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Trends of computed tomography use among children in Finland

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ABSTRACT

Objectives: CT is an essential diagnostic tool in health care. However, CT delivers relatively high levels of radiation which has been associated with an increased risk of childhood cancer. To address this, we evaluated patterns and time trends of CT use among children in Finland during the period in which changes in pediatric CT imaging practices were reported in several countries.
Methods: Data on CTs performed on children younger than 15 years were obtained from Finland's largest eight hospitals. CT data included the period 1996–2010 with an estimated coverage of more than 80 % of pediatric CT imaging in Finland. Joinpoint regression was used for trends analysis. CT radiation doses were estimated based on a Finnish dosimetry survey.
Results: A total of 48,807 pediatric CTs were performed in 1996–2010. More boys (55.5 %) were scanned than girls (42.8 %). CT numbers increased up to 2002, then decreased significantly (-6.9 % per year, 95 % CI: -10.4 to -3.2) towards 2005 and to a lesser extent thereafter, particularly among younger children. All CT types decreased in recent years, except for chest, spine, and extremities. The frequency of head CTs related to the diagnoses of intracranial injury, migraine and headache decreased towards the end of the study period. The estimated annual average effective dose from the three most common CT examinations was 0.004 mSv per child in the population.
Conclusions: The frequency of pediatric CTs in Finland started to decrease after 2002. Apart from chest and orthopedic CTs, the utilization of pediatric CT imaging declined in recent years, most likely explained by improved awareness of medical radiation risks and reliance on alternative modalities such as MRI and ultrasound.

1. Introduction

The benefits of computed tomography (CT) in the field of pediatrics are undeniable. However, CT use in children has been a topic of concern and debate for several reasons. In the 1990s and early 2000s, CT utilization in children increased in many countries, and several studies showed that children who have undergone CT imaging have a higher risk of malignancy such as leukemia and brain cancer [1–6]. The risk of cancer after exposure to pediatric CT radiation might be relatively small in absolute terms, yet it is a public health concern because of the large population of children exposed [7].

Several campaigns and international programs have been launched to raise awareness of the need to optimize CT dose and use among children. Although pediatric CT trends have been reported to be leveling off or decreasing in some studies, particularly in academic hospitals, these findings might not reflect a general trend across all settings, where children are exposed to CT radiation [8–12]. Hence, following CT rates overtime on the national level aids in clarifying imaging use patterns and guide radiation protection measures. This study evaluates CT utilization among children in Finland from 1996 to 2010, during which changes in pediatric CT imaging practices were reported in several countries. Evaluating CT use in this period is important to assess current and future health effects of radiation from CT. We analyzed CT data from eight large hospitals by age, CT type, recurrent use, institution type, and estimated CT radiation doses. The data covered more than 83 % of pediatric CT imaging performed in Finland.

Abbreviations: APC, annual percentage change; CTDIvol, volume computed tomography dose index; DLP, dose length product; mGy, milligray; mSv, millisievert; PECARN, pediatric emergency care applied research network; person-Sv, person-sievert; RBM, red bone marrow; STUK, Radiation and Nuclear Safety Authority.

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2. Materials and methods

Data on CT examinations performed on children aged 0−15 years were obtained from radiological databases from the ten largest Finnish hospitals for another study [5]. In Finland, primary healthcare is provided through municipal health centers. For secondary and tertiary medical care, Finland is divided into twenty hospital districts, each with a central hospital. The districts are grouped into five catchment areas with five university hospitals for highly specialized medical care.

The time period covered by CT data varied between hospitals, as radiological databases were introduced at the hospitals at different times. Thus, for the period 1996–2010, all five university hospitals and three of the central hospitals were included in the analysis (Table 1). According to a survey by STUK (Radiation and Nuclear Safety Authority), these eight hospital districts covered 83 % of all pediatric CT imaging performed in Finland in 2015 [13]. Data on each CT examination included personal identity code, examination date, examination code, child's date of birth, and child's sex. CT examination types were derived using a national coding system [14]. Moreover, three of the university hospitals (Tampere, Oulu and Kuopio) provided ICD-10 clinical diagnosis codes that were registered for children up to seven days before the CT examination. We evaluated these diagnoses in order to better understand the clinical paths that might have led to performing the CT examination.

CT examinations were categorized into seven groups: head/neck, chest, abdomen/pelvis, spine, extremities, combined, and miscellaneous/unknown. CT of combined regions included examinations of more than one anatomical region such as chest/abdomen/pelvis and abdomen/pelvis/lower extremity. The miscellaneous/unknown group included CT examinations labeled "others", and unknown CT examinations (167 or 0.3 % of all examinations). Participants were categorized into four age groups: under one year, 1−5 years, 6−10 years, 11−15 years. We stratified CT examinations by sex, hospital type, CT examination type, age group, and undergoing recurrent examinations. For analysis by sex and recurrent examinations, 818 CT examinations (1.6 % of all examinations) were excluded because of incomplete personal identity code or unknown sex.

To estimate CT radiation doses, we employed CT dose data collected in a Finnish survey between 2011 and 2013 [15]. Data (1049 CT examinations) were obtained from four university hospitals and included patients' information and scanning parameters such as the CT dose index (CTDIvol) and dose length product (DLP). We used NCICT software to assign organ and effective doses to three CT types: head, chest, and abdomen [16].

We employed joinpoint regression to evaluate CT trends. In the analysis, data are fitted into several lines connected at joinpoints. Monte Carlo calculations are used to determine the minimum number of points needed to adequately describe the trend. The output of regression is the annual percentage change (APC) for each segment between two joinpoints. Joinpoint software was used for trends analysis (Joinpoint Regression Program, Version 4.7.0.0. February 2019; Statistical Research and Applications Branch, National Cancer Institute) and Stata software for other analyses (StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX: StataCorp LLC). The study was exempt from ethical committee review and written informed consent in accordance with the Finnish regulation on register-based research.

Table 1
Number of CT examinations by hospital, sex and time period.

		CT examinations N	%
Hospitals	Helsinki University Hospital	21,733	43.6 %
	Tampere University Hospital	6945	13.9 %
	Oulu University Hospital	6654	13.4 %
	Turku University Hospital	5358	10.8 %
	Kuopio University Hospital	3957	7.9 %
	Central hospitals	5160	10.4 %
Sex	Boys	27,660	55.5 %
	Girls	21,329	42.8 %
Time period	1996−2000	16,673	33.5 %
	2001−2005	18,276	36.7 %
	2006−2010	14,858	29.8 %

3. Results

Over 15 years, from 1996 to 2010, 48,807 CT examinations were performed on patients younger than 15 years (Table 1). For all CT examination types, there were more examinations among boys (55.5 %) than girls (42.8 %). Older children underwent more CT examinations than younger children, with those under one year of age undergoing 8.1 % (4036) of the total examinations (Table 2). There were 31,643 head/neck CTs (63.5 %), 5196 chest CTs (10.4 %), and 3311 abdomen/pelvis CTs (6.7 %).

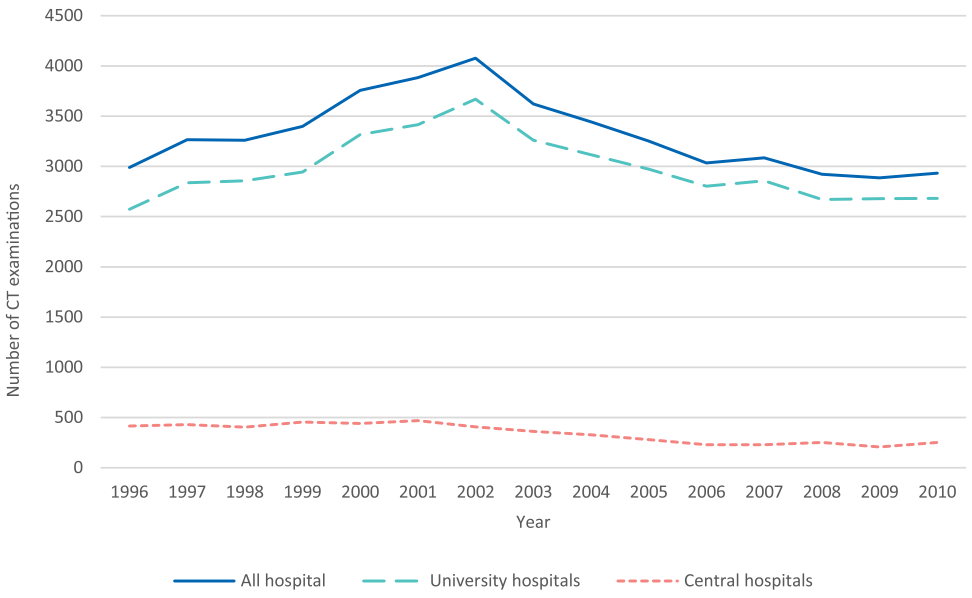
Overall, CT numbers increased significantly (APC 4.9, 95 % CI: 3.5–6.3) between 1996 and 2002, then started to decrease after 2002 (APC -6.9, 95 % CI: -10.4 to -3.2) and to a lesser extent after 2005 (APC -1, 95 % CI: -3.6 to 1.6) (Fig. 1). The decline in CT imaging was observed in both academic and central hospitals. The rate of pediatric CT imaging in 2010 was 43.5 examinations per 10,000 children, which is slightly higher than 42.5 in 1996. The peak was in 2002 with 59 examinations per 10,000 children

CT numbers among children in their first year of life exhibited a slightly decreasing trend throughout the study period (Fig. 2). In older age groups, however, CT use increased in the early period and started decreasing later, with the largest decrease in children aged 1−5 years (APC - 10.2, 95 % CI: -17.3 to -2.6). Head/neck CT was the most common type of examination, with numbers decreasing or stabilizing in recent years across all age groups (Fig. 3). Similarly, abdomen and combined regions CTs started to decrease later, whereas chest, spine, and extremities CTs continued to increase throughout the study period (Fig. 4). Most patients (88.8 %) underwent one or two CT examinations (Fig. 5), while 373 children (1.2 %) had ten or more CT examinations, of which almost half were head/neck examinations (46.2 %). Intracranial injury, headache, convulsions, hearing loss and migraine were the most common diagnoses related to head CT. The frequency of head CT examinations related to these diagnoses significantly decreased towards the end of the study period (Fig. 6). For abdomen CT, the most common related diagnoses were injury of intra-abdominal organs and abdominal and pelvic pain.

The average estimated brain dose was 17.7 mGy from head CT. Average red bone marrow (RBM) dose was 4.4 mGy from head CT and

Table 2
Number of CT examinations by examination type and age group.

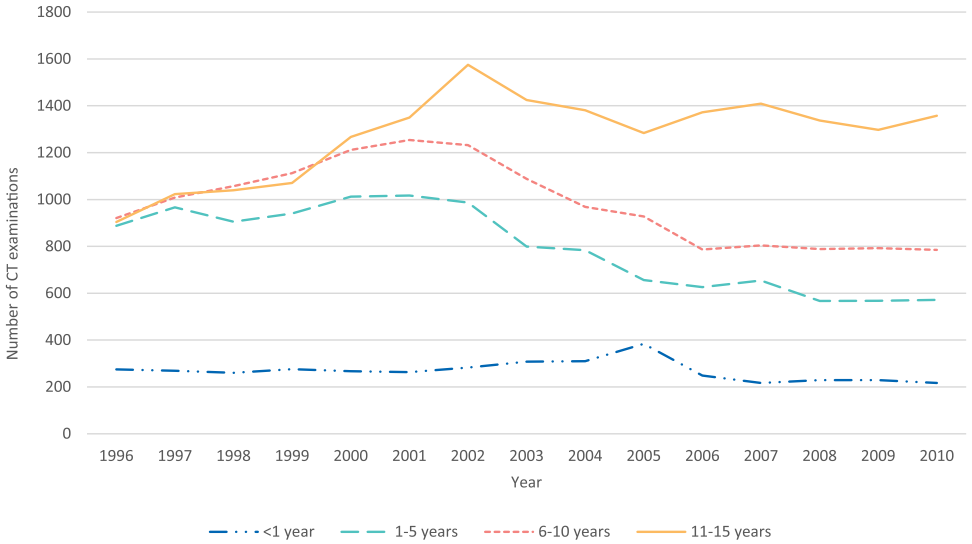
	N (%)				
CT examination	<1y	1–5y	6–10y	11–15y	0–15y
Head/Neck	2653 (65.7)	7823 (65.5)	9890 (67.1)	11,277 (59.1)	31,643 (63.5)
Chest	621 (15.4)	1603 (13.4)	1336 (9.1)	1636 (8.6)	5196 (10.4)
Combined regions	369 (9.1)	1003 (8.4)	912 (6.2)	1078 (5.7)	3362 (6.8)
Abdomen/Pelvis	290 (7.2)	773 (6.5)	935 (6.3)	1313 (6.9)	3311 (6.7)
Extremities	23 (0.6)	162 (1.4)	732 (5)	2214 (11.6)	3131 (6.3)
Spine	64 (1.6)	452 (3.8)	741 (5)	1268 (6.6)	2525 (5.1)
Miscellaneous/Unknown	16 (0.4)	126 (1.1)	191 (1.3)	306 (1.6)	639 (1.3)
Total	4036 (8.1)	11,942 (24)	14,737 (29.6)	19,092 (38.3)	49,807 (100)



All hospitals			University hospitals			Central hospitals		
Period	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*
1996-2002	4.9*	3.5 to 6.3	1996-2002	5.6*	4 to 7.2	1996-2001	2.7	-1.3 to 6.8
2002-2006	-6.9*	-10.4 to -3.2	2002-2005	-7	-14.7 to 1.4	2001-2006	-12.5*	-17.8 to -6.9
2006-2010	-1	-3.6 to 1.6	2005-2010	-1.9	-3.9 to 0.2	2006-2010	-0.4	-7.5 to 7.3

* Indicates that the annual percentage change (APC) is significantly different from zero (P<0.0.5)

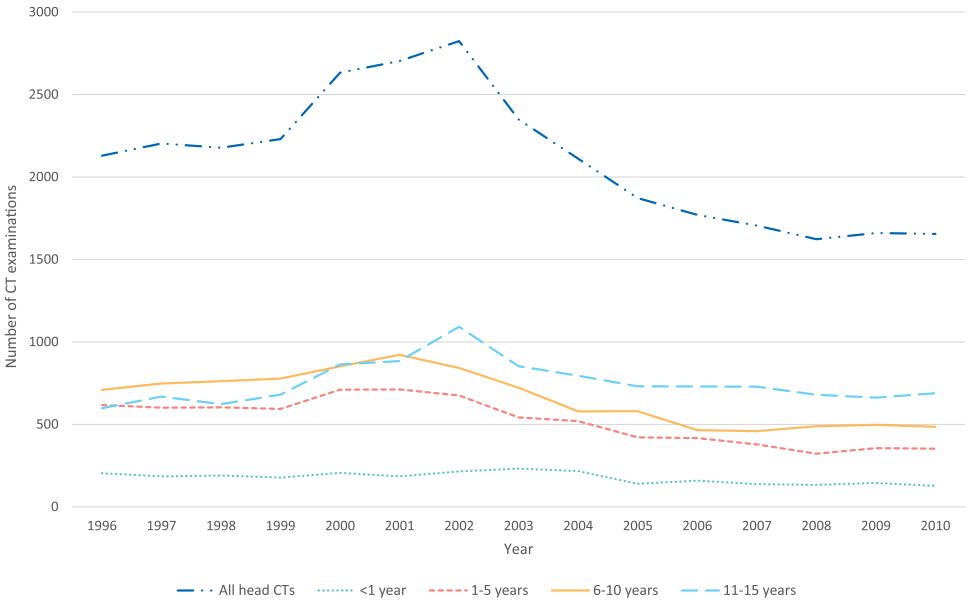
Fig. 1. Frequency trends of CT examinations by hospital type.



<1 year			1-5 years			6-10 years			11-15 years		
Period	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*
1996-2002	-1	-3 to 1.2	1996-2001	3	-0.5 to 6.7	1996-2001	6.9*	5.5 to 8.5	1996-2002	8.4*	6 to 10.8
			2001-2005	-10.2*	-17.3 to -2.6	2001-2006	-8.8*	-10.6 to -7	2002-2010	-1.4*	-2.6 to -0.1
			2005-2010	-3.7	-7.9 to 0.6	2006-2010	-1.1	-3.3 to 1.2			

* Indicates that the annual percentage change (APC) is significantly different from zero (P<0.0.5)

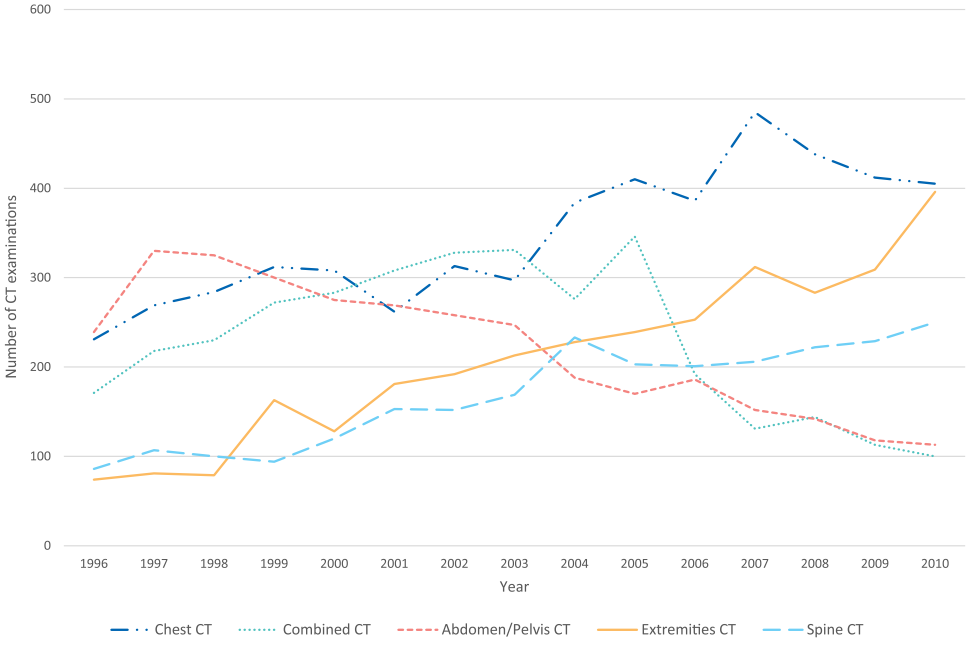
Fig. 2. Frequency trends of CT examinations by age group.



All head CTs			<1 year			1-5 years			6-10 years			11-15 years		
Period	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*
1996-2002	5.2*	2.8 to 7.7	1996-2003	1.7	-2.5 to 6.1	1996-2001	3.9	-0.7 to 8.7	1996-2001	5.7*	2.7 to 8.8	1996-2002	10*	6.2 to 14.0
2002-2005	-13.3*	-24.8 to -0.1	2003-2010	-7.7*	-12 to -3.2	2001-2008	-10.4*	-13.8 to -6.8	2001-2006	-12.3*	-16.0 to -8.4	2002-2005	-10.4	-26.4 to 9
2005-2010	-2.4	-5.8 to 1.2				2008-2010	4.5	-20.5 to 37.4	2006-2010	0.7	-4.4 to 6.2	2005-2010	-1.4	-5.9 to 3.4

* Indicates that the annual percentage change (APC) is significantly different from zero (P<0.0.5)

Fig. 3. Frequency trends of head/neck CT examinations by age group.



Chest CT			Combined CT			Abdomen/Pelvis CT			Extremities CT			Spine CT		
Period	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*	*Period*	*APC*	*95% CI*
1996-2010	4.4*	3 to 5.9	1996-2003	9.9*	3.4 to 16.7	1996-1998	15.8	-4.9 to 41	1996-2010	10.6*	8.4 to 12.8	1996-2010	7.5*	5.6 to 9.4
			2003-2010	-17.4*	-23.1 to -11.1	1998-2010	-8.6*	-9.9 to -7.3						

* Indicates that the annual percentage change (APC) is significantly different from zero (P<0.0.5)

Fig. 4. Frequency trends of CT examinations by examination type excluding head/neck CTs.

1.7 mGy from Abdomen CT. Average breast dose among girls was 1.9 mGy from chest CT and 3.3 mGy from abdomen CT. Average effective doses for head, chest, and abdomen CTs were 1 mSv, 1.1 mSv, and 2.8 mSv, respectively. The annual average collective dose from these three CT types (81 % of all CT examinations) was 3.7 person-Sv, translating into an annual effective dose of 0.004 mSv per child in the population.

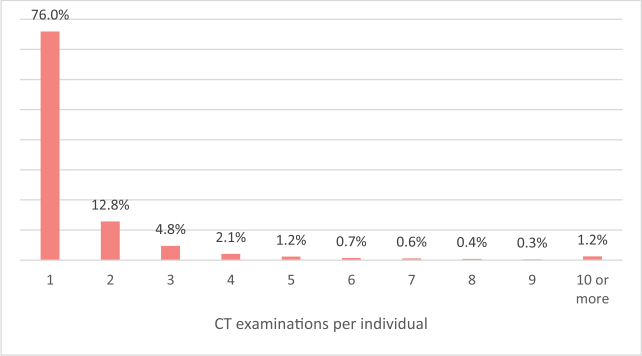


Fig. 5. Numbers of CT examinations per individual.

4. Discussion

This study evaluated CT utilization patterns over 15 years with a coverage of more than 80 % of pediatric CTs performed in Finland. Data from the eight largest Finnish hospitals showed that CT use in children increased by a third from 1996 through 2002, and then decreased towards 2010, particularly among younger children. Over the study period, the Finnish pediatric population showed little change. Several other studies have also reported declining or flattening trends, but starting later than in our study [8,9]. An Australian study found, however, that pediatric CT imaging rates leveled after 2000, whereas the numbers of CT examinations continued to increase towards 2012 in the Netherlands [10,11]

Concerns over the expanding use of pediatric CT in the 1990s and the associated cancer risks were expressed by Brenner et al. in 2001 [17]. Additional studies reported that children received unnecessarily high radiation doses, as scan parameters were not adjusted for pediatric patients [18]. Decreasing trends of pediatric CT imaging after 2002 in Finland likely reflect these concerns. In 2004, STUK (Radiation and Nuclear Safety Authority) started publishing guidelines for pediatric CT examinations [19]. STUK also regulates licensing of CT scanners and conducts surveys on the use of medical radiation in the country [13,20].

Head CT was the most common examination in this study, similar to findings from other countries. We observed a decrease in head CT use across all age groups in recent years. Head CT is often used in the management of children presenting with traumatic brain injury (TBI). In the US, it is estimated that 20–60 % of these children undergo CT imaging [21]. Improved clinical prediction tools, such as the pediatric emergency care applied research network (PECARN) guidelines, have led to a better-targeted CT use in children presenting with TBI [22,23]. Other clinical conditions leading to a head CT include headache, convulsions and migraine. The frequency of head CTs related to these conditions decreased towards the end of our study period. The utilization of MRI has been expanding as an alternative to head CT. In Finland, between 2008 and 2018, the annual number of head MRI examinations performed on children increased from 4185 to 7315 [24]. MRI has shortcomings in children as it usually requires sedation and the child to stay motionless for a few minutes. However, the development of faster MRI sequences might facilitate even a broader utilization of MRI in the field of head imaging. A recent study showed that fast MRI is accurate and feasible relative to CT in clinically stable patients with TBI [25].

Abdominal pain is a common presentation in pediatric patients, and the diagnosis might be challenging because of the wide range of possible etiologies [26]. The utilization of pediatric abdomen CT in the US has been stabilizing or decreasing in recent years; however, imaging rates are still considerably higher than two decades ago [8,9]. In our study, rates of abdominal CT started to decrease significantly after 1998, earlier than other CT types. The number of abdomen CTs decreased by more than half to become one of the least frequent examinations in 2010. In Finland, appendicitis is usually diagnosed based on clinical findings, and CT is seldom used in the assessment of acute abdomen [19]. Instead, abdominal ultrasound is widely utilized. Between 2008 and 2018, the annual number of pediatric abdominal ultrasound examinations in Finland increased from 10,690 to 14,735 [24]. Point-of-care ultrasound (POCUS) is an emerging addition to traditional radiology, where pediatricians perform the ultrasound and rapidly incorporate the findings into their clinical decision [27]. One study found that the utilization of POCUS in the emergency department reduced CT use in children presenting with appendicitis [28].

Unlike head and abdomen CT, chest CT rate continued to increase throughout the study period, particularly among children younger than five years. According to an expert in pediatric radiology, chest CT in Finland is still the preferred option to scan the lung parenchyma with a partial shift towards MRI (K. Lauerma, personal communication, 4 December 2019). Moreover, chest CT angiography is replacing conventional invasive angiography, particularly in younger children. We also found that extremities and spine CT examinations continued to increase throughout the study period, mainly for children aged 10−15 years. As orthopedic CTs are primarily performed for surgery planning, one explanation for this finding might be the increasing frequency of

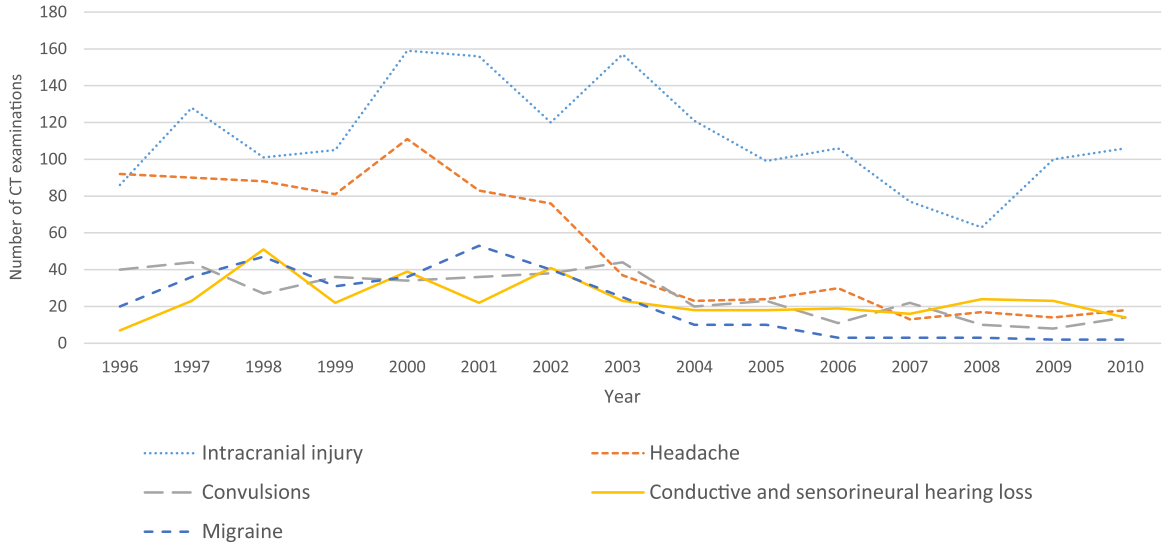


Fig. 6. Frequency trends of head/neck CT examinations by related clinical diagnosis (data from three university hospitals).

sports injuries among Finnish adolescents [19,29]. A number of studies also showed that the rate of operative management of fractures in children has increased in several countries, including Finland [30]. A provisional analysis of pediatric CT trends in three Finnish university hospitals showed that orthopedic and chest CTs kept increasing towards 2018 compared to declining trends of abdomen and head CTs (unpublished data).

Several studies have shown that CT imaging rates at general hospitals tended to decrease later than at academic hospitals and that ultrasound was utilized more frequently in pediatric-focused emergency departments [10,31,32]. However, in this study, trends of CT at central hospitals decreased concurrently with those at university hospitals. This might imply a collective awareness of medical radiation risks and commitment to radiation safety across various types of Finnish healthcare facilities.

Pediatric CT imaging rates in our study peaked at 59 examinations per 10,000 children in 2002, which is comparable to rates in the UK (51 in 2002) and the Netherlands (68 in 2012), but substantially below those in the United States (200 in 2005) [8,10,33]. Differences in imaging rates and trends may indicate higher awareness of medical radiation risks, but they may also reflect variances across healthcare systems. In the United States, financial incentives in fee-for-service health models can contribute to the overutilization of medical imaging [8,9,34]. Besides, concerns over medical malpractice litigation have led to "defensive medicine" with a low threshold for diagnostic testing, including imaging [35]. On the other hand, in a universal health system, such as in Finland and the UK, health services are primarily funded through public expenditure, and care is provided without direct benefit to health professionals but rather an inclination to contain costs and limit tests [36]. There is also less fragmentation in patient care, which minimizes imaging rates, particularly duplicate examinations [37]. The overuse of imaging might also involve patients' characteristics and preferences.

Dose estimations in this study were based on a Finnish dose survey conducted between 2011 and 2013 [15]. Generally, organ and effective dose estimates were lower than those reported in other countries such as Spain, the UK, Germany and the US [8,12,38,39]. Breast doses from chest CT were particularly low (1.4–2.7 mSv) relative to breast doses from abdomen CT (0.5–5.6 mSv). Scan lengths for abdomen CT were 15 cm longer on average than chest CT and consequently had higher DLPs. Alongside declining CT numbers, the annual average collective effective dose from the three most common CT types decreased from 4.7 person-Sv in 2002 to 2.9 person-Sv in 2010. Based on these estimates, the pediatric population in Finland received an annual effective dose of 0.004 mSv per capita, a tiny fraction of the 3.2 mSv mean annual effective dose for the Finnish population [40]. One limitation in our estimation is that the applicability of the dose estimates to scans from older periods is uncertain. Our dose estimates source was a survey performed at university hospitals and, thus, these estimates might not entirely reflect practice at central hospitals. However, we believe it is safe to assume that dose optimization measures are reasonably similar at university and central hospitals since CT radiation exposure reference levels are mandated nationally by law [41].

The variations in CT utilization and radiation doses across countries and institutions indicate that there is room for improvement. In many instances, doses can be lowered with minimal effect on image quality. In the UK, the absorbed dose for the brain from head CTs decreased after 2000 from 62 mGy to 30 mGy in children under 20 years of age [38]. These changes were the result of using pediatric protocols to adjust scan parameters. In one Finnish hospital, the percentage of justified CT examinations in patients under 35 years increased from 71 % to 87 % after improving the capacity of MRI and promoting guidelines and education on radiation protection [42].

Concerns over radiation dose from recurrent CT exposure have been recently raised by the International Atomic Energy Agency (IAEA) [43]. One study estimated that 1.33 % of patients undergoing recurrent CTs received more than 100 mSv of cumulative effective dose (CED) over a period of 1−5 years [44]. In our study, 1.2 % of patients underwent ten or more CT examinations. CED from the three most common CTs ranged between 1.4 and 61 mSv with a median of 6.2 mSv. The IAEA endorsed, among other measures, the Smart Card project, which aims to track the patient's radiation exposure history through summing effective doses as CED [43].

Clinical diagnoses registered before the CT examination were available only for part of the cohort and were utilized to infer the most common clinical conditions related to a CT examination and their trends over time, though direct information on indications as given in referrals was not available for us. A recent survey by STUK showed that the total number of pediatric CT examinations in Finland increased slightly in 2018 compared to 2015 [24]. Although this finding might not indicate a returning increasing trend of pediatric CTs in Finland, it is crucial to continuously evaluate adherence to national and institutional guidelines. Further research into the appropriateness of pediatric CT examinations is essential. The indications and clinical path that lead to the CT scan are worth investigating, coupled with the extent to which other imaging modalities like MRI and ultrasound had been utilized. This study has several strengths. The CT data covered the majority of pediatric CT imaging performed in Finland during the period in which CT use trends in children started to change in several countries. Grouping of CT examinations was reliable, as we used a national coding system. Moreover, numbers of recurrent examinations were reasonably accurate, as the repetition of imaging studies is not a significant issue in Finland.

5. Conclusions

CT imaging utilization in children started to decrease in Finland after 2002, particularly among children under five years of age. Numbers of all CT types decreased in recent years except for chest, extremities, and spine CTs. Our study suggests that there is a high level of awareness of medical radiation risks in Finnish hospitals. Further studies should evaluate the appropriateness of various pediatric CT examinations in an effort to standardize practices and minimize children's unnecessary exposure to medical radiation.

Funding statement

The authors have no source of funding to declare.

Ethical statement

Written informed consent was not required for this study because the Finnish legislation allows register-based research without informed consent.

CRediT authorship contribution statement

Jad Abuhamed: Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft, Project administration. **Atte Nikkilä:** Investigation, Data curation, Writing - review & editing. **Olli Lohi:** Writing - review & editing, Supervision. **Anssi Auvinen:** Conceptualization, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors report no declarations of interest.

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