing LVDI, a multifaceted approach is required, including strict adherence to clinical guidelines, enhanced provider education, real-time feedback systems, and sustained governmental policy support [28–30].

Level I EMCs are equipped to perform advanced imaging studies necessary for the diagnosis and treatment of critically ill patients on a 24-hour basis. In our study, CT utilization was highest in Level I EMC facilities. Furthermore, CT utilization was highest among critically ill patients classified as KTAS Level I. These findings indicate that CT utilization was higher in facilities that treat critically ill patients. In contrast, Level III EMCs, which manage a smaller volume of critically ill patients and are not legally required to have CT equipment, showed the lowest overall CT utilization. However, the relative increase in the CT utilization in Level III EMCs was greater than that observed in Level I and II EMCs. This may reflect improved access to CT scanning for Level III EMCs and a broader range of imaging indications. The increase in CT scans in Level III EMCs may have implications for emergency medical policy and warrants further investigation, including the population and types of scans.

Previous single-institution studies have reported substantial increases in CT imaging of the bones, neck, and blood vessels over a 10-year period [31]. However, our nationwide analysis demonstrated that brain, abdominal, and chest CT scans remain the most frequently performed imaging studies at EMCs in South Korea. This highlights the importance of conducting nationwide studies, as regional or institutional data may not fully capture national patterns of imaging trends. The findings suggest that CT scans in South Korea are still predominantly used to evaluate the brain and other major organ systems.

Our analysis of the distribution of CT scans by anatomical region in relation to patients' presenting symptoms revealed instances of discordance between the scanned anatomical region and the primary complaint, with a gradual increase in such discordance observed over time. Further investigation of these patterns and their underlying causes may provide meaningful insights for evaluating the appropriateness of CT utilization. However, this analysis was limited by its reliance

on a single chief complaint classification, which may not fully reflect the complexity of clinical reasoning underlying imaging decisions. Moreover, we were unable to directly assess the relationship between presenting symptoms and CT findings, making it difficult to determine the precise reasons for the observed discordance given the inherent limitations of the dataset. More comprehensive assessments incorporating detailed clinical information and decision-making data are needed to better evaluate the appropriateness of CT utilization.

Multi-region CT scanning enables comprehensive evaluation of multiple anatomical regions in a single acquisition, potentially reducing the need for additional studies, resolving diagnostic uncertainty, and improving diagnostic accuracy, particularly in complex cases involving multiple organ systems [32]. Recent studies have reported a growing trend in multi-region CT utilization in EDs [33, 34]. We hypothesize that the increasing use of multi-region CT scans may partially explain the observed discordance between presenting symptoms and scanned regions. However, multi-region CT scans may also raise concerns regarding unnecessary radiation exposure, increased healthcare costs, and potential overuse of healthcare resources, potentially contributing to low-value diagnostic imaging (LVDI) [21, 35]. Although understanding patterns of multi-region CT utilization is essential, their appropriateness and clinical rationale remain challenging to assess using administrative data alone. Further studies investigating discordance between presenting symptoms and scanned anatomical regions, as well as multi-region CT utilization in EMCs are warranted to guide more appropriate CT utilization in EMCs.

This study has several limitations. First, as with other analyses based on national administrative data, potential inaccuracies may exist due to manual data entry errors, missing or duplicated data, inter-hospital variability in diagnostic and procedure coding, and heterogeneity across different Electronic Medical Record (EMR) systems. Second, no imputation was performed for missing data, which may have affected the results. Third, the inability to examine associations between variables at the individual patient level limited definitive interpretations. Fourth, the absence of standardized appropriateness criteria precluded formal evaluation of the clinical justification for CT utilization. Fifth, due to the lack of multivariate modeling, potential confounding could not be fully accounted for, which may affect results interpretation. Sixth, subgroup and sensitivity analyses were not performed, which may limit the robustness and granularity of some findings. Future studies incorporating these analyses may provide more detailed insights into CT utilization patterns across different patient subgroups. Nevertheless, this study represents the first nationwide analysis of CT utilization in South Korean Emergency Medical Centers, using comprehensive national emergency care data to characterize current trends and identify areas for future investigation.

5. Conclusions

From 2014 to 2021, CT utilization in South Korean EMCs increased continuously, particularly among subgroups with higher CT utilization, including patients treated at Level I EMCs, patients aged ≥ 80 years, and those classified as KTAS

Level I, despite a decline in overall patient volumes during the COVID-19 pandemic. Notably, CT utilization also increased among radiation-sensitive populations, including pediatric patients aged ≤ 9 years. These findings highlight the need for careful medical and ethical considerations of radiation exposure, potential long-term risks, and the possibility of LVDI, as well as the need to balance diagnostic benefit and potential harm, particularly among subgroups with high CT utilization and radiation-sensitive pediatric patients. Therefore, we propose that continuous monitoring, systematic evaluation, and evidence-based imaging guidelines are essential to ensure appropriate CT utilization in South Korean EMCs, prevent unnecessary LVDI, and minimize avoidable radiation exposure.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

SYP and IHY—designed the research study and wrote the manuscript. JKK—performed the research. IHY, JKK and SML—analyzed the data. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Institutional Review Board (IRB No. KNUCH 2022-09-008) of Kyungpook National University Chilgok Hospital. The requirement for informed consent was waived by the IRB of Kyungpook National University Chilgok Hospital due to the retrospective nature of the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at <https://oss.signavitae.com/mre-signavitae/article/2114984895220465664/attachment/Supplementary%20material.docx>.

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