



National Trends in Pediatric CT Scans in South Korea: A Nationwide Cohort Study

소아 전산화단층촬영의 국내 동향: 전국적 코호트 연구

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Purpose This study evaluated the rates and annual trends of pediatric CT scans in South Korea using a nationwide population-based database.

Materials and Methods Data regarding pediatric CT scan usage between 2012 and 2017 were retrieved from the health insurance review and assessment service. Data on the age, sex, diagnosis, and the anatomical area of involved patients were also extracted.

Results A total of 576376 CT examinations were performed among 58527528 children aged below 18 years (9.8 scans/1000 children), and the number of CT examinations per 1000 children was noted to have increased by 23.2% from 9.0 in 2012 to 11.0 in 2017. Specifically, the number of CT examinations increased by 32.9% for the 6–12 years of age group (7.4/1000 to 9.8/1000) and by 34.0% for the 13–18 years of age group (11.4/1000 to 15.3/1000). Moreover, majority of the CT scans were limited to the head (39.1%), followed by the extremities (32.5%) and the abdomen (13.7%). Notably, the number of extremity CT scans increased by 83.6% (2.3/1000 to 4.2/1000), and its proportion as compared to other scans increased from 25.3% to 37.7%.

Conclusion CT scans in the pediatric population increased continuously from 2012 to 2017 at an annual rate of 4.4%. Therefore, physicians should balance the benefits of CT with its potential harms from associated radiation exposure in pediatric patients.

Index terms Computed Tomography, X-Ray; Child; Radiation

INTRODUCTION

CT is an important and powerful X-ray-based imaging tool that allows a cross-sectional analysis of the internal organs, bones, soft tissues, and blood vessels. The use of CT has increased worldwide during the past few decades, because it provides information that enables an accurate diagnosis and effective treatment (1-3).

However, there have been growing concerns regarding CT and the associated expo-

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sure of low-dose ionizing radiations (4-6). The biological hazards of such radiations have been well known since the atomic bombings in Japan that increased the risk of cancers in the victims (7, 8). The ionizing radiation dose delivered by CT is 100–500 times higher than that by conventional radiography and accounts for approximately half of the total annual medical radiation exposure (2, 9, 10).

Children are particularly susceptible to the long-term carcinogenic effects of ionizing radiations, secondary to the body size and the remaining years of life in which they can develop cancer (11). Several epidemiological studies have demonstrated that pediatric CT scan is associated with an increased risk of leukemia and brain tumor (12-16). Leukemia has a shorter latency period than radiation-associated solid tumors, and the bone marrow in almost all the body regions is exposed to radiation from scan (17). Moreover, because a majority of pediatric CT scanning is limited to the head, the brain is frequently exposed to radiation as well (12). Therefore, physicians should exercise caution when prescribing CT in pediatric patients to decrease the risk of cancer, associated with ionizing radiations, in this susceptible population.

We performed this study to evaluate the rate and annual trend of CT scan in children and adolescents in South Korea using a nationwide population-based database. We further analyzed pediatric CT scan with respect to the sex, age group, diagnosis, and anatomical area.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of our hospital. Informed consent was waived due to the study's retrospective nature (IRB No. SNUBH X-1810/498-901).

Data on the use of CT in children and adolescents between 2012 and 2017 was retrieved from the Korean health insurance review and assessment (HIRA) service. In South Korea, since 2000, approximately 97.0% of the population is obliged to enroll into the national health insurance service (NHIS) program. The remaining 3% of the population that is uninsured by the national health insurance program is either covered by another medical aid program or is composed of temporary or illegal residents; the claims submitted by the medical aid program are also reviewed by HIRA. Therefore, nearly all information about patients and their medical records can be obtained from the Korean HIRA database; this database has been used in previous epidemiological studies (18-20).

Because CT scans are covered by NHIS, data regarding the prescription of CT (including the number of prescriptions) could be obtained from the HIRA database. Additional data extracted included the age at the time of CT scan, sex, diagnosis based on International Classification of Diseases (ICD)-10 codes, and the anatomical area scanned by CT. To calculate the number of CT examinations per 1000 children (relative number), the population of children under 18 years of age between 2012 and 2017 was obtained from the Korean Statistical Information Service (21). The rate of CT examinations was analyzed according to the year, age groups (0–5, 6–12, and 13–18 years), diagnosis based on ICD-10 code, sex, and anatomical area scanned. Anatomical areas included the face/skull, brain, neck, dental area, chest, abdomen, extremities, and spine. However, because the first two were classified into head CT, the anatomical area was actually divided into 7 groups, i.e., the head, dental, neck, chest, abdomen, extremities, and spine.

STATISTICAL ANALYSIS

The Jonckheere–Terpstra trend test was used to determine the significance of a trend in our data. Data analysis was performed, using SAS Enterprise Guide version 6.1 (SAS Institute Inc., Cary, NC, USA) and R Statistical Software version 3.5.2 (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was accepted when the p values were < 0.05 .

RESULTS

Between 2012 and 2017, a total of 576376 CT examinations were performed among 58527528 children under 18 years of age (an average of 9.8 examinations per 1000 children). From 2012 to 2017, a 7.7% increase in the number of pediatric CT examinations was observed, with the numbers increasing from 93166 in 2012 to 100358 in 2017 ($p = 0.003$). The number of CT examination per 1000 children increased by 23.3% from 9.0 in 2012 to 11.0 in 2017 ($p = 0.003$), because the population of children decreased by 12.5% from 10405854 in 2012 to 9100191 in 2017 (Fig. 1). The average annual increase of CT examinations per 1000 children was 4.6%.

In terms of the age groups, the relative number of CT examinations in the 13–18 years group was the largest (13.1/1000 children), followed by in the 6–12 years group (8.6/1000 children) and the 0–5 years group (7.1/1000 children). The relative number of CT examinations did not increase for the 0–5 years age group (7.4 and 7.1 in 2012 and 2017, respectively; $p = 1.000$); however, it increased by 32.9% in the 6–12 years group (7.4 and 9.8/1000 children in 2012 and 2017, respectively; $p = 0.003$) and by 34.0% in the 13–18 years group (11.4 and 15.3/1000 children in 2012 and 2017, respectively; $p = 0.003$) (Fig. 2).

In terms of sex, the number of CT examinations in boys was about 1.9-times greater than that in girls. During the study period, both boys and girls showed annual increases in the relative number of CT examinations; the annual increase in boys was 5.0% (from 11.5 in 2012 to 14.4 in 2017; $p = 0.003$) and in girls was 3.9% (from 6.2 in 2012 to 7.4 in 2017; $p = 0.003$) (Table 1).

In terms of the anatomical area, the majority of the CT scans were performed in the head region (39.1%), followed by in the extremities (32.5%), abdomen (13.7%), and chest (5.8%) ar-

Fig. 1. Changes in the total number of CT examinations in the population under 18 years of age.

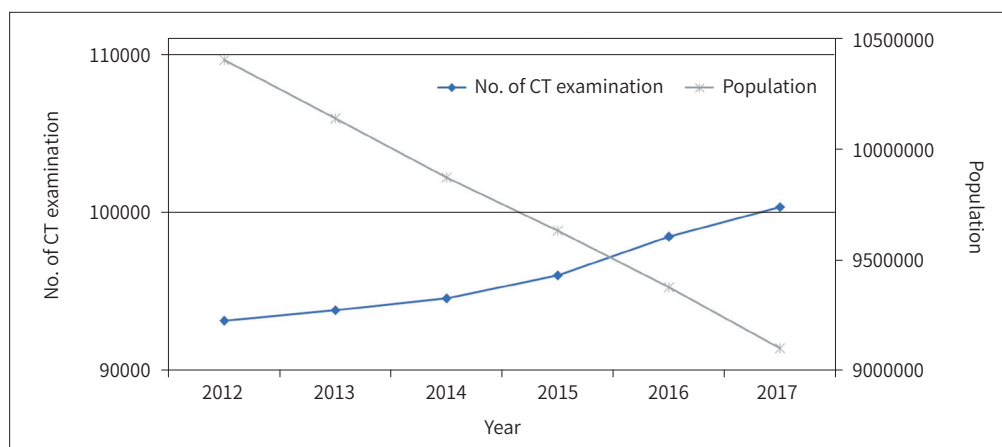


Fig. 2. Number of CT examinations per 1000 persons from 2012 to 2017 according to age group.

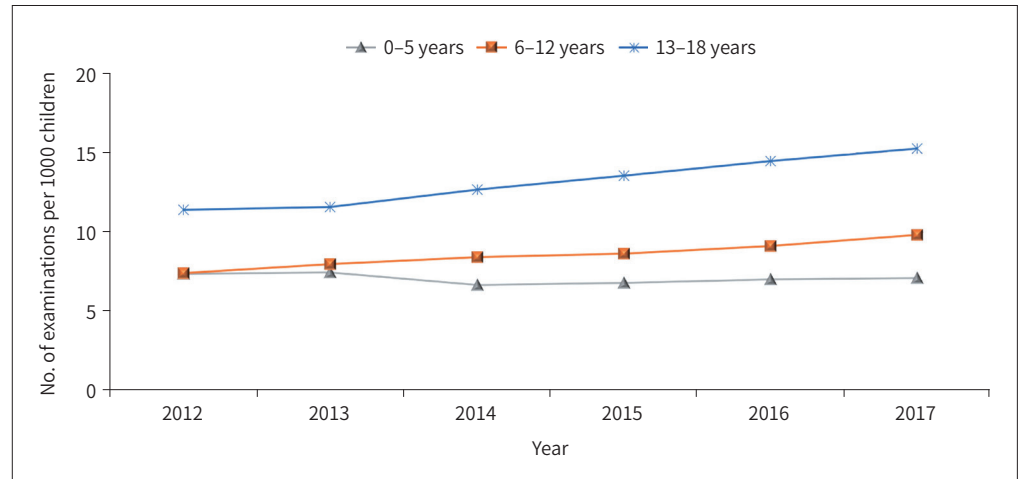


Table 1. Number of CT Examinations according to Age and Sex

Year		0-5 Years Old	6-12 Years Old	13-18 Years Old	Boy	Girl	Total
2012	Number	20805	26285	46076	62159	31007	93166
	No. per 1000 children	7.4	7.4	11.4	11.5	6.2	9.0
2013	Number	20633	27198	45995	62227	31599	93826
	No. per 1000 children	7.5	8.0	11.6	11.8	6.5	9.3
2014	Number	18247	27937	48370	63489	31065	94554
	No. per 1000 children	6.7	8.4	12.7	12.4	6.5	9.6
2015	Number	18608	28212	49182	64559	31443	96002
	No. per 1000 children	6.8	8.6	13.6	12.9	6.8	10.0
2016	Number	18836	29650	49984	66115	32355	98470
	No. per 1000 children	7.0	9.1	14.5	13.6	7.1	10.5
2017	Number	18215	32000	50143	67847	32511	100358
	No. per 1000 children	7.1	9.8	15.3	14.4	7.4	11.0
Total	Number	115344	171282	289750	386396	189980	576376
	No. per 1000 children	7.1	8.6	13.1	12.7	6.7	9.8

eas. The relative number of CT scans in the extremities increased by 83.6% (from 2.3 in 2012 to 4.2 in 2017; $p = 0.003$); while the relative number of head, neck, chest and abdominal CT scans remained unchanged (Fig. 3, Table 2). Furthermore, the proportion of head CT scans decreased from 43.8% in 2012 to 36.0% in 2017 ($p = 0.003$); conversely, the proportion of extremities' CT scans increased from 25.3% in 2012 to 37.7% in 2017 ($p = 0.003$) (Fig. 4).

In terms of diagnosis based on the ICD-10 codes, the most common diagnosis was injury, poisoning and certain other consequences of external causes (55.1%). These were followed by diagnoses of the diseases of the digestive (7.8%) and respiratory (6.1%) systems (Table 3). Among the total 576376 CT scans, 136376 (23.7%) scans were prescribed by the department of emergency medicine.

Among the 544777 children who underwent CT, 518796 children (95.2%) underwent the imaging only once. The remaining 25981 children (4.8%) underwent CT more than twice; of

Fig. 3. Number of CT examinations per 1000 persons from 2012 to 2017 according to anatomical area.

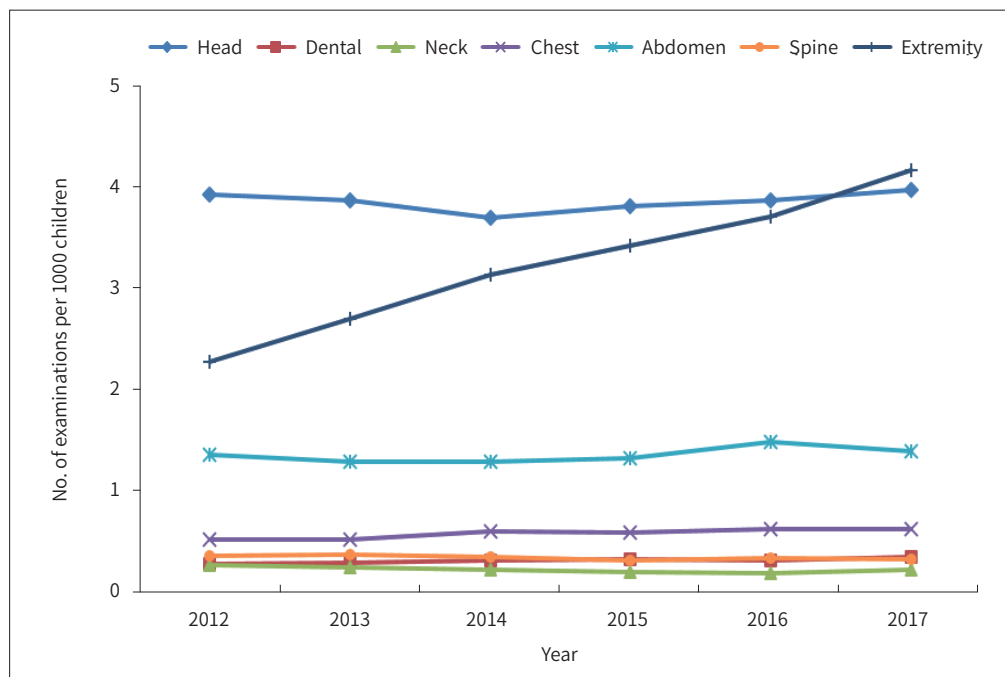


Table 2. Number of CT Examinations according to Anatomical Area

Year		Head	Dental	Neck	Chest	Abdomen	Spine	Extremity	Total
2012	Number	40810	2840	2722	5418	14094	3687	23595	93166
	No. per 1000 children	3.9	0.3	0.3	0.5	1.4	0.4	2.3	9.0
2013	Number	39097	2894	2427	5277	13071	3723	27337	93826
	No. per 1000 children	3.9	0.3	0.2	0.5	1.3	0.4	2.7	9.3
2014	Number	36444	3037	2175	5877	12669	3441	30911	94554
	No. per 1000 children	3.7	0.3	0.2	0.6	1.3	0.3	3.1	9.6
2015	Number	36656	3146	1861	5649	12770	3033	32887	96002
	No. per 1000 children	3.8	0.3	0.2	0.6	1.3	0.3	3.4	10.0
2016	Number	36202	2965	1795	5786	13901	3096	34725	98470
	No. per 1000 children	3.9	0.3	0.2	0.6	1.5	0.3	3.7	10.5
2017	Number	36074	3202	1972	5634	12672	2926	37878	100358
	No. per 1000 children	4.0	0.4	0.2	0.6	1.4	0.3	4.2	11.0
Total	Number	225283	18084	12952	33641	79177	19906	187333	576376
	No. per 1000 children	3.8	0.3	0.2	0.6	1.4	0.3	3.2	9.8

these, 507 children (0.1%) underwent scan more than 5 times (Table 4).

DISCUSSION

This study investigated the rate and annual trends of CT scan in South Korean pediatric patients using a nationwide, large cohort database. The use of pediatric CT scan was observed to have continuously increased from 2012 to 2017. Furthermore, among the anatomical areas

Fig. 4. Comparison of the proportion of CT scans between different anatomical areas from 2012 to 2017.

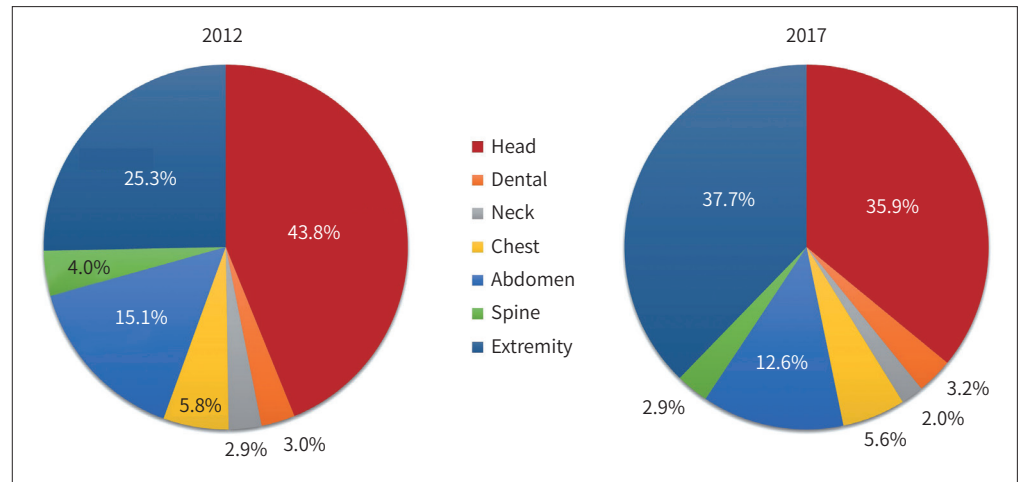


Table 3. Number of CT Examinations according to Diagnosis Based on International Classification of Diseases-10 Codes

Diagnosis	Number	%
Injury, poisoning and certain other consequences of external causes	317363	55.1
Disease of the digestive system	45161	7.8
Disease of the respiratory system	35335	6.1
Symptoms, signs and abnormal clinical and laboratory findings	33998	5.9
Congenital malformation, deformation and chromosomal abnormalities	31345	5.4
Disease of the musculoskeletal system and connective tissue	23441	4.1
Neoplasm	19453	3.4
Infectious and parasitic disease	17155	3.0
Disease of the nervous system	13644	2.4
Disease of the circulatory system	11884	2.1
Disease of the genitourinary system	8051	1.4
Disease of the ear and mastoid process	5562	1.0
Disease of the skin and subcutaneous tissue	3759	0.7
Factors influencing health status and contact with health services	2933	0.5
Disease of the eye and adnexa	2334	0.4
Certain conditions originating in the perinatal period	1372	0.2
Endocrine, nutritional and metabolic disease	1337	0.2
Disease of the blood and blood-forming organs and disorders involving the immune mechanism	1184	0.2
Mental and behavioral disorder	1030	0.2
Pregnancy, childbirth and the puerperium	41	0.0
Total	576376	100.0

scanned, the annual increase in the rate of CT scan was the greatest in case of the extremities.

Pola et al. (22) reported that in case of Italian children, the total number of CT scans increased by 68% from 2004 to 2014; the relative number of scans per 1000 children increased by 35%, rising from 6.3 in 2004 to 8.5 in 2014. For Taiwanese pediatric patients, the annual number of CT scans per 1000 children increased from 1.8 in 2000 to 6.1 in 2013 (average annu-

Table 4. The Number of CT Scans Used according to Sex

No. of CT per 1 Person	Boy	Girl	Total
1	346237	172559	518796
2	15497	6943	22440
3	1673	588	2261
4	558	215	773
5	215	100	315
6	84	38	122
7	32	18	50
8	8	6	14
9	3	1	4
10	2	0	2

al increase rate: 10.3%) (3). Pearce et al. (23) evaluated the trends of CT scanning among young people (under 22 years of age) in Northern England between 1993 and 2002. They found that the number of CT scan per 1000 children increased from 2.2 in 1993 to 3.5 in 2002, showing a 58% rise. Miglioretti et al. (9) investigated CT use in children aged below 15 years from 1996 to 2010 using 7 US healthcare systems. They reported that the number of CT examinations per 1000 children aged below 5 years ranged between 11 and 20 and that per 1000 children aged between 5 and 14 years ranged from 10.5 to 27.0. They observed that CT use increased between 1996 and 2005, remained stable between 2005 and 2007, and then began to decline. However, our cohort showed a 32.9% and 34.0% increase in CT use in children aged 6–12 years and 13–18 years, respectively; however, no increase was observed in case of children aged 0–5 years.

The most commonly scanned anatomical area in our cohort was the head; this observation is in accordance with previous studies (9, 22-24). The proportion of head CT in our cohort decreased from 43.8% to 35.9% over a six-year period. However, the proportion of extremities' CT substantially increased from 25.3% to 37.7%. Furthermore, while the relative number of head CT scans (per 1000 children) did not increase, the relative number of extremities' CT scans increased by 84% during the study period. According to the diagnostic data, more than half the CT scans performed during the study period were due to trauma. Head CT is essential in pediatric head trauma patients because it allows for an accurate diagnosis and treatment plan. However, findings from X-ray imaging may be sufficient for the diagnosis and treatment of most pediatric extremity fractures. Therefore, we believe that CT scan of pediatric extremities should be reserved for some intra-articular fractures for appropriate surgical planning.

Because the risk of cancer from radiation exposure is higher in female than in men, more attention should be paid to the increasing use of CT in female (25). Fortunately, our findings indicated that the number of CT scans in girls was only about half the number in boys. We believe that this may be due to a higher incidence of trauma in boys than in girls (26).

It has been known that the risk of cancer significantly increases when ionizing radiation doses are greater than 50 mSv (27); the overall median radiation dose of a single CT scan ranges from 2 to 31 mSv (5). Pearce et al. (12) reported that children who received an active bone marrow dose of ≥ 30 mSv from CT scanning were at a 3.2 times greater risk of leukemia, while children who received a brain dose of ≥ 50 mSv were at 2.8 times greater risk of

brain cancer. In the current study, 4.8% of the patients underwent CT scan more than twice. Children who had got multiple CT scans faced a potential risk of radiation. Therefore, a further study on the necessity of a close follow-up with monitoring for development of cancer may be needed in such patients.

We suggest the following considerations for decreasing the rate of pediatric CT scan and the radiation dose. First, physicians should deliberate whether CT scan is undoubtedly necessary for diagnosis or therapy, and should avoid non-essential scan in pediatric patients. Second, physicians should explain the long-term effects of radiation exposure secondary to CT scan to the patient's guardians. Third, physicians should consider alternatives to CT such as ultrasound and MRI, neither of which use ionizing radiations. Fourth, iterative reconstruction techniques have the potential to enable CT radiation dose optimization by either lowering tube current or tube potential (28).

There are some limitations in this study. First, this study only reported the number of pediatric CT scans and analyzed the annual trends (over a six-year period), without estimating the radiation dose and the associated cancer risk. The radiation dose of CT varies according to the body size and different scanning protocols. Furthermore, other diagnostic modalities including X-ray imaging and bone scan also use ionizing radiations. Therefore, it is difficult to estimate the radiation doses and the associated cancer risk. Second, this study only focused on the rate and trends of pediatric CT scanning and could not obtain adult data due to a huge data volume. Therefore, our result may not be generalizable to adults. Third, diagnoses based on ICD-10 classification does not always match the indications for CT scans. However, we do not think this limitation would have significantly changed the results of the study, since it focused on the rate and annual trends of pediatric CT scans according to age group, sex, and anatomical area.

Despite these limitations, our study has a major strength. It used a nationwide population-based cohort database, which contains information on nearly the entire national population. Therefore, we believe that our result is representative of the pediatric population who have undergone CT scans in South Korea.

In conclusion, this retrospective cohort study demonstrated that the use of CT scan in South Korean children and adolescents continuously increased from 2012 to 2017, with an annual rate of 4.4%. This study also showed that in terms of the anatomical area scanned, the annual increase in scanning was the greatest for the extremities; with respect to sex, this was greater in boys than in girls. Therefore, physicians should be concerned about the increased rate of CT utilization in children and adolescents, and should balance the benefits of CT scan against the potential harm from its associated radiation exposure.

Author Contributions

Conceptualization, P.M.S., S.K.H.; data curation, K.S.; formal analysis, K.S., S.K.H.; investigation, K.N.T; methodology, L.K.M., S.K.H.; project administration, P.M.S., S.K.H.; supervision, P.M.S., L.K.M.; validation, K.S., S.K.H.; visualization, K.N.T., S.K.H.; writing—original draft, K.N.T., S.K.H.; and writing—review & editing, all authors.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

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소아 전산화단층촬영의 국내 동향: 전국적 코호트 연구

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목적 본 연구는 전국 인구 기반 데이터베이스를 이용하여 국내 소아 전산화단층촬영의 비율과 연간 추세를 평가하였다.

대상과 방법 2012년부터 2017년까지 국내에서 촬영된 소아 전산화단층촬영에 대한 건강보험심사평가원의 데이터를 사용하였다. 연령, 성별, 진단명 및 해부학적 위치에 대한 데이터를 같이 추출하여 분석하였다.

결과 18세 미만 어린이 58527528명을 대상으로 총 576376건의 전산화단층촬영이 시행되었다(1000명당 9.8회). 어린이 1000명당 전산화단층촬영 횟수는 9.0회에서 11.0회로 23.2% 증가했다. 전산화단층촬영 건수는 6-12세 그룹에서 32.9%(1000명당 7.4회에서 9.8회로 증가), 13-18세 그룹에서 34.0% 증가했다(1000명당 11.4회에서 15.3회로 증가). 부위별 전산화단층촬영의 비율은 두부(39.1%), 사지(32.5%), 복부(13.7%) 순서로 확인되었다. 사지 전산화단층촬영 횟수는 83.6% 증가했으며(1000명당 2.3회에서 4.2회로 증가) 사지 전산화단층촬영의 비율은 25.3%에서 37.7%로 증가했다.

결론 소아 환자의 전산화단층촬영은 2012년부터 2017년까지 매년 4.4%의 속도로 지속적으로 증가했다. 따라서 의사는 소아 환자에서 전산화단층촬영으로 인한 이득과 방사선 노출로 인한 잠재적인 피해를 적절히 고려하여 신중하게 촬영을 결정해야 한다.

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