Chapter 3

Trends and patterns of computed tomography scan use among children in The Netherlands: 1990-2012

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Abstract

**Objective:** To evaluate trends and patterns in CT usage among children (aged 0-17 years) in The Netherlands during the period 1990-2012.

**Methods:** Lists of electronically archived pediatric CT scans were requested from the Radiology Information Systems (RIS) of Dutch hospitals which reported >10 pediatric CT scans annually in a survey conducted in 2010. Data included patient identification, birth date, gender, scan date and body part scanned. For non-participating hospitals and for years prior to electronic archiving in some participating hospitals, data were imputed by calendar year and hospital type (academic, general with <500 beds, general with ≥ 500 beds).

**Results:** Based on 236,066 CT scans among 146,368 patients performed between 1990 and 2012, estimated annual numbers of pediatric CT scans in The Netherlands increased from 7,731 in 1990 to 26,023 in 2012. More than 70% of all scans were of the head and neck. During the last decade, substantial increases of more than 5% per year were observed in general hospitals with fewer than 500 beds and among children aged 10 years or older.

**Conclusion:** The estimated number of pediatric CT scans has more than tripled in The Netherlands during the last two decades.
Introduction

The use of Computed Tomography (CT), a powerful diagnostic tool, has grown rapidly in Western countries over the last 20 years. According to a national survey in the Netherlands, the total number of CT scans has increased by more than 50% since 2001 to approximately 1.29 million scans in 2012, with the steepest growth in general hospitals. Due to the relatively high radiation dose, CT scans are currently responsible for approximately half of the total annual medical radiation exposure. Although many CT scans are beneficial to patients, radiation protection is a concern. This is particularly so for children, as their tissues and organs are more susceptible to the effects of ionizing radiation. In addition, their longer life expectancy after exposure provides more time during which they could develop late effects, such as cancer. While there is some variation among countries, approximately 2-10% of all CT scans are performed on children. Furthermore, studies in several countries (e.g., UK, Spain, the USA) reported that the number of pediatric CT scans has more than doubled in the past decades.

Recently, several epidemiologic studies on cancer following pediatric CT scans showed increasing risks of leukemia and brain tumors with CT-related radiation exposure. In The Netherlands, a similar cohort study is under way, The Dutch Pediatric CT Study. Here, we utilize the data from this study to describe nationwide trends and patterns of pediatric CT usage in The Netherlands during the past two decades.

Materials and methods

The Dutch Pediatric CT Study is a retrospective cohort study among subjects who received at least one electronically archived CT scan in any eligible Dutch hospital before the age of 18 years. Eligible hospitals were those 60 hospitals who reported performing more than 10 pediatric CT scans annually in a survey among all 94 Dutch hospitals in 2010 (response, 100%). The cohort was established through the electronic Radiology Information System (RIS), routinely used in The Netherlands to store and distribute data on performed radiology procedures. We assume that the number of pediatric CT scans that has been performed outside the 60 hospitals is negligible. Of the 60 eligible hospitals, 42 participated in our study (including all eight academic hospitals) and provided data on all electronically recorded CT scans in the RIS including patient identifiers, date of birth, sex, residential address, and the date and type of CT examination. The earliest recorded scans were from 1979, the latest from 2012. Years before 1990 were excluded from this analysis since only few hospitals provided data for this period. The study protocol was reviewed and approved by a judicial expert in health care law and by data protection officers of participating hospitals. The internal review
board of the Netherlands Cancer Registry waived the requirement for individual consent according to Dutch privacy laws and the regulatory Code of Conduct. The ethics committees of the Netherlands Cancer Institute and all participating hospitals waived the requirement of review since the study concerns secondary use of personal and medical data.

Surrogates for socio-economic status (SES), namely household income and house value, are publicly available in The Netherlands by 6-position postal code from Statistics Netherlands. An average postal code area includes 17 households and 40 people. These data were linked to patients’ residential address. Further details were reported elsewhere.

For each participating hospital, we computed the total number of CT scans performed in each year for which data were available. For hospitals where the first or last reported year of CT scanning did not cover the months from January to December, the total number of CT scans for those years was prorated for completeness. Within each year, we calculated the percentage of CT scans by age (0, 1-4, 5-9, 10-14, 15-17 years), sex, and body part scanned (head/neck, chest, abdomen/pelvis, spine, extremities, miscellaneous or unknown, based on European guidelines). We also calculated, for each year, the percentage of CT scans by quintiles of monthly household income in September 2003 (≤1600 Euro, 1601-1800 Euro, 1801-2100 Euro, 2101-2400 Euro, >2400 Euro) based on the general childhood population. If the number of CT scans is unrelated to household income, one would expect 20% of CT scans in each category.

For eligible hospitals, we obtained the total number of beds in 2008, the earliest year for which these data are publicly available. For the 18 non-participating hospitals, we estimated the total number of pediatric CT scans in 2008 by a linear regression model. The model was fitted to data from participating hospitals, with the total number of pediatric scans in 2008 as the dependent variable and the number of beds in 2008 by three types of hospitals (academic, general with <500 beds or general with ≥500 beds) separately as independent variables. We also considered the distance to the next academic or general hospital with >900 beds as an independent variable, but this did not contribute significantly to the goodness of fit of the model and was, therefore, not retained in the final model. For participating hospitals, we determined the geometric mean of the percentage change in the total number of scans for all pairs of two consecutive years between 1990 and 2012, by type of hospital. Based on the predicted number of scans in 2008 and the percentage change in consecutive years, we estimated the total number of pediatric scans for each year between 1990 and 2012 and each non-participating hospital. For example, if the imputed number of scans in 2008 in a non-participating small general hospital was 88, and if the number of CT scans in participating small general hospitals increased, on average, by 2.4% between 2008 and 2009, we imputed 88*1.024=90 CT scans for 2009 for that hospital. Similarly, we estimated the total number of pediatric scans in participating hospitals for each year for which no data were provided. For years with imputed number of scans, we assigned average percentages for categories of
age, gender, body part and quintiles of income and house value from years with observed number of CT scans, by hospital type. In the previous example, if 56% of all scans in 2009 in small general hospitals were performed on boys, the number of scans among boys in 2009 was estimated as 90*0.56=50 CT scans in that hospital.

To describe trends in CT rates over time overall and by type of hospital, age, body part and SES, we used joinpoint regression, i.e., a regression of the log-transformed number of CTs per year on calendar year in which several different lines are connected together at the “joinpoints”\(^ {21}\). Permutation tests, based on Monte Carlo methods, were used to determine the number of significant joinpoints, which was allowed to range between 0 and 4. The regression results in estimates of the annual percent change (APC) for each segment between two joinpoints. Homogeneity of trends (parallelism) by gender, age, body part and SES was tested pairwise for the most recent decade, i.e. 2003-2012\(^ {20}\). Categories of those variables were sometimes collapsed in order to limit the number of pairwise tests. The Joinpoint Regression Program was used for joinpoint regression (Joinpoint Regression Program, Version 4.2.0 - April 2015; Statistical Methodology and Applications Branch, Surveillance Research Program, National Cancer Institute). SAS software was used for all other calculations (Version 9.2; SAS Institute, Cary, NC, USA).

**Results**

The 42 participating hospitals provided data on 251,218 CT scans performed between 1979 and 2012 on 155,755 patients. Analyses are based on 236,066 pediatric CT scans among 146,368 children performed between 1990 and 2012, including examinations conducted before and after a cancer diagnosis. After imputation of missing scans, the total number of pediatric CT scans in the entire Netherlands between 1990 and 2012 was estimated to be 363,964. The percentage of observed scans was 65\%, 77\%, and 78\% for calendar periods 1990-2012, 2003-2012, and 2008-2012, respectively. The estimated annual number of pediatric CT scans increased from 7,731 in 1990 to 13,309 in 2000 and to 26,023 in 2012 (*Figure 1*).
A particularly steep increase by 50% was observed between 2003 and 2007 when the number of CT scans increased from 15,255 to 22,898, which corresponds to a significantly elevated APC of 11.3% (95% confidence interval [CI] 7.1-15.7). After 2007, the estimated annual number of CT scans barely increased at a non-significant APC of 2.4% (95% CI 0.6-4.2). Per 1,000 children in the Dutch population [23], the annual number of CT scans increased from 2.0 in 1990 to 3.4 in 2000 and to 6.7 in 2012. While the number of scans performed on boys was slightly higher compared with girls, trends during the period 2003-2012 were similar, i.e., parallelism was not rejected (p=0.59) [Supplementary figure S1].

The number of scans among children of age 10 years or older at examination was substantially higher than among younger children (Figure 2).
**Figure 2:** Annual number of CT examinations among children (<18 years) in The Netherlands, 1990-2012, by age at examination and annual percent changes from joinpoint analysis. APC, annual percentage change. *The APC is significantly different from 0 (P<0.05)*

For these younger children, there was no increase in number of scans after 2007 (APCs of -4.1%, -2.4% and -0.8% for age <1 year, 1-4 years, and 5-9 years, respectively) while among older children the number of CIs kept growing (significantly elevated APCs of 7.3% and 4.2% for age 10-14 years and 15-17 years, respectively). Parallelism of trends for children above and below age 10 years during 2003-2012 was rejected (p=0.004).

With 70.2% of all scans, the head/neck was the most commonly scanned body part. Abdomen/pelvis and chest each represented about 10% of all scans. Head/neck scans increased substantially between 2004 and 2007 (APC=12.2%, 95% CI=1.0-27.1) and leveled off thereafter (APC=1.2%, 95% CI=1.6-4.1) (Figure 3).
Figure 3: Annual number of CT examinations among children (<18 years) in The Netherlands, 1990-2012, by body part and annual percent changes from joinpoint analysis. APC, annual percentage change.*The APC is significantly different from 0 (P<0.05)

In contrast, scans of all other body parts, except miscellaneous/unknown, continued to increase significantly until 2012 with APCs of 5.1% (95% CI 3.6-6.6), 5.1% (95% CI 2.8-7.5), 14.2% (95% CI 10.6-17.9), and 12.0% (95% CI 10.3-13.8) for abdomen/pelvis, chest, extremities, and spine, respectively. For the last decade (2003-2012), the trend for head/neck differed significantly from that for extremities and spine combined (p<0.05) but not for that for all other body parts combined (p=0.17).

Children with low household income received more scans than expected because more than 20% of all scans were performed in children from lower household income categories, which were based on general childhood population quintiles (Figure 4). Although the number of scans increased for all categories and all time periods according to the joinpoint analyses, trends were no longer significant for the last period for low and medium household incomes (2006-2012 and 2007-2012, respectively). Trends for 2003-2012 did not differ between children with high and medium-high household income combined versus other children combined (p=0.10).
**Figure 4:** Annual number of CT examinations among children (<18 years) in The Netherlands, 1990-2012, by general childhood population quintiles of household income and annual percent changes from joinpoint analysis.

**APC, annual percentage change**

* The APC is significantly different from 0 (P<0.05)

Example: In 2000, 3,045 of all CT scans (22.9%) were performed among children in the lowest household income quintile and 1,942 of all scans (14.6%) were performed among children from the highest household income quintile, compared with 20% of the general Dutch childhood population.
The percentage of pediatric CT scans performed annually in general versus all hospitals ranged from 39% in 1990 to 63% in 2012 (Figure 5). An upward trend of usage was observed for general hospitals with <500 beds during the entire study period (APC=9.3%, 95% CI 8.5-10.0), without significant changes in the rate of increase. For general hospitals with ≥500 beds, growth was mixed and no longer significant in 2007-2012 (APC=3.1%, 95% CI 0.5-6.8). The number of pediatric CT scans in academic hospitals grew significantly until 2007 with APCs of 2.8% (95% CI 2.1-3.5) and 9.0% (95% CI 5.2-13.0) for 1990-2001 and 2001-2007, respectively. Since then, a non-significant decline was observed (APC=-1.3%, 95% CI -3.7-1.3) (Figure 5). For the period 2003-2012, trends for academic hospitals differed significantly from those for small (p=0.005) and large general hospitals (p=0.007).

![Graph: Number of CT scans by type of hospital and year](image)

**Figure 5:** Annual number of CT examinations among children (<18 years) in The Netherlands, 1990-2012, by type of hospital and annual percent changes from joinpoint analysis and annual percent change from joinpoint analysis.

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* The APC is significantly different from 0 (P<0.05)
Discussion

The number of pediatric CT scans in The Netherlands has increased substantially since 1990, with a striking rise during 2003-2007. In recent years, the total number of pediatric CT scans performed in academic hospitals declined, while the number of CT scans in general hospitals and among children above 10 years of age continued to increase through 2012.

The National Institute for Public Health and the Environment monitors medical radiation exposure in children by periodic surveys among hospitals. Based on data from two academic and 18 general hospitals, they estimated that the total number of pediatric CT scans in the Netherlands was 12,000 in 2005. This number increased to an estimated 22,000 pediatric CT scans in 2014, based on data from six academic and 17 general hospitals. We used data from the electronic RIS of 42 hospitals and estimated higher numbers: 18,383 pediatric CTs in 2005 and 26,023 in 2012. Possible reasons for the difference are the smaller sample of hospitals included in the survey, potential underreporting of CT scans by hospitals participating in the survey, and the fact that some hospitals in the survey used a maximum age under 18 years for children.

Reports from other Western countries, such as Australia, Israel, and the USA, showed a similar pattern with increasing numbers of CT scans in children but waning rates of increase in recent years. In Denmark, UK and Spain, the number of CT scans more than doubled in less than a decade, with little variation in recent years. The number of pediatric CT scans per 1,000 children was 6.8 in The Netherlands for 2012, which is comparable to rates from a decade ago in Germany (6.1 in 2001), Israel (6.3 in 2003), UK (between 3.7 to 11.6 for age groups <1 year until 15-19 years in 2002), whereas higher recent rates are reported from Catalonia (16.6 in 2012) and USA (15.8 for children <5 years and 23.9 for 5-15 years in 2010)

Our data on household income, an indicator of SES, suggest that children from deprived areas received more CT examinations. Data from the UK study indicated an association in the same direction. In contrast, the Australian study found that children from deprived areas are slightly less likely to undergo a CT scan. Children from deprived areas have higher rates of injuries and therefore these children may receive more CTs, especially of the head.

To our knowledge, this is the first nation-wide report on numbers and trends in CT use among children. We obtained data from the majority of Dutch hospitals where children are scanned, covering all areas of the Netherlands and the full range of hospitals from very small general hospitals to large general and academic hospitals. We used regression analysis to impute missing data in order to estimate nation-wide numbers of CT scans.

Our study has limitations. First, the imputation of missing data is based on the assumption that the participating hospitals are representative, within the strata used for imputation, for the non-participating hospitals. For example, we assumed that a CT scanner was available
for the entire period 1990-2012 in each of the 18 eligible but non-participating general hospitals, since this was the case for the participating hospitals. Based on aggregated data from the National Institute for Public Health and the Environment (RIVM), there were 131 CT scanners in 2013 in the 42 participating hospitals (average 3.1, range 1-9) and 33 CT scanners in the 18 non-participating hospitals (average 1.8, range 1-5) [personal communication]. However, these numbers might have been different in the beginning of the period. We did not extrapolate into the future. Second, our analysis is purely descriptive and does not allow conclusions about the cause of changes or differences in trends, mainly due to the absence of data on the indication for most scans. However, the patterns we observed might reveal the most promising targets for education on radiation protection in order to further reduce the number of pediatric CT scans to the clinically justifiable minimum. Third, our conclusions about trends in pediatric CT scanning do not necessarily translate to patient dose. Although average doses per CT examination have likely decreased over time, there is, to our knowledge, no representative data on average doses per pediatric CT examination during the study period. Therefore, it is unclear to what extent patient doses from CT examinations increased.

During the time period covered by our analysis, several relevant changes took place. The number of clinical indications for which CT is an appropriate imaging modality has increased substantially. This is partly due to technical advances. Multi-detector CT, introduced in the early 2000s, substantially shortened scan times, which reduces motion artefacts and makes CT more suitable for pediatric patients. Incidence of trauma, a common indication for pediatric head and spine scans, increased with 15,600 per 100,000 treatments in the emergency room among children and young adults aged 5-24 in 2011 in the Netherlands. A US study about the current guideline of mild traumatic head injury suggests that the use of head scans for minor head trauma can be reduced. However, after the introduction of the current guideline in the Netherlands percentages of CTs have still increased significantly.

Finally, concerns have been raised that a substantial fraction of pediatric CT scans might not be justified. Consequently, the appropriateness of CT scans as well as the need to adjust machine parameters to the smaller size of children in order to reduce radiation exposure have become important topics in pediatric radiology since 2000. For example, in 2007, the Society of Pediatric Radiology launched the Image Gently campaign (www.imagegently.org), and in 2014, the European Society of Radiology started the EuroSafe Imaging campaign (www.eurosafeimaging.org).

Ionizing radiation-free imaging modalities, such as ultrasound and Magnetic Resonance Imaging (MRI), are generally available in academic hospitals with pediatric radiologists. However, in smaller general hospitals, limited access to pediatric ultrasound, especially during off hours, and to MRI coupled with its longer imaging times requiring sedation or general anaesthesia in young children, might favour CT.
Conclusion
CT scan is a powerful diagnostic tool with a relatively high radiation exposure. Its massive use has raised radiation protection concerns. The estimated number of pediatric CT scans has more than tripled in the Netherlands during the last two decades. While the number of pediatric CT scans in academic hospitals declined, the number done in general hospitals and among teenagers increased through 2012. Focussing campaigns and education in those groups might be most effective to reduce the number of CT scans to a clinically acceptable minimum.

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Supplemental materials

Supplementary figure S1: Annual number of CT examinations per 1,000 children (<18 years) in The Netherlands, 1990-2012, by gender.