Research Article

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Benefits of computed tomography in reducing mortality in emergency medicine

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Abstract: Performing accurate diagnosis using computed tomography (CT) in emergency medicine may reduce mortality rates in various diseases. In this observational, correlational and cross-sectional study, we conducted multiple regression analyses to investigate the relationship between CT utilization rates and mortality. In addition, we estimated the annual net profits from CT to show the profitability of introducing a CT system in each Japanese prefecture.

We conducted a multiple regression analysis to investigate correlations between CT utilization rates and mortality from each disease adjusted for the population density, number of doctors, as well as transportation time to the medical institution.

The results of multiple regression analysis showed that traffic accident mortality was related to CT utilization rate and population density. Extrinsic death such as mortality due to falling, drowning and asphyxia was related to CT utilization, indicating that CT in emergency medicine reduced mortality. Moreover, the annual net profit from multi-slice CT (MSCT) was estimated as positive.

Our study clearly demonstrates that CT utilization rates relate to a reduction in mortality from accidents, indicating that screening patients with CT in the emergency room has a beneficial effect and reduces mortality. Therefore, CT equipment has a beneficial effect in both emergency medicine and hospital management.

Keywords: Computed tomography; Mortality; Emergency medicine; Traffic accident; Hospital management

1 Introduction

As computed tomography (CT) systems have high spatial resolution, they are particularly useful in the diagnosis of stroke, damage to internal organs including the intracranial cavity, acute abdominal pain, as well as for cancer screening [1–5]. In recent years, use of multi-slice CT (MSCT) equipped with a multi-row detector has become widespread, and it is now possible to acquire thin slices in a short time. This has allowed inspection of the coronary arteries, colon, etc. with CT [6–9]. Moreover, with the development of iterative reconstruction method, it is now possible to obtain high-quality images with a low radiation dose [10]. Consequently, screening for lung cancer at a low dose is widely performed [11]. Due to these rapid advances and their extensive diagnostic capabilities, CT systems have quickly become widespread worldwide, especially in Japan.

In Japan, the age-adjusted mortality rate for cerebrovascular disease has dramatically reduced since 1970, and that of cancer has reduced since 2000. Mortality rates following accidents by age group have also been decreasing since 1995, with mortality from traffic accidents halving in most age groups. Both improved vehicle safety and progress in medical care may have contributed to such improvements [12]. Furthermore, development of emergency medical system including emergency transportation and treatment based on accurate diagnosis using CT systems may affect improvements in mortality associated with various diseases/injuries such as trauma, cancer and cerebrovascular events.

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Japan has the highest number of CT systems in clinical use worldwide. CT systems have been introduced not only at major hospitals, but also at small hospitals and clinics across the country. Health data obtained from the Organization for Economic Co-operation and Development (OECD) in 2013 demonstrated that the number of CT scans per million individuals in Japan was 101.3, which is about 4.3 times higher than the OECD average of 23.6 [13]. However, this could be a major liability for hospital management because CT systems are expensive [14].

Thus, in this study, we analyzed the relationship between CT utilization and reduced mortality rates of various diseases/injuries from the viewpoint of emergency medicine. Additionally, we estimated the net yearly profits from CT use by prefecture (local governments of 47 prefectures that are considered the largest administrative districts in Japan) and discussed the profitability of introducing CT systems.

2 Methods

This was an observational, correlational and cross-sectional study spanning from 2010 to 2014. We obtained data published by the Ministry of Health, Labor and Welfare of the Japanese government as described later. The data used in this study did not include detailed personal information since it was aggregated data publicized by the Japanese Government (Ministry of Health, Labor, and Welfare of Japan).

Age-adjusted mortality rates for various diseases were calculated from the 2010 Vital Statistics [15] using the annual report of aggregated data including mortality per 100,000 people. We defined age-adjusted mortality for five major causes of death in Japan: malignant neoplasms, cerebrovascular diseases, heart diseases, pneumonia, and accidents. Accidents were subdivided into traffic accidents, falling, drowning, and asphyxia. Population density data was obtained from the 2010 Population Census [16]. The number of doctors per 100,000 individuals was calculated using data from the 2011 Survey of Medical Institutions [17]. The data of transport time to the medical institution by EMS (emergency medical service) was obtained from the 2010 Current state of emergency rescue [18].

The CT utilization rate was defined as the number of examinations per CT scanner and calculated from the total number of CT units and total number of examinations in each prefecture according to the 2014 Survey of Medical Institutions [19]. The number of CT scanners in Japan was determined from the Data Book of Medical Devices & Systems 2016 (reported in 2014) [20]. Personnel expenses were calculated using the Osaka Prefectural Public Hospital Questionnaire and the 2014 Basic Survey on Wage Structure [21]. Annual CT costs were calculated as the sum of the depreciation expenses of the main unit, maintenance fees, and labor costs. This was estimated for each procedure and prefecture using a CT cost model (as shown in Table 1) and the number of CT scanners. The depreciation expenses of the main unit were calculated using a linear method on the main unit price assuming an amortization period of 6 years. The maintenance fee was calculated as the total maintenance costs each year, including periodic inspections, and all repair costs. The labor cost was estimated based on the average number of doctors, medical radiology technicians, and nurses necessary for CT examinations at Osaka prefectural public hospitals and the average number of examinations and CT systems in each prefecture.

To estimate the yearly net profits from CT by 47 prefectures, the annual net profits per CT scanner were calculated for each procedure and each prefecture using the

Table 1: Computed tomography (CT) cost model

Performance		Unit price		Depreciation		Maintenance cost		Total cost	
		(JPY)	(USD)	(JPY)	(USD)	(JPY)	(USD)	(JPY)	(USD)
SSCT		20,000,000	188,929	3,333,333	31,488	3,000,000	28,339	6,333,333	59,827
MSCT	<4 detector rows	30,000,000	283,393	5,000000	47,232	7,000,000	66,125	12,000,000	113,357
	4–16 detector rows	40,000,000	377,858	6,666667	62,976	8,000,000	75,572	14,666,667	138,548
	16–64 detector rows	70,000,000	661,251	11,666667	110,208	15,000,000	141,697	26,666,667	251,905
	>64 detector rows	150,000,000	1,416,966	25,000000	236,161	20,000,000	188,929	45,000,000	425,090

SSCT: single-slice computed tomography, MSCT: multi-slice computed tomography, 1(USD) = 105.86(JPY) annual income and costs per CT scanner. The number of examinations conducted per CT scanner in each prefecture was calculated using the following equation: total number of CT examinations performed divided by total number of CT scanners in clinical use. The income per CT examination was estimated using medical treatment fees in Japan from 2014. The medical treatment fee is the remuneration that medical institutions and pharmacies receive from insurers as compensation for insured medical services. The fees corresponding to each item were added for each medical procedure conducted, and the total fee was calculated. Based on these figures, the annual income per CT scanner was calculated for each procedure and prefecture by multiplying the number of examinations per CT scanner by the income per CT examination. The income per CT examination was calculated for each procedure according to the imaging fee, contrast-enhancement fee, diagnosis fee, electronic image management, and radiologic diagnosis fee 1 or 2 (as shown in Table 2).

To analyze the relationship between CT utilization and reduced mortality rates of various diseases/injuries, we conducted the following analyses. Pearson correlation coefficients were calculated for the correlation analysis between CT utilization rates and mortality from various diseases/injuries. A multiple regression analysis was used to determine the significance of difference between the CT utilization rate and the highest correlated mortality rate. Explanatory variables included CT utilization rates for each prefecture, population density, number of doctors per 100,000 individuals, and transport time to the medical institution from the viewpoint of medical services and social infrastructure for each prefecture. A p-value <0.05 was considered statistically significant. Data processing and statistical analyses were performed using the Statistical Package for the Social Sciences version 20.0 (SPSS Japan Inc., Tokyo, Japan).

3 Results

3.1 The relationship between CT utilization rate and mortality

Table 3 shows the results of correlation analysis on the relationship between CT utilization rate and mortality from each disease. A negative correlation was observed between the CT utilization rate and age-adjusted mortality from accidents (r = -0.598, p=0.000). In contrast, there was no significant correlation between the CT utilization rate and mortality from malignant neoplasms, cerebrovascular disease, heart diseases, or pneumonia.

Table 4 shows the results of multiple regression analysis on mortality from accidents, which most strongly correlated with CT utilization.

Results of multiple regression analyses in which mortality was used as the dependent variable and the items in this table were used as explanatory variables.

Table 3: The relationship between CT utilization rate and mortality from each disease

Disease	r	P-value
Malignant neoplasms	-0.009	0.955
Cerebrovascular diseases	-0.370	0.809
Heart diseases	-0.037	0.809
Pneumonia	-0.275	0.065
Accidents	-0.598	0.000

CT: computed tomography

Table 2: Medical fees

Medical fee		(JPY)	(USD)
Imaging fee	<4 detector rows (including SSCT)	6,000	56.7
	4–16 detector rows	7,700	72.7
	16–64 detector rows	9,000	85.0
	>64 detector rows	10,000	94.5
Contrast-enhanced fee		5,000	47.2
Diagnostic fee		4,500	42.5
Electronic imaging management		1,200	11.3
Radiological diagnosis fee I		700	6.6
Radiological diagnosis fee II		1,800	17.0

SSCT: single-slice computed tomography, 1(USD)=105.86(JPY)

Table 4: Relationship between mortality from accidents and CT utilization

Variable	Coefficient	Standard error	Standardized coefficient	P-value
Computed tomography utilization rate	-0.003	0.001	-0.579	0.000
Population density	0.000	0.000	0.078	0.603
Number of doctors	-0.016	0.009	-0.227	0.095
Transport time to the medical institution	-0.170	0.107	-0.214	0.122

Adjusted R^2: 0.390

Table 5: Results of multiple regression analysis for accidents by each classification

Type of accident	Variable	Coefficient	Standard error	Standardized coefficient	P-value
Traffic accidents	CT utilization rate	-0.001	0.000	-0.414	0.004
	Population density	0.000	0.000	-0.297	0.045
	Number of doctors	-0.003	0.003	-0.128	0.326
	Transport time to the medical institution	-0.069	0.040	-0.227	0.090
Adjusted R2: 0.432					
Falling	CT utilization rate	0.000	0.000	-0.363	0.044
	Population density	0.000	0.000	0.187	0.321
	Number of doctors	-0.001	0.002	-0.087	0.605
	Transport time to the medical institution	-0.042	0.028	-0.255	0.139
Adjusted R2: 0.052					
Drowning	CT utilization rate	-0.001	0.000	-0.418	0.018
	Population density	0.000	0.000	0.127	0.486
	Number of doctors	-0.003	0.004	-0.125	0.443
	Transport time to the medical institution	-0.073	0.047	-0.254	0.130
Adjusted R2: 0.102					
Asphyxia	CT utilization rate	0.000	0.000	-0.323	0.047
	Population density	0.000	0.000	-0.217	0.203
	Number of doctors	-0.003	0.002	-0.214	0.162
	Transport time to the medical institution	-0.030	0.026	-0.177	0.252

Adjusted R^2: 0.225

Table 5 shows the results of multiple regression analysis by classification of accidents. Mortality from traffic accidents was significantly related to the CT utilization rate and population density. Mortality from falling and drowning also related to the CT utilization rate as did mortality from asphyxia.

Results of multiple regression analyses in which mortality was used as the dependent variable and the items in this table for each classification (type of accidents) were used as explanatory variables. CT: computed tomography,

3.2 Estimation of net profits from CT by prefecture

Table 6 shows annual net profits from CT in 47 prefectures. Estimations for the annual revenue per CT scanner by prefectures varied from \$33,247–\$94,930 and \$304,684–\$632,971 for single-slice CT (SSCT) and MSCT, respectively. Meanwhile, estimations for the annual cost per CT scanner by prefectures varied from \$65,668–\$74,884 and \$264,970–\$356,700 for SSCT and MSCT, respectively. Estimations for annual net profits per SSCT scanner varied by

Table 6: Annual net profits from CT in 47 prefectures

Prefecture	Number of CT units		Annual income (USD)		Annual cost (USD)		Annual net profits (USD)	
	SSCT	MSCT	SSCT	MSCT	SSCT	MSCT	SSCT	MSCT
Hokkaido	231	673	62,326	425,089	72,258	312,510	-9,932	112,578
Aomori	71	147	51,072	358,374	67,817	293,667	-16,745	64,707
Iwate	66	132	49,478	371,320	69,127	279,121	-19,648	92,199
Miyagi	53	77	54,603	430,981	69,394	334,860	-14,791	96,121
Akita	28	195	41,106	479,493	72,728	317,451	-31,622	162,042
Yamagata	27	91	51,901	491,271	74,884	326,256	-22,983	165,015
Fukushima	62	174	91,195	446,602	73,599	303,382	17,596	143,220
Ibaraki	83	258	40,634	462,959	67,441	310,578	-26,807	152,381
Tochigi	54	168	59,249	472,104	67,256	303,509	-8,008	168,595
Gumma	49	188	52,377	398,989	67,349	307,802	-14,972	91,187
Saitama	135	479	61,570	473,488	72,442	309,531	-10,872	163,956
Chiba	83	444	60,894	579,704	69,977	341,375	-9,082	238,329
Tokyo	219	1010	83,450	571,109	71,306	334,699	12,144	236,411
Kanagawa	139	535	75,962	632,971	72,811	340,942	3,151	292,029
Niigata	73	184	47,085	469,375	69,363	318,687	-22,278	150,687
Toyama	56	95	33,487	547,545	66,168	345,706	-32,681	201,839
Ishikawa	41	113	52,497	553,806	69,100	322,580	-16,604	231,226
Fukui	25	91	36,907	426,647	68,300	287,501	-31,393	139,145
Yamanashi	24	72	94,930	408,582	74,069	308,500	20,861	100,082
Nagano	45	207	43,562	498,254	72,284	309,310	-28,722	188,944
Gifu	94	172	52,897	574,335	67,522	327,718	-14,625	246,617
Shizuoka	110	288	63,110	560,570	68,146	314,169	-5,036	246,401
Aichi	175	516	50,430	624,427	69,622	348,924	-19,193	275,503
Mie	78	132	48,245	566,459	67,797	354,602	-19,553	211,857
Shiga	18	91	61,756	631,964	70,263	356,700	-8,507	275,264
Kyoto	37	215	49,448	608,749	71,106	351,839	-21,657	256,910
Osaka	198	778	67,561	548,792	71,393	323,741	-3,832	225,051
Hyogo	138	497	59,410	496,000	70,330	324,500	-10,920	171,500
Nara	26	118	33,247	555,202	68,303	344,535	-35,056	210,668
Wakayama	40	126	46,330	408,857	67,493	301,656	-21,163	107,201
Tottori	19	66	47,401	460,244	68,454	316,173	-21,052	144,071
Shimane	16	74	90,830	439,091	70,382	316,429	20,448	122,662
Okayama	59	233	53,053	426,122	68,384	299,187	-15,331	126,935
Hiroshima	80	322	58,218	386,224	68,889	295,934	-10,671	90,290
Yamaguchi	72	171	53,009	391,834	68,152	294,497	-15,143	97,338
Tokushima	62	116	42,055	324,197	65,668	264,970	-23,613	59,227
Kagawa	43	135	33,504	398,050	68,427	315,366	-34,923	82,683
Ehime	68	161	45,152	455,159	67,395	314,613	-22,243	140,546
Kochi	54	110	36,156	336,973	66,106	284,914	-29,950	52,058

Table 6 continued: Annual net profits from CT in 47 prefectures

Fukuoka	174	505	56,303	445,921	70,698	321,948	-14,396	123,973
Saga	35	109	87,408	313,153	67,436	285,139	19,972	28,014
Nagasaki	73	168	66,044	449,811	71,061	318,133	-5,018	131,678
Kumamoto	88	235	46,323	328,697	67,216	280,747	-20,893	47,950
Oita	45	181	42,127	353,114	66,858	293,316	-24,731	59,797
Miyazaki	60	130	54,662	325,586	70,151	298,661	-15,489	26,925
Kagoshima	103	253	54,650	304,684	69,874	291,619	-15,224	13,064
Okinawa	35	114	45,751	522,334	65,947	335,711	-20,195	186,622
Mean	76	241	55,093	462,451	69,378	314,547	-14,285	147,904

CT: computed tomography, SSCT: single-slice computed tomography, MSCT: multi-slice computed tomography. 1(USD)=105.86(JPY)

prefecture and ranged from +$20,861 to -$35,056 with an average deficit of -$14,285. In contrast, MSCT was profitable, with annual net profits ranging from $13,064–$292,029 and an average surplus of +$147,904.

4 Discussion

Our study clearly demonstrated that CT utilization rates relate to reduced age-adjusted mortality from accidents. Specifically, significant decreases in mortality from traffic accidents and drowning were observed, indicating that CT screening for patients in the emergency room had a beneficial effect on mortality, especially for patients who experienced injuries from traffic accidents and drowning. Our study also demonstrated that the average estimated net profit from MSCT was positive (in black), whereas the average estimated annual net profit from SSCT was negative (in red). Therefore, our study indicates that MSCT equipment has a beneficial effect for both reducing mortality in emergency room patients and increasing income in hospital management.

In cases of trauma such as traffic accidents, patients often present with multiple injuries to various body parts, including the head, neck, trunk, and extremities. Wagner *et al.* [22] reported that the survival rate of patients with multiple injuries significantly increased when whole-body CT (WBCT) was used, and therefore, recommended using WBCT as a standard diagnostic measure. Similarly, Wada et al. [23] reported that the use of WBCT in the initial screening of patients with blunt trauma requiring emergency management (surgery or transcatheter arterial embolization) improved their survival rate. Furthermore, other studies have reported the usefulness of CT scanning for the diagnosis of blunt trauma patients in emergency room [24 - 26]. Jiang *et al.* [26] indicated that application of WBCT not only reduces the mortality rate of major trauma patients but also the time spent in emergency room. They showed that WBCT has higher accuracy, especially in the diagnosis of solid organ injuries compared with conventional diagnostic approaches. WBCT can significantly reduce time intervals between patient's arrival and the end of life saving procedures, the end of diagnostic procedures, and the beginning of emergency surgery.

Generally, a delay in proper surgical care is associated with higher risk of preventable death in trauma care. Tsutsumi *et al.* [24] reported that WBCT can be beneficial in patients with blunt trauma that has compromised vital signs. They suggested that physicians should consider WBCT for blunt trauma patients when warranted by vital signs. Kinoshita et al. [25] reported that immediate CT diagnosis and rapid bleeding control without patient transfer, as achieved in the hybrid emergency room using an interventional radiology (IVR)-CT system, may improve mortality in severe trauma cases. Moreover, head injuries due to traffic accidents may cause intracranial hemorrhage such as acute subdural hematoma [27]. Imaging of arterial injuries causing cerebral hemorrhage has become possible by performing CT angiography [28]. Recently, the use of MSCT has become more common in the clinical diagnoses of patients and can even be used to diagnose patients who cannot hold their breath, as well as patients who make slight movements during imaging because image acquisition is very fast. Moreover, because CT scan can instantaneously acquire a wide range of images, it is useful for whole-body screening examinations and is considered effective for the initial and subsequent diagnoses of accidents. Therefore, the results of the current study showing a relationship between CT utilization rate and mortality from accidents are consistent with those from previous studies [22–28].

Our study also indicated the interesting aspect of CT for hospital management. MSCT, which is currently being widely introduced to medical centers across Japan, appears to be highly profitable, whereas SSCT may lead hospital management into financial losses. Although annual net profits from SSCT were generally negative in our study, 3,564 SSCT scanners were still in operation for clinical diagnosis in Japan in 2014. Since SSCT scanners are not currently available commercially, they will be replaced by MSCT in the near future. This could further improve mortality rates from accidents and generate profits in hospital management. From the viewpoint of emergency medicine and hospital management, we recommend hospital managers to consider replacing SSCT scanners with MSCT. As described, our results suggest that CT is effective in reducing the mortality rate from accidents in emergency medical care while increasing profitable merit for hospital management, especially with MSCT.

Our study has several limitations to be acknowledged. First, it was impossible to obtain details on the causes of death such as traffic accidents and falling with respect to age-adjusted mortality, since the data used in our study was aggregated by the Government (Ministry of Health, Labor, and Welfare of Japan). Second, the mortality rate of each disease/injury is substantially different in each country and area [29]. The social infrastructure including emergency medical system and introduction of CT equipment are quite different even among developed countries, i.e. Japan has free access to emergency medical transportation and medical service system in the entire nation, as well as the highest number of CT systems in clinical use worldwide. Third, the data used in our study (the number of examinations per CT scanner in Survey of Medical Institutions) included both selective CT and WBCT. Therefore, we could not conduct further investigation to assess whether what type of CT scan was more effective for diagnosing injuries in the emergency room. Fourth, estimation of net profits from CT accounted for only the cost of the main unit of CT scanner, along with maintenance and labor costs as expenses. However, this did not consider the proceeds of the hospital as a whole, including indirect costs, etc. Finally, the CT cost model was a simplified estimate of the unit and maintenance costs of CT scanners, which may differ from actual costs. In particular, although the price of CT scanners thoughts believed to vary greatly depending on the medical institution and date of purchase; however, they were assumed to be equivalent across all institutions in this study.

5 Conclusion

Our results demonstrate that CT utilization rates are related to reduced age-adjusted mortality from accidents such as traffic accidents and drowning, indicating that CT screening of patients in the emergency room has the benefit of reducing mortality. Our results also demonstrate that the average estimation of annual net profits from MSCT is positive, whereas that from SSCT is negative. Therefore, our study suggests that MSCT equipment also has a beneficial effect of increasing income in hospital management.

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