Title pages

Title:

Changes in Radiological Imaging Frequencies in Children Before and After the Accident at the Fukushima Daiichi Nuclear Power Plant in Fukushima Prefecture, Japan

Koji Yoshida・Naomi Hayashida・Yoshiko Fukushima・Akira Ohtsuru・Takashi Ohba・Arifumi Hasegawa・Hisashi Sato・Fumio Shishido・Kiyotaka Yasui・Atsushi Kumagai・Takeshi Yusa・Takashi Kudo・Shunichi Yamashita・Noboru Takamura

Koji Yoshida

Department of Global Health, Medicine and Welfare, Graduate School of Biomedical Sciences, Nagasaki University, Nagasaki, Japan

Naomi Hayashida

Division of Promotion of Collaborative Research on Radiation and Environment Health Effects, Atomic Bomb Disease Institute, Nagasaki University, Nagasaki, Japan

Yoshiko Fukushima

Hirosaki University School of Health Sciences, Hirosaki, Japan

Akira Ohtsuru・Takashi Ohba
Department of Radiation Health Management, Fukushima Medical University School of Medicine, Fukushima, Japan

Arifumi Hasegawa
Department of Radiation Disaster Medicine, Fukushima Medical University School of Medicine, Fukushima, Japan

Hisashi Sato
Department of Radiation Oncology, Fukushima Medical University School of Medicine, Fukushima, Japan

Fumio Shishido
Department of Radiology, Fukushima Medical University School of Medicine, Fukushima, Japan

Koji Yoshida・Kiyotaka Yasui・Atsushi Kumagai
Education Center for Disaster Medicine, Fukushima Medical University, Fukushima, Japan

Takeshi Yusa
Department of Radiological Technology, Fukushima Medical University Hospital, Fukushima, Japan

Takashi Kudo
Department of Radioisotope Medicine, Atomic Bomb Disease Institute, Nagasaki University, Nagasaki, Japan

Shunichi Yamashita
Department of Radiation Medical Sciences, Atomic Bomb Disease Institute, Nagasaki University, Nagasaki, Japan

Correspondence to: Noboru Takamura, M.D. Ph.D. Professor
Department of Global Health, Medicine and Welfare, Atomic Bomb Disease Institute, Nagasaki University, 1-12-4, Sakamoto, Nagasaki 8528523, Japan
TEL: +81-95-819-7170
FAX: +81-95-819-7172
e-mail: takamura@nagasaki-u.ac.jp

Original article

Abstract

PURPOSE: The accident at the Fukushima Daiichi Nuclear Power Plant has raised concerns about radiation exposure, including medical radiation exposure such as X-ray and CT, in residents of Fukushima.

MATERIALS AND METHODS: We compared the numbers and the ratio of outpatients less than 10 years old who underwent imaging examinations (e.g., CT, X-ray, MRI, ultrasonography [US], etc.) at Fukushima Medical university hospital in Fukushima, Japan between before (April 1, 2008, to March 31, 2011) and after (April 1, 2011, to March 31, 2014) the accident.

RESULTS: The number of outpatients less than 10 years old decreased after the accident. The number of outpatients less than 10 years old who underwent CT and X-ray examinations also significantly decreased after the accident ($p<0.001$, $p<0.01$, respectively).

CONCLUSION: Our results suggest that the number of pediatric radiological examinations decreased after the accident in Fukushima. We should continue to communicate with patients and their families to ensure that they understand the risks and benefits of radiological imaging in order to overcome their concerns about the nuclear disaster.

Keywords: Radiological examination; Radiation exposure; Fukushima Daiichi Nuclear Power Plant accident; Fukushima prefecture; Children

Introduction

The use of radiological imaging such as plain radiograph (X-ray) and computed tomography (CT) has expanded worldwide, and the number of these types of examination has dramatically increased over the past several decades [1-3]. The number of CT examinations has particularly increased in developed countries [4]. The developments and improvements in radiological imaging have definitely contributed to early, accurate, and noninvasive diagnoses of various diseases, including malignancies.

On the other hand, radiological imaging carries some risk of adverse effects, including carcinogenesis [4-7]. The increase in CT examinations since the 1980s in particular has raised concerns about the risks of medical radiation exposure in children, due to their higher radiation sensitivity, their relatively higher absorbed doses because of their smaller bodies, and their longer lifetime compared to adults [8-10]. Recent epidemiological studies in some developed countries indicated an increased risk of cancer in children who underwent CT examination at relatively low doses [11-14]. In contrast, an epidemiological study in Germany did not find evidence for an increased risk of cancer in children who underwent X-ray examination [15].

The nuclear accident at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Plant (FNPP) on 11 March 2011 was an aftereffect of a 9.0 Richter-scale earthquake and resulting tsunami, the largest in Japan's recorded history [16,17]. The accident resulted in the release of a large amount of radionuclides into the atmosphere. The total release of iodine-131 (I-131), caesium-134 (Cs-134), and caesium-137 (Cs-137), estimated by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), was 120, 9.0, and 8.8 petabecquerels (PBq) [18], respectively.

Since the accident, much attention has been paid to radiation exposure, including medical radiation exposure, in the Japanese general population and especially in Fukushima [19]. In this study, we investigated the changes in the numbers of imaging examinations (e.g., CT, X-ray, magnetic resonance imaging [MRI], ultrasonography [US], etc.) performed before and after the accident.

Materials and Methods

Study population and data collection

We collected imaging examination data for the outpatients of Fukushima Medical University hospital, Japan. This hospital provides medical care to people living in the north-central area of the Fukushima prefecture (the Kenpoku area). It is a full-service center featuring an oncology unit, emergency care and a disaster medicine of the Fukushima prefecture, with 5 CT scanners, 12 X-ray instruments, and 3 MRI scanners (one MRI scanner was added in December, 2012). We collected data on the number of outpatients who underwent CT, X-ray, MRI, and US from the Department of Medical Information of the Hospital, and combined the information about the age at examination obtained from the hospital's Radiological Information System (Fujitsu Limited, Japan). Also, for the population statistics data, we collected data for April of each year from the official homepage of the municipality of Fukushima Prefecture, Japan [20]. Data from April 1, 2008, to March 31, 2014, were analyzed for this study.

Statistical analysis

We calculated the numbers of outpatients and types of examinations for each year. We also determined the numbers of outpatients in age group, and the number of outpatients who underwent imaging examinations in two age groups; overall or less than 10 years old. We then compared the numbers and the types of examinations between outpatients who underwent imaging examinations before (Group I; April 1, 2008, to March 31, 2011) and after (Group II; April 1, 2011, to March 31, 2014) the FNPP accident in overall outpatients and in outpatients less than 10 years old. We used t-test and chi-square test to compare the data before and after the accident. P values less than 0.05 were considered to be significant. Statistical analysis was performed using SPSS statistics 22.0 (IBM Japan, Tokyo, Japan).

Ethics statement

This study was approved by the ethics committee of the institution before the start of the study (No.

1,959). The study was conducted in accordance with the guidelines expressed in the Declaration of Helsinki. All the data used in this study were analyzed anonymously and securely protected under the data protection officer of hospital.

Results

During April 1, 2008, to March 31, 2014, about 0.5 million residents lived in the Kenpoku area and a total of about 2.2 million outpatients visited the hospital. The numbers of outpatients before (Group I) and after (Group II) the FNPP accident are shown in Table 1. A total of 106,009 CT, 289,607 X-ray, 34,172 MRI, and 112,507 US examinations were conducted during this period. Figure 1 shows the annual overall numbers of outpatients and Figure 2 shows the numbers of outpatients less than 10 years of age who underwent imaging examinations.

The mean number of overall outpatients was 378,418±5,741 (11,325,255/three years) before the accident and 357,373±2,148 (10,721,120/three years) after the accident. The mean number of outpatients less than 10 years old was 20,486±26 (61,458/three years) before the accident and 17,175±831 (51,525/three years) after the accident. The number of outpatients in both age groups significantly decreased after the accident ($p<0.01$, respectively; Table 1). The mean number of overall outpatients who lived in the Kenpoku area was 500,202±2,437 (1,500,607/three years) before the accident and 485,470±7,962 (1,456,411/three years) after the accident. The mean number of outpatients less than 10 years old who lived in the Kenpoku area was 43,938±934 (131,815/three years) before the accident and 37,915±2,706 (113,747/three years) after the accident. The number of outpatients in both age groups significantly decreased after the accident ($p<0.05$, respectively; Table 1). The ratio of outpatients of all ages who lived in the Kenpoku area did not significantly change from before to after the accident (82.7% vs 74.9%, respectively, $p=0.38$; Table 1), but the ratio of outpatients less than 10 years old who lived in the Kenpoku area decreased after the accident (46.6% vs 45.3%, $p<0.05$; Table 1).

The mean number of overall outpatients who underwent CT and X-ray examinations was 17,151±2048 (51,454/three years) and 48,337±4,208 (145,011/three years) before the accident, and 18,182±792 (54,545/three years) and 48,199±2,949 (144,596/three years) after the accident. The mean number of outpatients less than 10 years old who underwent CT and X-ray examinations was 644±49 (1,933/three years) and 3,218±217 (9,655/three years) before the accident, and 315±41 (945 /three years) and 2,332±29 (6,997/three years) after the accident. The number of overall outpatients who underwent CT and X-ray examinations did not change from before to after the accident (p=0.46, p=0.97, respectively, Table 2), and the ratio of overall outpatients who underwent CT and X-ray examinations did not change from before to after the accident (p=0.16, p=0.38, respectively, Table 2, Figure 3). However, the number of outpatients less than 10 years old who underwent CT and X-ray examinations significantly decreased after the accident ($p<0.001$ and $p<0.01$, respectively, Table 2), and the ratio of outpatients less than 10 years old who underwent CT and X-ray examinations also decreased after the accident ($p<0.01$ and $p<0.05$, respectively, Figure 4).

On the other hand, the mean number of overall outpatients who underwent MRI examinations was 5,716±604 (17,096/three years) before the accident and 5,692±490 (17,076/three years) after the accident. The mean number of outpatients less than 10 years old who underwent MRI examinations was 321±54 (964/three years) before the accident and 256±25 (768/three years) after the accident. The number of outpatients in both age groups who underwent MRI examinations did not change from before to after the accident (p=0.96, p=0.13, respectively; Table 2). The ratio of outpatients in both age groups who underwent MRI examinations also did not change from before to after the accident (p=0.54, p=0.74, respectively, Table 2, Figure 3, Figure 4).

The mean number of overall outpatients who underwent US examinations was 19,455±672 (57,135/three years) before the accident and 18,457±1071 (55,372/three years) after the accident. The mean number of outpatients less than 10 years old who underwent US examinations was 889±72 (2,668/three years) before the accident and 891±20 (2,672/three years) after the accident. The number of outpatients in both age groups who underwent US examinations did not change from before to after the accident ($p=0.47$, $p=0.98$, respectively; Table 2). The ratio of overall outpatients who underwent US examinations also did not change from before to after the accident ($p=0.55$; Table 2 and Figure 3). However, the ratio of outpatients less than 10 years old who underwent US examinations significantly increased after the accident ($p<0.05$; Table 2 and Figure 4).

In addition, we analyzed head CT, abdominal CT, head MRI, and abdominal US in patients under the age of 10 years (Table 3). The mean number of outpatients less than 10 years old who underwent head CT and abdominal CT examinations were 157±19 (471/three years) and 99±12 (297/three years) before the accident, respectively, and 72±3 (216/three years) and 68±7 (204/three years) after the accident, respectively. The number of outpatients less than 10 years old who underwent head CT and abdominal CT examinations significantly decreased after the accident ($p<0.01$, $p<0.05$, respectively; Table 3). The ratio of outpatients less than 10 years old who underwent head CT examinations significantly decreased after the accident ($p<0.05$; Table 3), but the ratio of outpatients less than 10 years old who underwent abdominal CT did not significantly decrease after the accident ($p=0.09$; Table 3). On the other hand, the number of outpatients less than 10 years old who underwent head MRI and abdominal US examinations did not change significantly after the accident ($p=0.18$, $p=0.43$, respectively; Table 3). The ratio of outpatients less than 10 years old who underwent head MRI and abdominal US examinations also did not change significantly after the accident ($p=0.68$, $p=0.07$, respectively; Table 3).

Discussion

This study showed a decrease in the number of overall outpatients, including outpatients less than 10 years old, after the accident, and the ratio of outpatients less than 10 years old who lived in the Kenpoku area decreased after the accident. From the result of the population changes in the Kenpoku area, these decreases were mostly caused by decreases in the general population numbers due to evacuations after the accident. Also, this study showed that the number of overall outpatients who underwent CT and X-ray examinations did not change from before to after the accident, but the number and ratio of outpatients less than 10 years old who underwent these examinations decreased after the accident. These results may suggest that the decrease was caused not only by the decrease in the number of outpatients but also by anxiety in children and their parents over the possible health effects due to radiation exposure. Since the accident, information on the relatively high radiation sensitivity in children has been widely distributed. Recently, Miyazaki also found that the number of CT examinations at the main children's hospital in Japan decreased after the Fukushima nuclear disaster, possibly reflecting increased public awareness of the radiation risk to children; one-quarter of surveyed physicians reported refusal of CT by the parents of pediatric patients or the patients themselves after the accident [21]. In addition, locally conducted questionnaires revealed that 20% of physicians reported ordering fewer radiologic tests after the Fukushima accident than before, indicating the possibility of concerns among the medical community about radiation exposure in children. On the other hand, Townsend *et al.* also found a tendency toward decreased pediatric CTs and increased pediatric MRIs in North America. They reported that MRIs were carried out as an alternative to CT [22]. In this study, we investigated the number and ratio of outpatients who underwent MRI and US examinations. A significant increase was observed in the ratio of outpatients less than 10 years old who underwent US (from 4.34 to 5.19 per 100 outpatients) after the accident, despite the significant decrease in CT (from 3.15 to 1.83 per 100 outpatients). In addition, we investigated the number of outpatients who underwent head CT, abdominal CT, head MRI, and abdominal US, and found that both head and abdominal CTs decreased but abdominal US examinations were relatively increased after the accident. These results suggest that after the accident, outpatients might prefer MRI and US as alternative strategies to CT, since these examinations do not carry a risk of ionizing radiation exposure. Furthermore, from the viewpoint of justification, unnecessary imaging might be avoided by doctors due to increased awareness of radiation exposure.

An increased risk of cancer following CT examination has recently been reported in several studies. For example, Pearce *et al.* estimated that children who received an active bone marrow dose of 30 mGy or higher from CT had a 3.2 times greater risk of developing leukemia and that children who received a brain dose of 50 mGy or higher had a 2.8 times greater risk of brain cancer [11]. Mathew *et al.* compared the cancer incidence rate in a group of children exposed to a CT examination and a control group of children that were not exposed and found that the total number of excess cancers for the exposed group was 608 out of 3150 observed cancers [12]. Miglioretti *et al.* also projected that one radiation-induced solid cancer would result from every 300 to 390 abdomen/pelvis scans for girls and from every 670 to 760 abdomen/pelvis scans for boys [13]. Journy *et al*. found the excess risks to children with scans at the age of 1 year could be 1.3-2.5 times higher for breast cancer and 2-3 times higher for thyroid cancer, compared with children exposed at the same doses at the age of 10 years [14]. Brenner *et al.* estimated the lifetime cancer mortality risk attributable to radiation exposure in a 1-year-old child as about 1 in 550 for a single abdominal CT scan, and about 1 in 1500 for a single head CT scan [9]. On the other hand, a non-increased risk of cancer following CT examination has recently been reported in several studies. Krille *et al.* reported for leukemia, CNS tumors and solid tumors other than CNS, standardized incidence ratio were elevated but not statistically significant [23]. Also, Huang *et al.* found the risk of benign brain tumor was significantly higher in the exposed cohort than in the unexposed cohort, but malignant brain tumor not significantly increased [24]. Although these studies have limitations, such as uncertain dose estimations and inconsistency with other epidemiological studies in view of radiation sensitivity, they do indicate that the risks and benefits of radiological imaging, especially in children, should be carefully evaluated.

Since the accident at FNPP, the radiation doses to exposed individuals have been estimated and directly measured [25,26]. The Fukushima Health Survey estimated the external radiation dose based on descriptions of self-reported behavior following the accident [25-27]. The survey covered 26.9% of 2 million residents of Fukushima Prefecture; among these residents, the external effective dose between March 12 and July 11, 2011 was estimated at less than 1 mSv in 62.2% of individuals, less than 2 mSv in 93.9%, less than 3 mSv in 99.4%, less than 4 mSv in 99.7%, and less than 5 mSv in 99.8% [25,26,28]. In addition, thyroid dose monitoring conducted from March 26 to March 30, 2011, using a NaI (Tl) scintillation survey meter in 1,080 children under the age of 15, measured at Iwaki City, Kawamata Town, and Iitate Village in Fukushima Prefecture, showed that 55% had only background radiation levels or lower, and 99% had levels below 0.04 μSv/h, which is equal to 20 mSv of a thyroid equivalent dose [25,26,29]. These findings suggest that the external and internal doses from the FNPP accident were relatively limited in the general population.

Nevertheless, many residents continue to have strong anxieties about the radiation exposure. A recent study conducted a study to identify the determinants that affect the decision to return home after the FNPP accident, and found that expressing anxiety over radiation exposure, as well as being female and living in areas with relatively higher ambient doses, was independently associated with decisions not to return [30]. On the other hand, radiological imaging has clearly contributed to medical advances including early diagnosis. Careful radiation health risk communication is needed between medical specialists, including doctors and nurses, and patients and their families in order to evaluate risks and benefits of radiological imaging in each case.

This study has several limitations. It was not a multi-institutional study, which might cause selection bias in the choice of study participants. Although we also investigated changes in the number of patients receiving radiological imaging, we could not investigate the indications for the imaging or the awareness of the doctors and families of the patients. Further studies are needed to clarify the factors associated with the indication for radiological imaging after the accident.

In conclusion, ionizing radiological examinations such as X-ray and CT, and non-ionizing radiological examinations such as MRI show a trend of patient estrangement after the accident at FNPP. Although 4 years has passed since the accident, many residents of Fukushima Prefecture have not been allowed to return to their homes and remain evacuated throughout Japan. Families of pediatric patient and residents may be lack of risk perception about radiation exposure. To overcome the disruptions caused by the nuclear disaster and to re-establish the medical system in Fukushima Prefecture, we should continue to communicate with patients and their families to ensure that they understand the risks and benefits of radiological imaging.

Conflict of Interest: The authors declare that have no conflict of interest.

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Table 1. Annual number and ratio of outpatients and residents who lived in the Kenpoku area before (group Ⅰ) or after (group Ⅱ) the accident in each age group

	Group Ⅰ	Group Ⅱ	p values
Outpatients			
The mean number Overall (Min-Max)	378,418 (373,326-384,640)	357,373 (354,926-358,250)	<0.01**
The mean number less than 10 years old (Min-Max)	20,486 (20,463-20,514)	17,175 (16,374-18,033)	<0.01**
Residents who lived in the Kenpoku area			
Mean number overall (min-max)	500,202 (497,738-502,612)	485,470 (478,611-494,202)	<0.05*
Mean number less than 10 years old (min-max)	43,938 (42,991-44,859)	37,915 (35,621-40,900)	<0.05*
Outpatients/residents who lived in the Kenpoku area			
Overall (%)	82.7	74.9	0.38
Less than 10 years old (%)	46.6	45.3	<0.05*

* $p < 0.05$, ** $p < 0.01$

Table 2. Annual number and ratio of outpatients who underwent imaging examinations at Fukushima Medical University hospital before (group I) or after (group II) the accident

	Group I	Group II	*p* values
CT examinations			
The mean number Overall	17,151±2048	18,182±792	0.46
(Min-Max)	(14,879-18,858)	(17,289-18,800)	
The mean number less than 10 years old	644±49	315±41	<0.001***
(Min-Max)	(615-701)	(278-359)	
Overall examinations/ Overall outpatients (%)	4.53	5.09	0.16
Less than 10 years old examinations/ Less than 10 years old outpatients (%)	3.15	1.83	<0.01**
X-ray examinations			
The mean number Overall	48,337±4,208	48,199±2,949	0.97
(Min-Max)	(45,680-53,189)	(44,932-50,668)	
The mean number less than 10 years old	3,218±217	2,332±29	<0.01**
(Min-Max)	(2,976-3,284)	(2,299-2,351)	
Overall examinations/ Overall outpatients (%)	12.76	13.49	0.38
Less than 10 years old examinations/ Less than 10 years old outpatients (%)	15.71	13.60	<0.05*
MRI examinations			
The mean number overall	5,716±604	5,692±490	0.96
(Min-Max)	(5,020-6,082)	(5,214-6,194)	
The mean number less than 10 years old	321±54	256±25	0.13
(Min-Max)	(277-382)	(228-276)	
Overall examinations/ Overall outpatients (%)	1.51	1.59	0.54
Less than 10 years old examinations/ Less than 10 years old outpatients (%)	1.57	1.50	0.74
US examinations			
Mean number overall	19,455±672	18,457±1071	0.47
(min-max)	(18,270-19,469)	(17,608-19,661)	
Mean number less than 10 years old	889±72	891±20	0.98
(min-max)	(819-962)	(868-906)	
Overall examinations/	5.03	5.16	0.55

Overall outpatients (%)			
Less than 10 years old examinations/ Less than 10 years old outpatients (%)	4.34	5.19	<0.05*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$,

Table 3. Annual number of outpatients less than 10 years old who underwent imaging examinations (head CT, abdominal CT, head MRI, and abdominal US) before (group I) or after (group II) the accident

	Group I	Group II	*p* values
Examinations			
Mean number of head CTs (min-max)	151±19 (136-174)	72±3 (70-75)	<0.01**
Number of head CTs/outpatients (%)	0.77	0.42	<0.01**
Mean number of abdominal CTs (min-max)	99±12.5 (89-113)	68±6.6 (61-74)	<0.05*
Number of abdominal CTs/outpatients (%)	0.48	0.40	0.09
Mean number of head MRIs (min-max)	141±32 (114-176)	110±8 (105-119)	0.18
Number of head MRIs/outpatients (%)	0.69	0.64	0.68
Mean number of abdominal USs (min-max)	323±67 (264-395)	361±39 (319-396)	0.43
Number of abdominal USs/outpatients (%)	1.57	2.10	0.07

* $p < 0.05$, ** $p < 0.01$,

Figure Legends

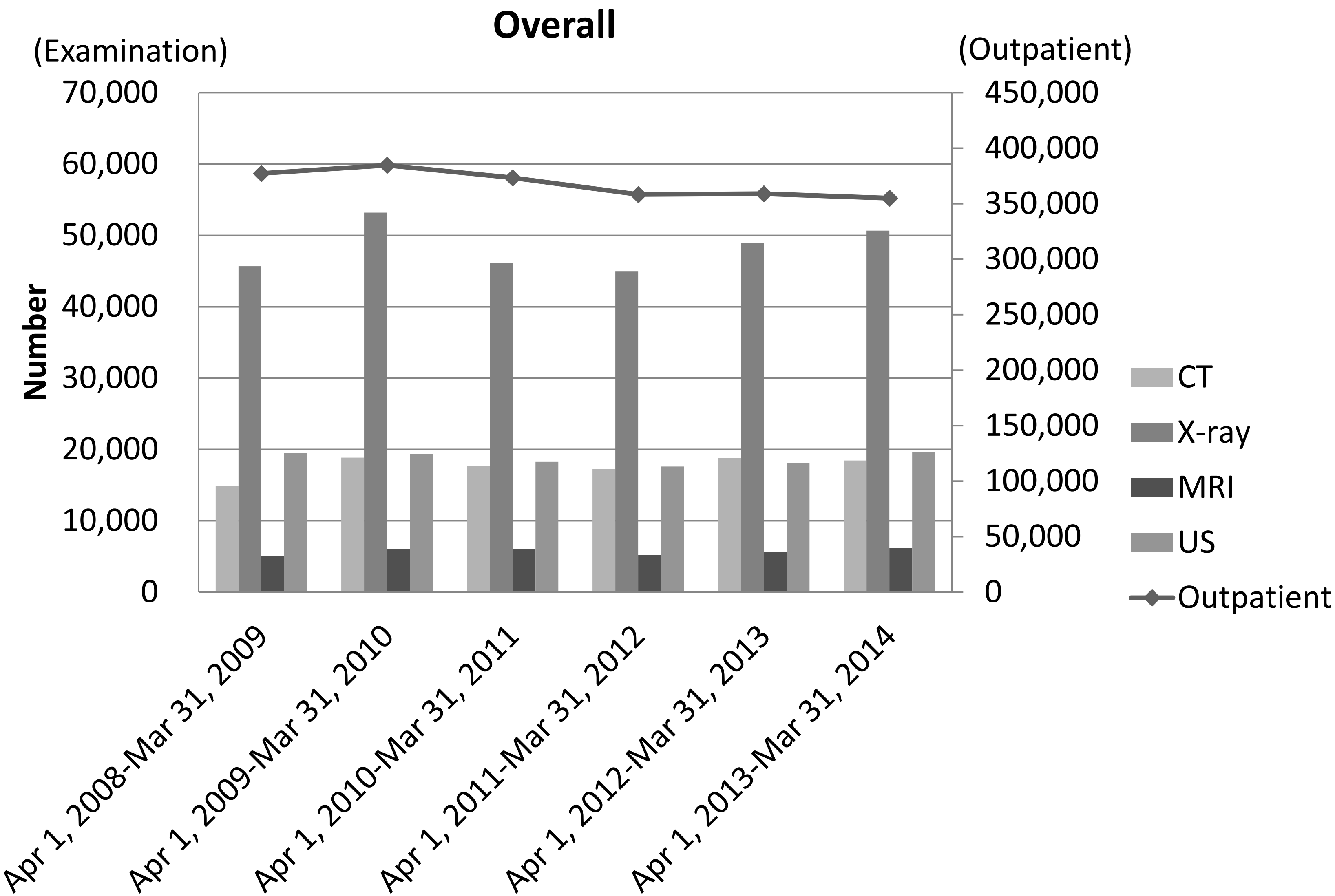
Figure 1. Numbers of X-ray, CT, MRI, and US examinations and overall outpatient visits from 2008 to 2011

Figure 2. Numbers of X-ray, CT, MRI, and US examinations and outpatient visits in outpatients under 10 years old from 2008 to 2011

Figure 3. Ratios of outpatients of all ages who underwent imaging examinations before (group I) and after (group II) the accident

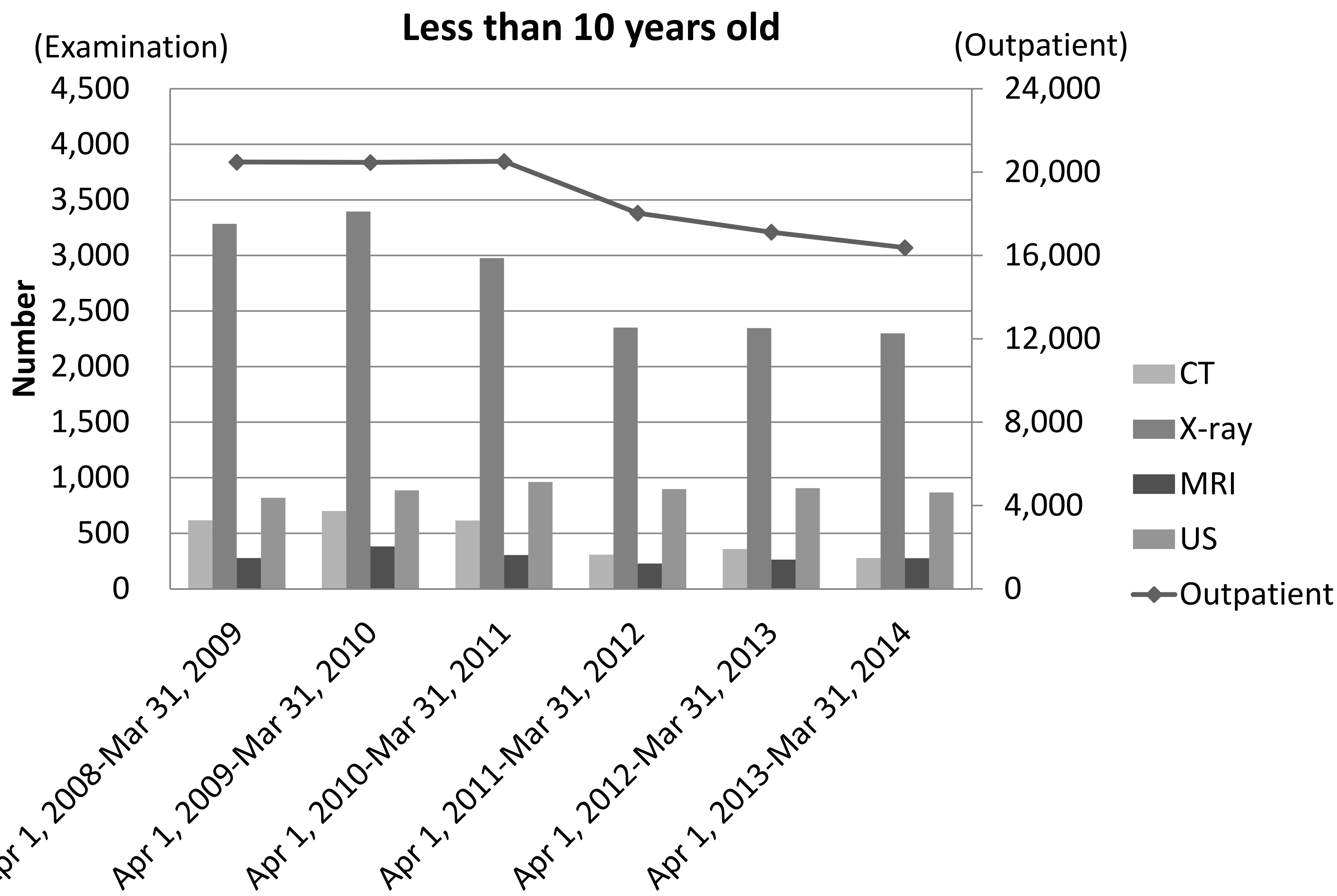
Figure 4. Ratios of outpatients less than 10 years old who underwent imaging examinations before (group I) and after (group II) the accident

Figure 1.



Overall
(Examination)
(Outpatient)
Number
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
CT
X-ray
MRI
US
Outpatient
Apr 1, 2008-Mar 31, 2009
Apr 1, 2009-Mar 31, 2010
Apr 1, 2010-Mar 31, 2011
Apr 1, 2011-Mar 31, 2012
Apr 1, 2012-Mar 31, 2013
Apr 1, 2013-Mar 31, 2014

Figure 2.



Less than 10 years old
(Examination)
(Outpatient)
Number
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
24,000
20,000
16,000
12,000
8,000
4,000
0
CT
X-ray
MRI
US
Outpatient
Apr 1, 2008-Mar 31, 2009
Apr 1, 2009-Mar 31, 2010
Apr 1, 2010-Mar 31, 2011
Apr 1, 2011-Mar 31, 2012
Apr 1, 2012-Mar 31, 2013
Apr 1, 2013-Mar 31, 2014

Figure 3.

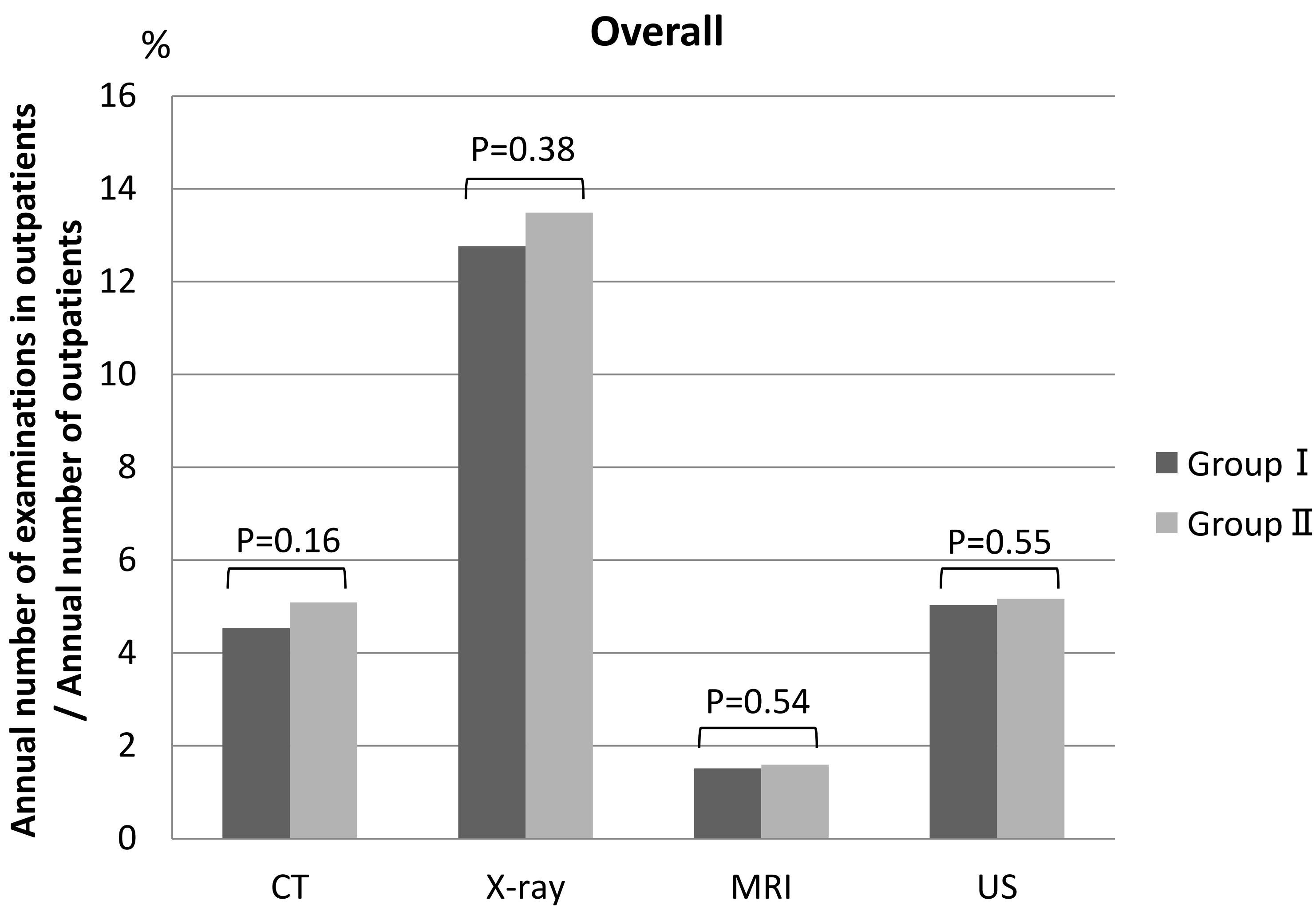
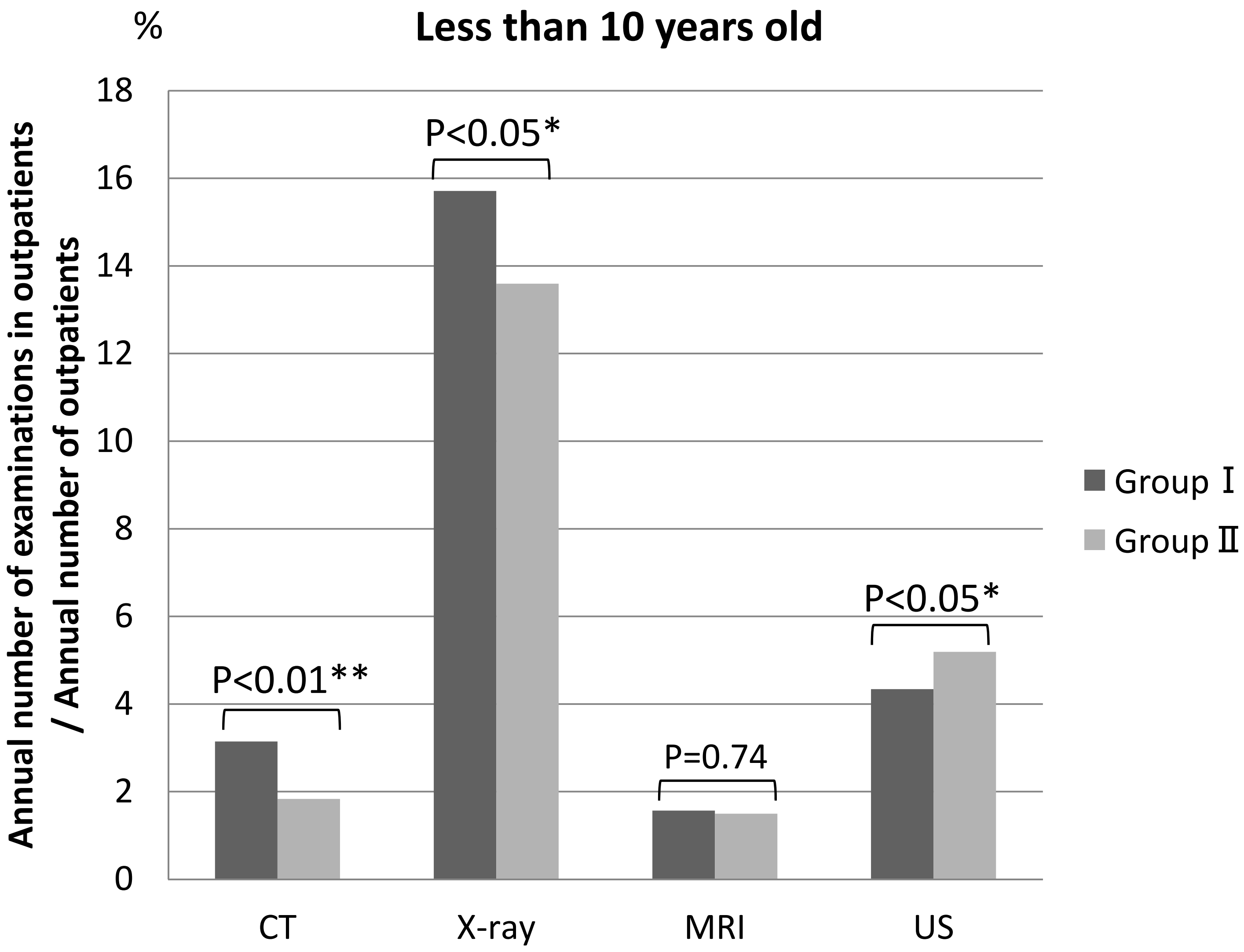

Overall
%
16
14
12
10
8
6
4
2
0
Annual number of examinations in outpatients
/ Annual number of outpatients
P=0.38
P=0.16
P=0.54
P=0.55
CT
X-ray
MRI
US
Group Ⅰ
Group Ⅱ

Figure 4.



%
Less than 10 years old
Annual number of examinations in outpatients / Annual number of outpatients
18
16
14
12
10
8
6
4
2
0
P<0.01**
P<0.05*
P=0.74
P<0.05*
CT
X-ray
MRI
US
Group Ⅰ
Group Ⅱ