Trends in computed tomography scan uses in Taiwan from 2000 to 2013

Yung-Wei Hsueh[a], You-Cheng Lin[a], Ching-Heng Lin[b], Hung-Chieh Chen[a,c], Zheng-Yi Huang[a,*], Jyh-Wen Chai[a,d], Clayton Chi-Chang Chen[a,e,f,g]

[a]Department of Radiology, Taichung Veterans General Hospital, Taichung, Taiwan, ROC; [b]Department of Medical Research, Taichung Veterans General Hospital, Taichung, Taiwan, ROC; [c]National Yang-Ming University School of Medicine, Taipei, Taiwan, ROC; [d]College of Medicine, China Medical University, Taichung, Taiwan, ROC; [e]Department of Radiological Technology, Central Taiwan University of Science and Technology, Taichung, Taiwan, ROC; [f]Department of Medical Education, Taichung Veterans General Hospital, Taichung, Taiwan, ROC; [g]College of Science, Tunghai University, Taichung, Taiwan, ROC

Abstract

Background: The trends in computed tomography (CT) scan uses in Taiwan were examined in different age and sex groups and compared between catastrophic illness and noncatastrophic illness groups.

Methods: This retrospective cohort study used data from the National Health Insurance Research Database (NHIRD) in Taiwan to analyze CT scan uses from the beginning of 2000 to the end of 2013. The number, annual growth rate, and cumulative fold change ratio were estimated in different groups classified by sex, age, or disease category (catastrophic illness, noncatastrophic illness).

Results: The number of CT scan uses per million people per year in Taiwan increased 2.5 times from 24 257 in 2000 to 60 351 in 2013, at the average annual growth rate of 7.4% ± 5.9%. The annual number of CT scan uses in different age groups and disease category groups was significantly higher in males than in females. However, the average annual growth rate and the cumulative fold change ratio were slightly higher in females than in males. The majority of CT scan uses were in middle age and young adult groups. The annual number of CT scan uses in the young adult, child/adolescent, and middle age groups increased 3.7-, 3.5-, and 2.7-fold from 2000 to 2013, but decreased 0.8-fold in the old-age group. The annual number of CT scan uses was highest in the noncatastrophic illness group, followed by the catastrophic illness cancer group and catastrophic illness others group.

Conclusion: CT scan uses in Taiwan increased continuously from 2000 to 2013, even in the groups with higher radiation-related cancer risk. Therefore, clinicians, radiologists, and medical policy makers should weigh diagnostic benefit against sex-specific and age-specific risks in the future.

Keywords: Computed tomography; CT scan uses; NHIRD

1. INTRODUCTION

Computed tomography (CT) scan is an important powerful medical x-ray-based imaging tool for cross-sectional analysis of internal organs, bones, soft tissues, and blood vessels.[1] Since its introduction in the 1970s, this imaging modality has improved the quality of health care by providing information that aids the diagnosis and leads to effective treatment and management. With the advance of CT imaging technology, physicians' ability for accurate diagnosis of injury and disease has improved. CT scan continues to play a major role in cancer staging, treatment planning, and follow-up to therapy. Early disease detection, reduction in mean hospitalization length, and reduction in healthcare cost have also been attributed to greater use of CT scan. For the reasons above, CT scan uses had increased dramatically in developed countries over the past two decades.[2–5]

CT scan is regarded as a radiation diagnostic technology in which various bodily structures are discernible and distinguished based on their ability to absorb the x-ray beam. In biological material exposed to x-rays, the most common scenario is the creation of hydroxyl radicals. These radicals in turn interact with nearby DNA to cause strand breaks or base damage. Most radiation-induced damage is rapidly repaired, but DNA double-strand breaks are repaired less easily and can lead to point mutations, chromosomal translocations, and gene fusions occasionally, all of which play a role in the induction of cancer.[6–8] Radiation doses are higher from CT scan than from other imaging modalities, and CT scan is a major source of medical radiation exposure.[6,9] Concerns about radiation dose and unnecessary CT scans have been addressed by improving CT equipment and technology. These advancements include solid state detectors, iterative reconstruction technique, automatic exposure control, and progress in collimator design.[10,11] In most circumstances, the lifetime risk of developing radiation-related secondary cancer associated with CT scan is low and acceptable compared with the substantial benefits of CT scan.[12–14] However, considering that the number of people exposed is large, cancer risk in even a small number of these individuals could be problematic.

*Address correspondence: Dr. Zheng-Yi Huang, Department of Radiology, Taichung Veterans General Hospital, 1650, Taiwan Boulevard Section 4, Taichung 407, Taiwan, ROC. E-mail address: antidonor@gmail.com (Z.-Y. Huang).

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Taiwan launched its National Health Insurance (NHI) program in 1995.[15] The NHI program is a single-payer government-run system. The national population of Taiwan is about 23 million, and the NHI coverage rate is above 99%. The demographic and medical data of all beneficiaries of NHI are recorded in the Taiwan National Health Insurance Research Database (NHIRD).[16] These data include the date of birth, gender, insured amount based on monthly income, living area, and clinical information such as disease diagnoses, medical examinations, medication dosage and duration, surgical procedures, etc. This is a unique feature that distinguishes the NHIRD from many other electronic healthcare databases, which serve as repositories of data from either a specific population (e.g., the Veterans Administration or Medicare databases from the United States) or selected samples (e.g., Clinical Practice Research Datalink from the United Kingdom). Because it is the largest and most representative medical database in Taiwan, the NHIRD enables us to demonstrate trends in CT scan uses by assessing variables such as number, annual growth rate, and cumulative fold change ratio in different groups classified according to age, gender, and disease category.

2. METHODS

2.1. The database

The NHIRD contains the comprehensive computerized NHI records of almost the entire population of Taiwan for the past two decades.[16] In addition to imposing a low barrier to data access, the NHIRD has several advantages that continue to attract investigators. The above 99% coverage is an obvious strength that enables researchers to test their hypotheses in a large, nationwide population. Because the NHIRD continuously collects data and annually updates the database, investigators can theoretically track beneficiary data from 1995 to 1 year before receiving study approval. These advantages greatly enhance statistical power when studying rare diseases or infrequent outcomes. Moreover, the NHIRD contains information about every billing order, including details on service type, the claimant's doctor (anonymously coded), product brand, prescription date, and the cost. Researchers can figure out where, when, how much, how frequently, and for how long a patient received a specified intervention.

For investigators' convenience, the Longitudinal Health Insurance Database was created by extracting a representative subset of data from the NHIRD. It consists of the details of 1 million individuals randomly sampled from all beneficiaries, and the representativeness of this sample is supported by its similarity to the entire NHIRD population in terms of age distribution, sex distribution, and healthcare cost distribution. The diseases and outcomes were carefully defined, bearing in mind that diagnostic codes in the NHIRD are principally meant for billing purposes and may not be accurate enough. This limitation was overcome by searching, when necessary, the Registry for Catastrophic Illness Patient Database to secure a reliable definition. Entry into this registry, which waives co-payment of the enrollee, is permitted only after explicit criteria are fulfilled. The present study was a retrospective analytic study of data from the Taiwan NHIRD.

2.2. Case selection and study design

The annual records of individuals registered in the NHIRD from the beginning of 2000 to the end of 2013 were collected. We determined the annual number of CT scan uses per million people, annual growth rate (or change in that number in 1 year), and the cumulative fold change ratio (or the number performed each year from 2001 to 2013 divided by the number performed in 2000).

Using the NHIRD, we counted the number of CT scan uses in different groups based on gender, age, and disease category. The total population was divided into groups based on sex: male and female, and based on age range: below 20 years (child/adolescent group), 21 to 45 years (young adult group), 46 to 70 years (middle age group), and above 71 years (old-age group). The total population was also divided into three groups based on catastrophic illness certificate status: one group without catastrophic illness certificates (the noncatastrophic illness group [group 1]), and two groups with catastrophic illness certificates (catastrophic illness cancer group [group 2] and catastrophic illness others group [group 3]). In turn, these three groups were subdivided on the basis of sex and age distribution.

Catastrophic illness was defined as any illness that requires lengthy hospitalization, extremely expensive therapies, or other care that would deplete a family's financial resources, unless covered by special medical insurance policies.[17,18] If a patient is diagnosed by physician as having a condition classified as a catastrophic illness or rare disease under the Department of Health guidelines, the patient can submit related information and apply for a catastrophic illness certificate. The differences in number, annual growth rate, and cumulative fold change ratio were, respectively, analyzed in the total population and the above three disease category groups.

2.3. Statistical analysis

The statistically significant differences of the mean annual growth rates between two sex groups were calculated using a paired-sample, two-tailed t test with p value of <0.05.

3. RESULTS

Tables 1 and 2 show the number of CT scan uses and the annual growth rate (i.e., rate of growth in the number per million people per year) in Taiwan from 2000 to 2013, according to annual records of the NHIRD. The annual number of CT scan uses per million people rose from 24 257 in 2000 to 60 351 in 2013, increasing 7.4% ± 5.9% on average every year. The annual number of CT scan uses per million people was significantly higher in males than in females ($p < 0.001$) and in males than in females in each age group (all $p < 0.001$). The average annual rates in the number of CT scan uses were 10.3% ± 7.5%, 10.9% ± 6.9%, and 8.2% ± 5.6% in the child/adolescent, young adult, and middle age groups. In the old-age group, the annual number of CT scan uses per million people was highest in 2004, but progressively declined from 2004 to 2013, with the average annual rate of −1.3% ± 6.6%. The average annual rate in the number of CT scan uses was slightly higher in the females of all four age groups, but this difference was only statistically significant in the middle age group (8.8% ± 5.5% in females and 7.6% ± 5.9% in males, $p = 0.01$). The annual number of CT scan uses per million people in the different disease groups was significantly higher in males than in females ($p < 0.001$). The average annual rate in the number of CT scan uses was 6.4% ± 6.8%, 9.5% ± 5.2%, and 9.4% ± 8.1% in the disease group 1 (noncatastrophic illness group), group 2 (catastrophic illness cancer group), and group 3 (catastrophic illness others group). The average annual rate in the number of CT scan uses was slightly but not significantly higher in the females of those three disease groups.

In the disease group 1, the annual number of CT scan uses per million people was highest in the middle age group, followed by the young adult group, the old-age group, and the child/adolescent group. The average annual rate in the number of CT scan uses was highest in the child/adolescent group (10.5% ± 7.9%), followed by the young adult group (9.2% ± 7.9%), the middle age group (6.9% ± 6.6%), and the old-age group (−1.6% ± 6.9%). The average annual rates of CT scan uses was slightly

Table 1

Annual number of CT scan uses per million people in Taiwan from 2000 to 2013

			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total		Total	24 257	24 894	29 196	29 851	35 552	34 922	36 267	40 275	44 019	47 616	50 526	53 357	57 975	60 351
		Males	13 958	14 341	16 517	16 950	20 139	19 890	20 562	22 585	24 334	26 199	27 561	29 197	31 362	32 558
		Females	10 299	10 553	12 679	12 901	15 413	15 032	15 705	17 690	19 685	21 417	22 965	24 160	26 613	27 793
Age groups	≦20 y	Total	1773	2015	2374	2418	3074	3048	3185	3610	3869	4323	4948	5341	5947	6139
		Males	1032	1235	1407	1475	1865	1852	1917	2155	2282	2522	2815	3067	3369	3569
		Females	741	780	967	943	1209	1196	1268	1455	1587	1801	2133	2274	2578	2570
	21-45 y	Total	5434	5672	6852	7393	9161	9036	9480	10 934	12 692	14 176	15 261	16 611	18 663	20 313
		Males	3107	3250	3902	4192	5141	5252	5497	6183	7127	7852	8418	9283	10 232	11 086
		Females	2327	2422	2950	3201	4020	3784	3983	4751	5565	6324	6843	7328	8431	9227
	46-70 y	Total	10 425	10 817	12 821	13 173	15 683	15 745	16 701	18 728	20 461	22 408	23 669	25 311	27 286	28 420
		Males	5852	6013	7113	7301	8736	8740	9264	10 297	11 091	12 164	12 798	13 594	14 483	14 983
		Females	4573	4804	5708	5872	6947	7005	7437	8431	9370	10 244	10 871	11 717	12 803	13 437
	≧71 y	Total	6625	6390	7149	6867	7634	7093	6901	7003	6997	6709	6648	6094	6079	5479
		Males	3967	3843	4095	3982	4397	4046	3884	3950	3834	3661	3530	3253	3278	2920
		Females	2658	2547	3054	2885	3237	3047	3017	3053	3163	3048	3118	2841	2801	2559
Disease group 1 (noncatastrophic illness)																
Age groups	All	Total	17 040	17 063	19 594	19 417	23 570	22 699	23 283	25 920	28 024	30 175	31 831	33 863	36 312	37 415
		Males	9627	9705	10 925	10 833	12 911	12 635	12 985	14 240	15 145	16 260	17 054	18 167	19 309	19 743
		Females	7413	7358	8669	8584	10 659	10 064	10 298	11 680	12 879	13 915	14 777	15 696	17 003	17 672
	≦20 y	Total	1511	1684	2021	2037	2616	2641	2759	3108	3307	3729	4271	4597	5217	5399
		Males	865	1037	1214	1252	1574	1601	1647	1853	1947	2183	2394	2630	2907	3094
		Females	646	647	807	785	1042	1040	1112	1255	1360	1546	1877	1967	2310	2305
	21-45 y	Total	4213	4313	5064	5267	6689	6353	6683	7464	8606	9466	10 053	11 070	12 107	12 866
		Males	2408	2433	2843	2951	3709	3661	3850	4229	4792	5186	5529	6186	6639	6994
		Females	1805	1880	2221	2316	2980	2692	2833	3235	3814	4280	4524	4884	5468	5872
	46-70 y	Total	6697	6782	7850	7783	9401	9211	9537	10 800	11 574	12 634	13 118	14 145	14 974	15 516
		Males	3674	3721	4253	4182	4975	4973	5148	5734	6073	6636	6898	7296	7676	7832
		Females	3023	3061	3597	3601	4426	4238	4389	5066	5501	5998	6220	6849	7298	7684
	≧71 y	Total	4619	4284	4659	4330	4864	4494	4304	4548	4537	4346	4389	4051	4014	3634
		Males	2680	2514	2615	2448	2653	2400	2340	2424	2333	2255	2233	2055	2087	1823
		Females	1939	1770	2044	1882	2211	2094	1964	2124	2204	2091	2156	1996	1927	1811
Disease group 2 (catastrophic illness cancer)																
Age groups	All	Total	5261	5617	6800	7016	8046	8264	8917	10 012	11 352	12 581	13 295	14 021	15 646	16 833
		Males	3220	3363	4075	4224	4975	5024	5394	5977	6669	7340	7595	8046	8835	9505
		Females	2041	2254	2725	2792	3071	3240	3523	4035	4683	5241	5700	5975	6811	7328
	≦20 y	Total	100	150	154	139	153	133	151	191	255	239	264	290	301	329
		Males	67	76	91	84	99	81	92	101	144	128	160	173	184	188
		Females	33	74	63	55	54	52	59	90	111	111	104	117	117	141
	21-45 y	Total	795	893	1180	1304	1557	1741	1889	2384	2863	3332	3659	3951	4749	5484
		Males	424	490	665	726	852	977	1075	1284	1569	1833	1961	2139	2526	2952
		Females	371	403	515	578	705	764	814	1100	1294	1499	1698	1812	2223	2532
	46-70 y	Total	2913	3116	3755	3952	4566	4750	5232	5887	6676	7482	7907	8496	9284	9786
		Males	1738	1822	2223	2349	2780	2824	3128	3547	3911	4401	4571	4919	5297	5557
		Females	1175	1294	1532	1603	1786	1926	2104	2340	2765	3081	3336	3577	3987	4229
	≧71 y	Total	1453	1458	1711	1621	1770	1640	1645	1550	1558	1528	1465	1284	1312	1234
		Males	991	975	1096	1065	1244	1142	1099	1045	1045	978	903	815	828	808
		Females	462	483	615	556	526	498	546	505	513	550	562	469	484	426
Disease group 3 (catastrophic illness others)																
Age groups	All	Total	1956	2214	2802	3418	3936	3959	4067	4343	4643	4860	5400	5473	6017	6103
		Males	1111	1273	1517	1893	2253	2231	2183	2368	2520	2599	2912	2984	3218	3310
		Females	845	941	1285	1525	1683	1728	1884	1975	2123	2261	2488	2489	2799	2793
	≦20 y	Total	162	181	199	242	305	274	275	311	307	355	413	454	429	411
		Males	100	122	102	139	192	170	178	201	191	211	261	264	278	287
		Females	62	59	97	103	113	104	97	110	116	144	152	190	151	124
	21-45 y	Total	426	466	608	822	915	942	908	1086	1223	1378	1549	1590	1807	1963
		Males	275	327	394	515	580	614	572	670	766	833	928	958	1067	1140
		Females	151	139	214	307	335	328	336	416	457	545	621	632	740	823
	46-70 y	Total	815	919	1216	1438	1716	1784	1932	2041	2211	2292	2644	2670	3028	3118
		Males	440	470	637	770	981	943	988	1016	1107	1127	1329	1379	1510	1594
		Females	375	449	579	668	735	841	944	1025	1104	1165	1315	1291	1518	1524
	≧71 y	Total	553	648	779	916	1000	959	952	905	902	835	794	759	753	611
		Males	296	354	384	469	500	504	445	481	456	428	394	383	363	289
		Females	257	294	395	447	500	455	507	424	446	407	400	376	390	322

CT = computed tomography.

Table 2

Annual growth rate (i.e., rate of growth in the number of CT scan uses per million people per year) in Taiwan from 2000 to 2013

			2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean ± SD	t-test
Total		Total	1.03	1.17	1.02	1.19	0.98	1.04	1.11	1.09	1.08	1.06	1.06	1.09	1.04	1.07 ± 0.06	
		Males	1.03	1.15	1.03	1.19	0.99	1.03	1.10	1.08	1.08	1.05	1.06	1.07	1.04	1.07 ± 0.05	
		Females	1.02	1.20	1.02	1.19	0.98	1.04	1.13	1.11	1.09	1.07	1.05	1.10	1.04	1.08 ± 0.07	0.031
Age group	0-20 y	Total	1.14	1.18	1.02	1.27	0.99	1.04	1.13	1.07	1.12	1.14	1.08	1.11	1.03	1.10 ± 0.08	
		Males	1.20	1.14	1.05	1.26	0.99	1.04	1.12	1.06	1.11	1.12	1.09	1.10	1.06	1.10 ± 0.07	
		Females	1.05	1.24	0.98	1.28	0.99	1.06	1.15	1.09	1.13	1.18	1.07	1.13	1.00	1.10 ± 0.09	0.918
	21-45y	Total	1.04	1.21	1.08	1.24	0.99	1.05	1.15	1.16	1.12	1.08	1.09	1.12	1.09	1.11 ± 0.07	
		Males	1.05	1.20	1.07	1.23	1.02	1.05	1.12	1.15	1.10	1.07	1.10	1.10	1.08	1.10 ± 0.06	
		Females	1.04	1.22	1.09	1.26	0.94	1.05	1.19	1.17	1.14	1.08	1.07	1.15	1.09	1.11 ± 0.08	0.321
	46-70y	Total	1.04	1.19	1.03	1.19	1.00	1.06	1.12	1.09	1.10	1.06	1.07	1.08	1.04	1.08 ± 0.06	
		Males	1.03	1.18	1.03	1.20	1.00	1.06	1.11	1.08	1.10	1.05	1.06	1.07	1.03	1.08 ± 0.06	
		Females	1.05	1.19	1.03	1.18	1.01	1.06	1.13	1.11	1.09	1.06	1.08	1.09	1.05	1.09 ± 0.05	0.01
	71+ y	Total	0.96	1.12	0.96	1.11	0.93	0.97	1.01	1.00	0.96	0.99	0.92	1.00	0.90	0.99 ± 0.07	
		Males	0.97	1.07	0.97	1.10	0.92	0.96	1.02	0.97	0.95	0.96	0.92	1.01	0.89	0.98 ± 0.06	
		Females	0.96	1.20	0.94	1.12	0.94	0.99	1.01	1.04	0.96	1.02	0.91	0.99	0.91	1.00 ± 0.08	0.099
Disease group 1 (noncatastrophic illness)																	
Age group	Total	Total	1.00	1.15	0.99	1.21	0.96	1.03	1.11	1.08	1.08	1.05	1.06	1.07	1.03	1.06 ± 0.07	
		Males	1.01	1.13	0.99	1.19	0.98	1.03	1.10	1.06	1.07	1.05	1.07	1.06	1.02	1.06 ± 0.06	
		Females	0.99	1.18	0.99	1.24	0.94	1.02	1.13	1.10	1.08	1.06	1.06	1.08	1.04	1.07 ± 0.08	0.083
	0-20 y	Total	1.11	1.20	1.01	1.28	1.01	1.04	1.13	1.06	1.13	1.15	1.08	1.13	1.03	1.11 ± 0.08	
		Males	1.20	1.17	1.03	1.26	1.02	1.03	1.13	1.05	1.12	1.10	1.10	1.11	1.06	1.11 ± 0.07	
		Females	1.00	1.25	0.97	1.33	1.00	1.07	1.13	1.08	1.14	1.21	1.05	1.17	1.00	1.11 ± 0.11	0.912
	21-45y	Total	1.02	1.17	1.04	1.27	0.95	1.05	1.12	1.15	1.10	1.06	1.10	1.09	1.06	1.09 ± 0.08	
		Males	1.01	1.17	1.04	1.26	0.99	1.05	1.10	1.13	1.08	1.07	1.12	1.07	1.05	1.09 ± 0.07	
		Females	1.04	1.18	1.04	1.29	0.90	1.05	1.14	1.18	1.12	1.06	1.08	1.12	1.07	1.10 ± 0.09	0.315
	46-70y	Total	1.01	1.16	0.99	1.21	0.98	1.04	1.13	1.07	1.09	1.04	1.08	1.06	1.04	1.07± 0.07	
		Males	1.01	1.14	0.98	1.19	1.00	1.04	1.11	1.06	1.09	1.04	1.06	1.05	1.02	1.06 ± 0.06	
		Females	1.01	1.18	1.00	1.23	0.96	1.04	1.15	1.09	1.09	1.04	1.10	1.07	1.05	1.08 ± 0.08	0.042
	71+ y	Total	0.93	1.09	0.93	1.12	0.92	0.96	1.06	1.00	0.96	1.01	0.92	0.99	0.91	0.98 ± 0.07	
		Males	0.94	1.04	0.94	1.08	0.90	0.98	1.04	0.96	0.97	0.99	0.92	1.02	0.87	0.97 ± 0.06	
		Females	0.91	1.15	0.92	1.17	0.95	0.94	1.08	1.04	0.95	1.03	0.93	0.97	0.94	1.00 ± 0.09	0.103
Disease group 2 (catastrophic illness cancer)																	
Age group	Total	Total	1.07	1.21	1.03	1.15	1.03	1.08	1.12	1.13	1.11	1.06	1.05	1.12	1.08	1.09 ± 0.05	
		Males	1.04	1.21	1.04	1.18	1.01	1.07	1.11	1.12	1.10	1.03	1.06	1.10	1.08	1.09 ± 0.06	
		Females	1.10	1.21	1.02	1.10	1.06	1.09	1.15	1.16	1.12	1.09	1.05	1.14	1.08	1.10 ± 0.05	0.147
	0-20 y	Total	1.50	1.03	0.90	1.10	0.87	1.14	1.26	1.34	0.94	1.10	1.10	1.04	1.09	1.11 ± 0.18	
		Males	1.13	1.20	0.92	1.18	0.82	1.14	1.10	1.43	0.89	1.25	1.08	1.06	1.02	1.09 ± 0.16	
		Females	2.24	0.85	0.87	0.98	0.96	1.13	1.53	1.23	1.00	0.94	1.13	1.00	1.21	1.16 ± 0.37	0.543
	21-45y	Total	1.12	1.32	1.11	1.19	1.12	1.09	1.26	1.20	1.16	1.10	1.08	1.20	1.15	1.16 ± 0.07	
		Males	1.16	1.36	1.09	1.17	1.15	1.10	1.19	1.22	1.17	1.07	1.09	1.18	1.17	1.16 ± 0.07	
		Females	1.09	1.28	1.12	1.22	1.08	1.07	1.35	1.18	1.16	1.13	1.07	1.23	1.14	1.16 ± 0.09	0.959
	46-70y	Total	1.07	1.21	1.05	1.16	1.04	1.10	1.13	1.13	1.12	1.06	1.07	1.09	1.05	1.10 ± 0.05	
		Males	1.05	1.22	1.06	1.18	1.02	1.11	1.13	1.10	1.13	1.04	1.08	1.08	1.05	1.09 ± 0.06	
		Females	1.10	1.18	1.05	1.11	1.08	1.09	1.11	1.18	1.11	1.08	1.07	1.11	1.06	1.10 ± 0.04	0.455
	71+ y	Total	1.00	1.17	0.95	1.09	0.93	1.00	0.94	1.01	0.98	0.96	0.88	1.02	0.94	0.99 ± 0.08	
		Males	0.98	1.12	0.97	1.17	0.92	0.96	0.95	1.00	0.94	0.92	0.90	1.02	0.98	0.99 ± 0.08	
		Females	1.05	1.27	0.90	0.95	0.95	1.10	0.92	1.02	1.07	1.02	0.83	1.03	0.88	1.00 ± 0.11	0.687
Disease group 3 (catastrophic illness others)																	
Age group	Total	Total	1.13	1.27	1.22	1.15	1.01	1.03	1.07	1.07	1.05	1.11	1.01	1.10	1.01	1.09 ± 0.08	
		Males	1.15	1.19	1.25	1.19	0.99	0.98	1.08	1.06	1.03	1.12	1.02	1.08	1.03	1.09 ± 0.08	
		Females	1.11	1.37	1.19	1.10	1.03	1.09	1.05	1.07	1.07	1.10	1.00	1.12	1.00	1.10 ± 0.10	0.648
	0-20 y	Total	1.12	1.10	1.22	1.26	0.90	1.00	1.13	0.99	1.16	1.16	1.10	0.94	0.96	1.08 ± 0.11	
		Males	1.22	0.84	1.36	1.38	0.89	1.05	1.13	0.95	1.10	1.24	1.01	1.05	1.03	1.10 ± 0.17	
		Females	0.95	1.64	1.06	1.10	0.92	0.93	1.13	1.05	1.24	1.06	1.25	0.79	0.82	1.07 ± 0.22	0.797
	21-45y	Total	1.09	1.30	1.35	1.11	1.03	0.96	1.20	1.13	1.13	1.12	1.03	1.14	1.09	1.13 ± 0.11	
		Males	1.19	1.20	1.31	1.13	1.06	0.93	1.17	1.14	1.09	1.11	1.03	1.11	1.07	1.12 ± 0.09	
		Females	0.92	1.54	1.43	1.09	0.98	1.02	1.24	1.10	1.19	1.14	1.02	1.17	1.11	1.15 ± 0.17	0.424
	46-70y	Total	1.13	1.32	1.18	1.19	1.04	1.08	1.06	1.08	1.04	1.15	1.01	1.13	1.03	1.11 ± 0.09	
		Males	1.07	1.36	1.21	1.27	0.96	1.05	1.03	1.09	1.02	1.18	1.04	1.09	1.06	1.11 ± 0.11	
		Females	1.20	1.29	1.15	1.10	1.14	1.12	1.09	1.08	1.06	1.13	0.98	1.18	1.00	1.12 ± 0.08	0.785
	71+ y	Total	1.17	1.20	1.18	1.09	0.96	0.99	0.95	1.00	0.93	0.95	0.96	0.99	0.81	1.01 ± 0.11	
		Males	1.20	1.08	1.22	1.07	1.01	0.88	1.08	0.95	0.94	0.92	0.97	0.95	0.80	1.00 ± 0.12	
		Females	1.14	1.34	1.13	1.12	0.91	1.11	0.84	1.05	0.91	0.98	0.94	1.04	0.83	1.03 ± 0.15	0.572

CT = computed tomography.

higher in the female groups, but only statistically significant in the middle age group (7.7% ± 7.5% in females and 6.1% ± 5.9 % in males, $p = 0.04$).

In the two catastrophic illness groups, the annual number of CT scan uses per million people was highest in the middle age group, followed by the young adult, old-age, and child/adolescent groups. The annual number of CT scan uses per million people was significantly higher in males than in females in each age group (all $p < 0.01$), except in disease group 3 where this gender difference was not significant after age 70 years. In the disease group 2, the average annual rate in the number of CT scan uses was highest in the young adult group (16.2% ± 7.3%), followed by the child/adolescent group (10.8% ± 17.6%), middle age group (9.9% ± 4.8%), and old-age group (–1.0% ± 7.7%). In disease group 3, the average annual rate in the number of CT scan uses was highest in the young adult group (12.9% ± 10.7%), followed by the middle age, child/adolescent, and old-age groups (11.2% ± 8.7%, 8.0% ± 11.2%, and 1.4% ± 11.4%). There was no significant between-gender difference in growth rate in these two catastrophic illness groups.

Figure 1 depicts trends in CT scan uses and the number per million people per year in different age groups from 2000 to 2013. The annual number of CT scan uses per million people was highest in the middle age group, followed by the young adult group and old-age group, and lowest in the child/adolescent group. The annual number of CT scan uses per million people increased gradually from 2000 to 2013 in all except the old-age group, where it was highest in 2004 and progressively declined thereafter.

Figure 2 shows the cumulative fold change in CT utilization ratio per million people in four different age groups. The ratio from 2000 to 2013 was 3.7, 3.5, and 2.7 in the young adult, child/adolescent, and middle age groups, but only 0.8 in the old-age group.

Figure 3 presents the trends in CT scan uses and the number per million people per year in the three disease groups from 2000 to 2013. The annual number of CT scan uses per million people was highest in the noncatastrophic illness group, followed by the catastrophic illness cancer group and catastrophic illness others group and gradually increased in these three disease groups from 2000 to 2013.

Figure 4A–C shows the cumulative fold change in CT utilization ratio from 2000 to 2013 in different disease groups and in each disease group according to age. These ratios were 2.2, 3.2, and 3.1 in disease groups 1, 2, and 3 from 2000 to 2013 and were higher in females (2.4, 3.6, and 3.3) than in males (2.1, 3.0, and 3.0).

In the noncatastrophic illness group (Fig. 4A), the cumulative fold change ratio was 3.6, 3.1, 2.3, and 0.8 in the child/adolescent, young adult, middle age, and old-age groups and was slightly higher in females (3.3, 2.5, and 0.9) than in males (2.9, 2.1, and 0.7) in the young-age, middle age, and old-age groups, but statistically similar between females and males in the child/adolescent group (3.6 vs 3.6).

In the catastrophic illness cancer group (Fig. 4B), the cumulative fold change ratio was highest (6.9) in the young adult group, followed by 3.4, 3.3, and 0.9 in the middle age, child/adolescent, and old-age groups, respectively, and it was lower in females (6.8) than in males (7.0) in the young adult group and higher in females (4.3, 3.6, 0.9) than in males (2.8, 3.2, 0.8) in the child/adolescent, middle age, and old-age groups, respectively.

In the catastrophic illness others group (Fig. 4C), the cumulative fold change ratio was highest (4.6) in the young adult group, followed by 3.8, 2.5, and 1.1 in the middle age, child/adolescent, and old-age groups, and it was lower in females (2.0) than in males (2.9) in the child/adolescent group and higher in females (5.5, 4.1, and 1.3) than in males (4.2, 3.6, and 1.0) in the young adult, middle age, and old-age groups, respectively.

4. DISCUSSION

In Taiwan, the number of CT scan uses per million people per year rose from 24 257 in 2000 to 60 351 in 2013 and grew at the average annual rate of 7.4% ± 5.9% as compared to the 3.5% to 13.5% reported in more than 20 American-European countries.[2] The cumulative fold change in CT utilization ratio

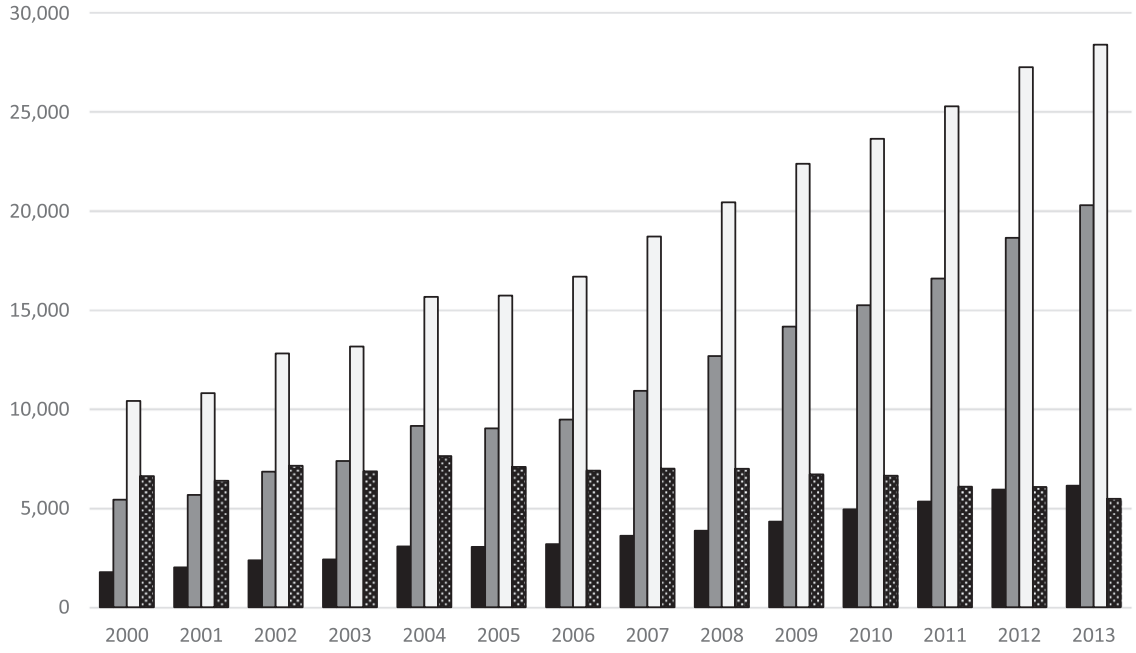

Fig. 1 Annual number of CT scan uses per million people in Taiwan from 2000 to 2013 in four age groups. From left to right: child/adolescent group (≦20 y), young adult group (21-45 y), middle age group (46-70 y), old-age group (≧71 y). CT, computed tomography.

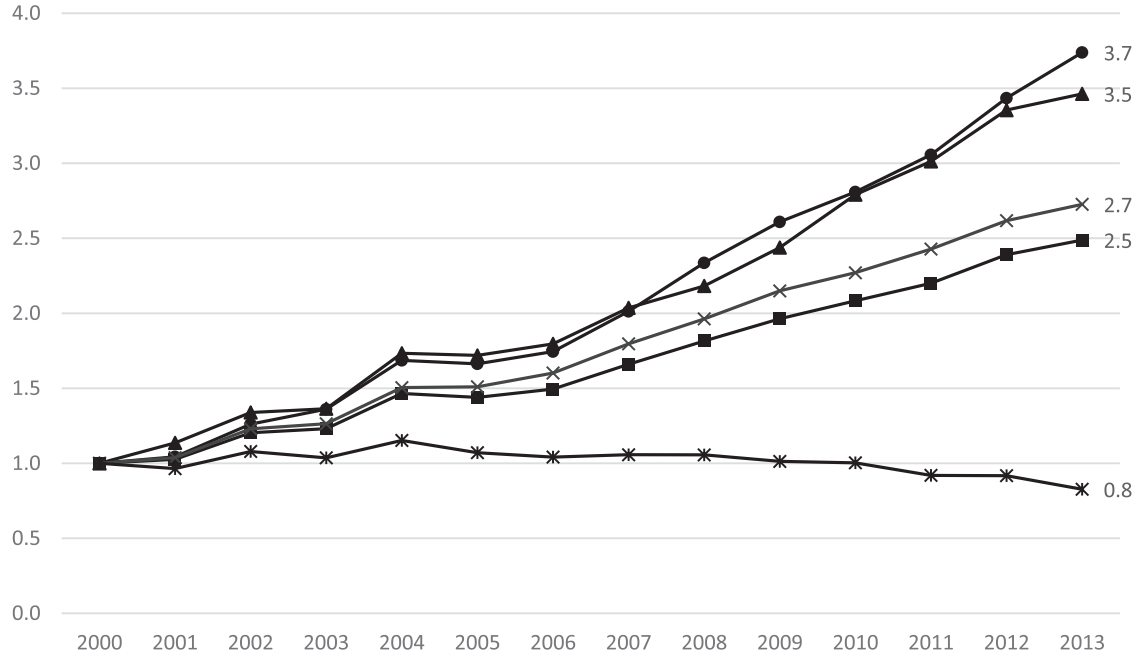

Fig. 2 Cumulative fold change in CT utilization ratio from 2000 to 2013 in total population and four age groups. ■, Total population; ▲, child/adolescent group; ●, young adult group; ×, middle age group; *, old-age group. CT, computed tomography.

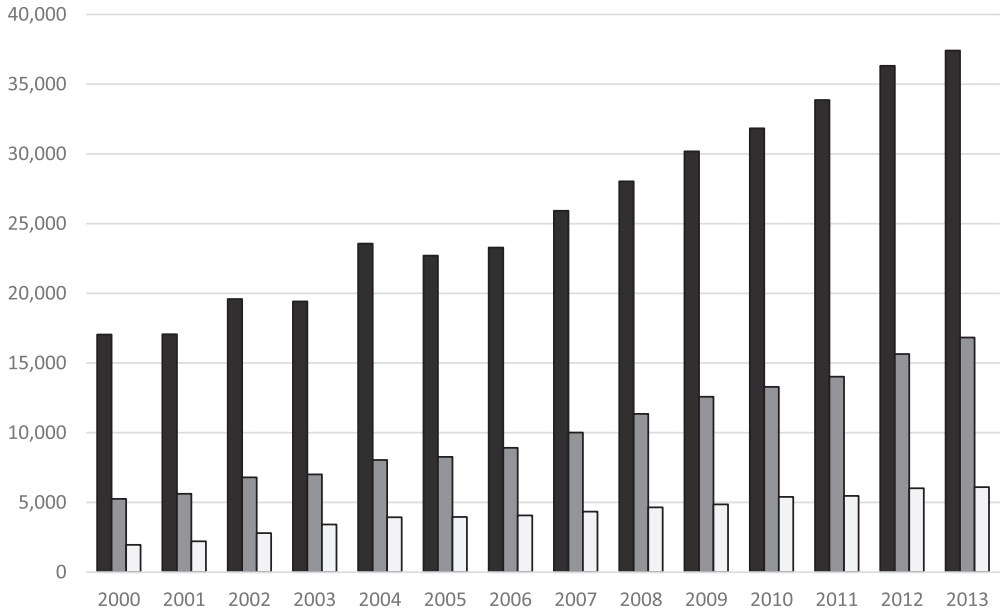

Fig. 3 Annual number of CT scan uses per million people in Taiwan from 2000 to 2013 in three disease groups. From left to right: group 1 (noncatastrophic illness), group 2 (catastrophic illness cancer), group 3 (catastrophic illness others). CT, computed tomography.

was 2.5 from 2000 to 2013 in Taiwan, and 1.6, 1.8, 1.9, 2.2, 2.3, and 2.5 in Belgium, Spain, Hungary, United States, United Kingdom, and New Zealand, respectively. In 2013, the annual number of CT scan uses per 1000 inhabitants was 60.3 in Taiwan, which is higher than in Finland and Slovenia (31.0 and 55.1 examinations per 1000 inhabitants) and much less than in other American-European countries (70.3-240.3 examinations per 1000 inhabitants).[2] However, the number of CT scan uses was the total number of reimbursed CT scans, including scans of different body parts or organs, each of which would be counted as a different examination in most countries (http://www.oecd.org/health/healthdata). Owing to differences in billing policy between Taiwan and other countries, each reimbursed CT scan in Taiwan included more than one body part or one organ. Therefore, we believe that the frequency of CT scan uses in Taiwan also is about the same as that in other developed American-European countries.

The majority of CT scan uses in Taiwan from 2000 to 2013 were in middle age and young adult individuals. The annual number of CT scan uses per million people in the middle age and young adult groups rose from 10 425 and 5434 in 2000 to 28 420 and 20 313 in 2013, increasing at the average annual

rate of 8.2% ± 5.6% and 10.9% ± 6.9%. Although the number of CT scan uses was smallest in the child/adolescent group, the annual number per million people rose from 1773 in 2000 to 6139 in 2013, and increased at the average annual rate of 10.3% ± 7.5%. Furthermore, the total population in Taiwan rose from 21.8 million people in 2000 to 23.3 million people in 2013, according to annual census figures.[19] The vast majority of the Taiwan population was young adults and children/adolescents, declining from 42% and 31% of the total in 2000 to 39% and 22% of the total in 2013. The percentage of the total population that was middle aged and old aged increased from 21% and 5% in 2000 to 31% and 8% in 2013. Notably, the frequency of CT scan uses has been increasing at a higher rate in the young adult and child/adolescent groups than in the middle age and old-age groups. Because the relevant biological effect of x-rays is stochastic, with the likelihood rising as the

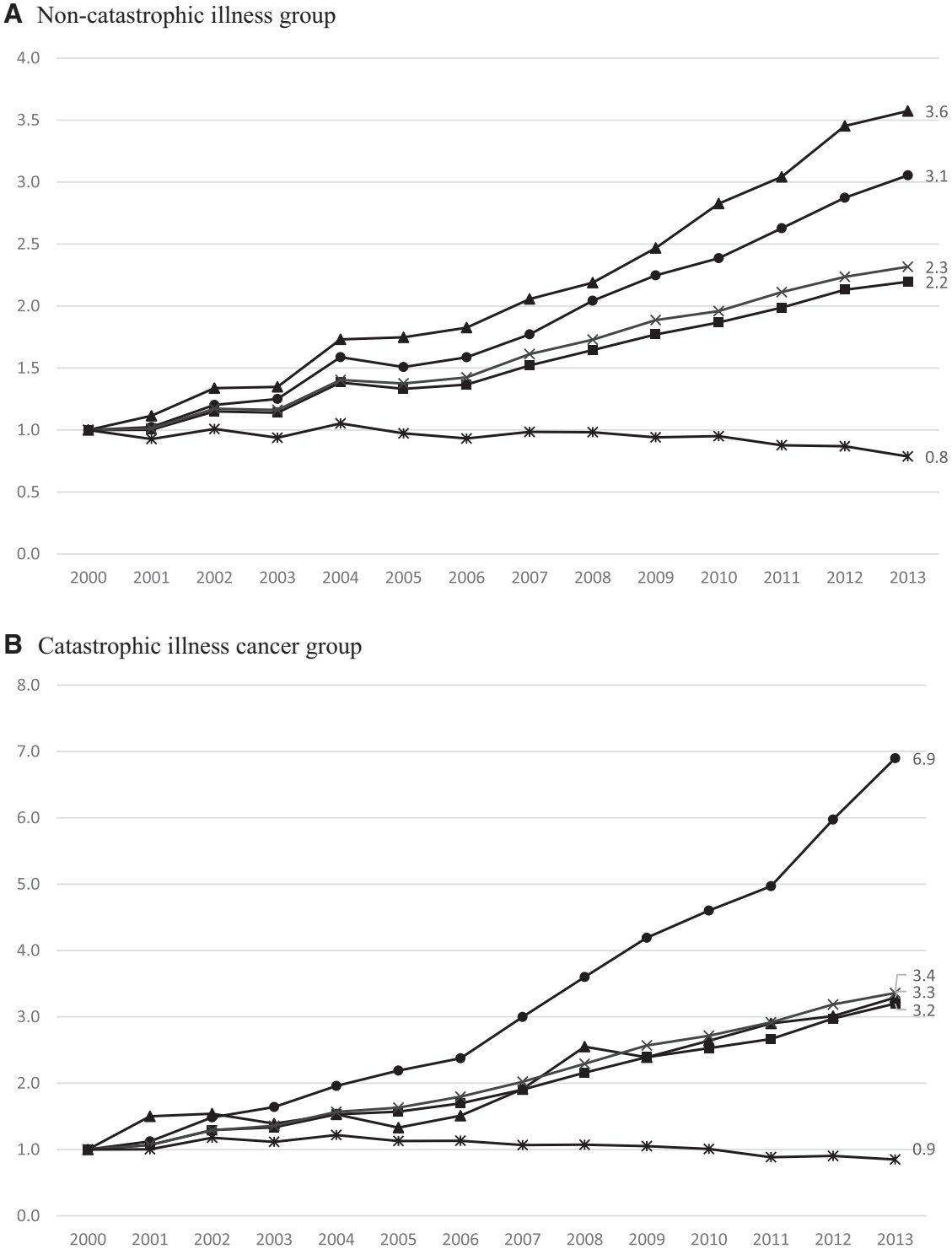

Fig. 4 (Continued)

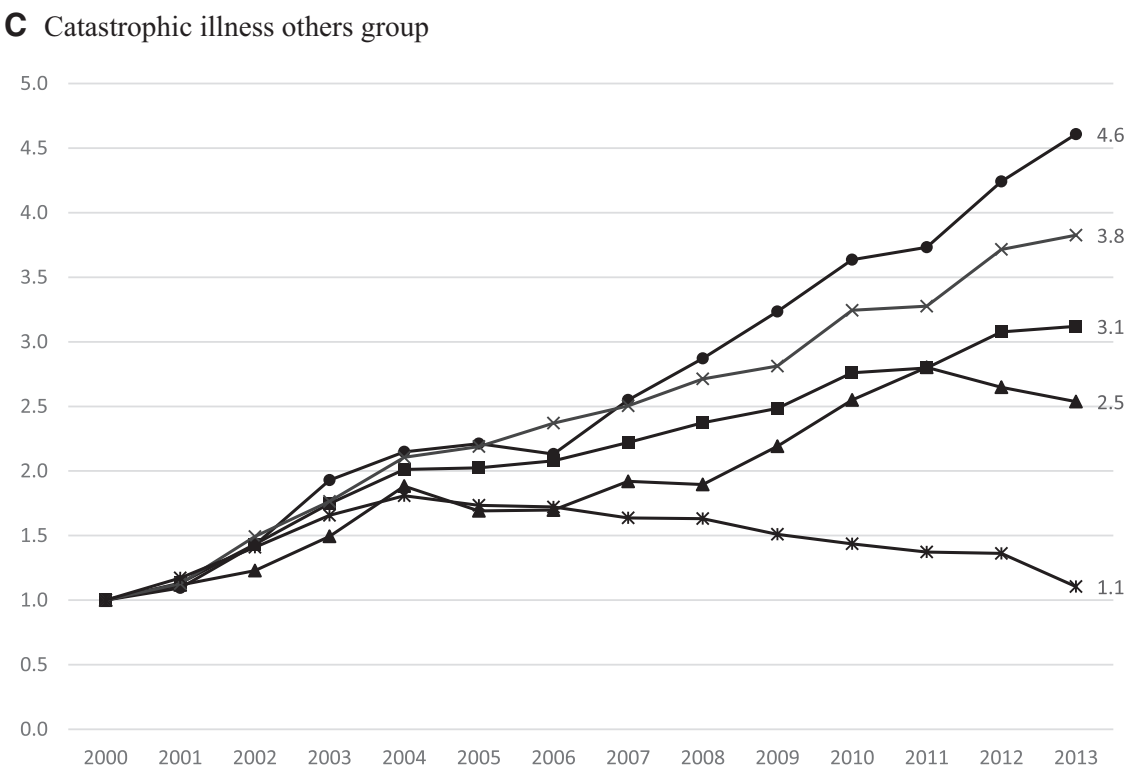

Fig. 4 Cumulative fold change in CT utilization ratio from 2000 to 2013 in three disease groups according to age groups. (A) Noncatastrophic illness group. (B) Catastrophic illness cancer group. (C) Catastrophic illness others group. ■, Total population; ▲, child/adolescent group; ●, young adult group; ×, middle age group; * old-age group. CT, computed tomography.

radiation dose increases, younger people are at a substantially higher risk from radiation and also have more remaining years of life during which a radiation-induced cancer might develop. Contrarily, for the old-age group, the annual number of CT scan uses per million people declined from 7634 in 2004 to 5479 in 2013 at the average annual rate of –1.3% ± 6.6%.

In this study, we found the interesting result of average annual rate declining only in the old-age group, but could not explain the reason. However, it would be clarified by analyzing the healthy conditions, medical behaviors, alterative imaging modality uses, and national medical policies of the old-age group in the future work.

From 2000 to 2013, the annual number of CT scan uses per million people was significantly higher in males than in females, and females had significantly higher average annual rate (8.1% ± 6.6% vs 6.9% ± 5.4%) and cumulative fold change in CT utilization ratio (2.7 vs 2.3). The cumulative fold change ratio was slightly higher in females (4.0, 2.9, and 1.0) than males (3.6, 2.6, and 0.7) in the young adult, middle age, and old-age groups, but similar between females and males in the child/adolescent group (3.5 vs 3.5). Since the higher cancer risk of radiation exposure among women has long been recognized, more attention should be paid to the issue of markedly increasing CT scan uses in females.[20,21]

In the analysis of CT scan uses in the disease groups from 2000 to 2013, the majority of CT scans were performed in disease group 1, with the annual number per million people being 17 040 in 2000 and 37 415 in 2013 at average annual rate of 6.4% ± 6.8%, which was much the same as the rate in the whole population. However, the average annual rate and cumulative fold change ratio from 2000 to 2013 were highest in the child/adolescent group (10.5% ± 7.9%, 3.57), followed by the young adult group (9.2% ± 7.9%, 3.05), the middle age group (6.9% ± 6.6%, 2.32), and the old-age group (–1.6% ± 6.9%, 0.79). In disease group 1, the annual number of CT scan uses per million people was significantly higher in males than in females. Although the average annual rate was higher in females than in males, this intergender difference was only significant in the middle age group (7.7% ± 7.5% in females and 6.1% ± 5.9% in males; $p < 0.05$). Because of the higher correlation of radiation exposure with CT scan than with other medical imaging examinations, cancer risk should be a great concern in Taiwan when contemplating CT scan uses in younger and female patients with noncatastrophic illnesses.

The percentage of the total population in Taiwan that received catastrophic illness certifications was 2.6% in 2000 and 4.7% in 2013. The annual number of CT scan uses per million people was 5261 and 1956 in disease groups 2 and 3 in 2000 and 16 833 and 6103 in 2013, accounting for approximately 30% to 38% of the total. Although people with catastrophic illness utilized only about one-third of CT scans performed between 2000 and 2013, the estimated frequency of CT scan uses was approximately 10 times higher in those with catastrophic illness than in those without catastrophic illness. The annual number of CT scan uses per million people was highest in middle-aged patients with catastrophic illness and increased from 2913 (group 2) and 815 (group 3) in 2000 to 9786 and 3118 in 2013, and the average annual rate was 9.9% ± 4.8% (group 2) and 11.2% ± 8.7% (group 3). Notwithstanding that the minority of CT scans were performed in the young adult group, the annual number of CT scan uses per million people increased from 795 (group 2) and 426 (group 3) in 2000 to 5484 and 1963 in 2013, and the average annual rate was much higher in the young adult group (16.2% ± 7.3% [group 2] and 12.9% ± 10.7% [group 3]) than in the middle age group (9.9% ± 4.8% and 11.2% ± 8.7%).

Furthermore, the cumulative fold change ratio from 2000 to 2013 was also much higher in the young adult group (6.9 [group 2] and 4.6 [group 3]) than in the middle age group (3.4 and 3.8). The growth in the number of CT scan uses in disease group 2 was probably driven by increasing number of newly diagnosed cancer cases in Taiwan, which increased 1.5 times from 2004 to 2013,[19] and also by the development of new medications for cancer treatment.[22,23] In addition, in 2004, the NHI began reimbursing costs associated with targeted therapy for cancer. The cancer patients receiving targeted therapy need short- and long-term follow-up medical imaging for evaluation of the therapeutic effect. More attention should be paid to the growth rates of CT utilization in young adults, children, and adolescents, particularly because many of them have previously undergone multiple CT scans and higher radiation exposure, which is associated with higher lifetime risk of radiation-induced secondary cancers.[4,6–8]

The strengths of this study include the use of (1) nationwide bill collection data from a large population (more than 99% of patients in Taiwan); (2) actual CT scan use data collected from a single-payer billing database (in contrast to patient self-reported survey data or data obtained from the literature); (3) data collected continuously and retrospectively from 2000 to 2013; and (4) the NHIRD, providing CT scan use data divided by age, gender, and disease category for comparison of the differences between groups. This study had several limitations including: (1) possible underestimation of the number of CT scan uses because a single patient visit to a CT machine in Taiwan can involve more than one examination, one body part, or one internal organ; (2) inability to accurately estimate the anatomical area scanned by CT and level of exposure to radiation because a single CT examination in Taiwan always includes more than one body part or one internal organ; (3) failure to obtain CT scan use data from health examination or screening study records that are not included in the NHIRD.

In conclusion, this retrospective cohort study used the NHIRD in Taiwan as a source of data to demonstrate trends in CT scan uses from 2000 to 2013 and analyze the differences between groups classified according to sex, age, and disease classification. We found that CT scan uses in Taiwan were continuously increasing from 2000 to 2013 with the cumulative fold change ratio reaching 2.5. We should be concerned that this ratio, and therefore radiation-related cancer risk, was higher in females, young adults, and children/adolescents. There is reason for concern that CT scan uses are increasing among healthy individuals since lifetime risk of developing radiation-related secondary cancer, though small, is not zero. The increasingly large number of people exposed, particularly in young and female individuals, could translate into many cases of radiation-related cancer in Taiwan. Therefore, clinicians, radiologists, and medical policy makers should be concerned with the increasing CT utilization rates and carefully weigh the balance between its potential for harm and benefit. Furthermore, both clinicians and patients need to be cognizant that radiation exposure from CT scan may pose a cumulative risk of radiation-related cancer to younger patients over time. Increasing CT utilization rates and cumulative fold change ratios in young adults, adolescents, and children are a concern because many of them have received CT scans multiple times. To reduce subsequent adverse outcomes and health system savings in the future, sex-specific risks, age-specific radiation risks, and diagnostic benefits should be weighed before deciding the most appropriate imaging modality for every single individual.

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