Research Article

The Effect of Advanced Diagnostic Imaging on Mortality and Length of Stay in Tehran General University Hospitals

Ebrahim Jaafaripooyan [1], Ali Akbarisari [1], Abbas Rahimiforoushani [2], Zahra Abedini [1, *]

[1]Department of Health Management and Economics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
[2]Department of Epidemiology and Biostatistics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

*Correspondence: Zahra Abedini, Department of Health Management and Economics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran. Tel: +98-9108168646, Email: abedini.saeede75@gmail.com

Received 2020 August 27; Accepted 2020 Ocrober 06.

Abstract

Background: As fast and accurate techniques, advanced medical imaging technologies (AMIT) allow healthcare professionals to better diagnose and treat various health conditions, which translates into higher use of non-invasive operational procedures.

Objectives: The current study intended to investigate the effect of inpatient use of MRI and CT scan on the inpatient mortality and length of stay (LOS) in Tehran general university hospitals.

Methods: Data were collected from all general university hospitals in Tehran in 2017. A multiple linear regression model was constructed for each combination of technology and outcomes (i.e., mortality and LOS), and all models were controlled for patients' demographic and clinical characteristics and structural profile of hospitals. In calculating hospital standardized mortality ratio (HSMR) for each of 72 diagnosis groups related to death, a binary logistic regression model was fitted with predictors including LOS, admission type, comorbidity level, sex, and age.

Results: The use of CT varied from 0.39 to 149.35, and MRI from 0.24 to 80.23 exams per 100 discharges. The HSMR ranged from 76.8% to 146%, and the average length of stay (ALOS) was 3 - 8.46 days. MRI and CT had no significant effect on the HSMR and ALOS.

Conclusions: Further use of AMIT was not linked with improved efficiency and quality but was associated with better resource management in healthcare organizations. Effective management of the AMIT use requires clear rules and regulations with assertive commitment, in addition to establishing clinical guidelines with the support of insurance companies.

Keywords: Advanced Diagnostic Imaging; Mortality; Length of Stay; Tehran; General Hospitals

1. Background

Advanced medical imaging technologies (AMIT) such as computed tomography (CT) scan, magnetic resonance imaging (MRI), and positron emission tomography (PET) scan are fast and accurate techniques that allow healthcare professionals to better diagnose and treat various diseases, which translates into higher use of non-invasive operational procedures (1). AMIT not only can improve health outcomes but can also enhance the efficiency of provided care and reduce healthcare expenditures (2). However, there is growing evidence on the unnecessary utilization of these technologies, and there are doubts about their positive impact on patients' care (3). For instance, USA studies showed that 20% -50% of AMIT are ineffective in diagnosis and treatment (4). In 2011, a report revealed that 35% of MRI services in the USA were unnecessary for patients' diagnosis (5). Similar evidence are reported in Iran (6-8).

Measuring the potential value of advanced diagnostic imaging (ADI) is of crucial importance. In addition, it is necessary to evaluate the association between the utilization of such services and the care outcomes (9). Some studies have investigated this association in developed countries; however, no study has been performed in developing countries. A study conducted on 102 hospitals in the USA reported that utilization of MRI and CT has reduced the average length of stay (ALOS) and mortality (2). In the same vein, another study on 127 Canadian hospitals found that the use of CT and MRI has reduced mortality while resulted in increased ALOS (10). Mortality (risk-adjusted mortality) is one of the most important outcomes of medical care, which has been widely used to evaluate the quality of hospital care (11). Length of Stay (LOS) is the main determinant of the use of hospital resources and is widely considered as a measure of clinical efficiency (12). Several studies have used the combination of mortality and LOS to measure the quality and efficiency of healthcare services, respectively (12).

According to the Iranian Ministry of Health (MoH), in 2016, the rate of MRI and CT scanners was 3.7 (n = 297) and 6.5 (n = 524) per one million population, respectively, which is significantly less than that of the Organization for Economic Co-operation and Development (OECD) countries (13, 14). It is noteworthy that the distribution of these devices in the country is asymmetric so that about one-quarter of MRI and

CT scanners are installed in the capital city of Tehran (owning 10 percent of the total country population). Moreover, in Tehran, about one-third of MRI and CT scanners are located in two municipal regions, so that six areas are entirely deprived (13).

In recent years, some changes have taken place in the Iranian healthcare system that have affected access to various medical equipment, including increasing the engagement of the private sector in the medical equipment regionalization regulations (since 2010) and the implementation of the health transformation plan (since 2013). These changes not only have boosted access to AMTIs but also have improved their distribution. However, the potential effects of these reforms on hospital care efficiency and quality are not still clear. Hence, evaluating the effect of AMIT on the patient care outcomes is expected to help managers and policymakers in: better management of such devices, improved efficiency, and quality of hospital care, and increased access to these services.

2. Objectives

Accordingly, the current study aimed to, firstly, investigate the inpatient CT and MRI utilization and, secondly, their effect on care outcomes, including inpatient mortality and LOS, in general, university hospitals located in the city of Tehran.

3. Methods

3.1. Study Setting

In 2017, there were 42 university hospitals in the capital city of Tehran, all of which were included in this study. Nonetheless, to calculate the hospital standardized mortality ratio (HSMR), 27 sub-specialized hospitals were excluded, such as those providing specialized services related to cancer, cardiology, and pediatric, and chronic care, because they serve patients with highly different case mix. Therefore, a total of 15 hospitals were included.

3.2. Data Collection

To calculate HSMR, access to patients' sociodemographic and clinical characteristics is necessary, including age, sex, LOS, type of admission, comorbidity category, diagnosis codes assigned to each patient in the seventy-two diagnosis groups. Hence, these data were collected using the Hospitals' Information systems (HIS) from patients' medical records. Furthermore, data on the use of MRI and CT were collected from the hospitals' statistics centers (HSC). Furthermore, the number of hospital beds and specialties, number of patients and physicians, and

hospital revenue were obtained from the MoH. Data related to the number of people living in each region was obtained from the National Statistics Center (NSC).

3.3. Variables and Statistical Measurement

The number of MRIs and CTs prescribed per each 100 discharged patients was considered as the use of MRI and CT, which was defined as an independent variable, while the HSMR and the ALOS were envisaged as the dependent variables. HSMR is an adjusted hospital mortality index drawing on age, sex, diagnosis group, comorbidity, LOS, type of admission, and transferred patients to or from the hospital. This index enables the comparison of mortality rates between hospitals or in the same hospital over time. The HSMR was calculated based on the methodology used by the Canadian Institute for Health Information (CIHI) (15) to control the potential confounding effect of demographic and clinical characteristics of patients on the hospital mortality rate. For each hospital, the HSMR is equal to the ratio of observed deaths to the expected deaths (×100), for those diagnosis groups leading to 80 percent of hospital deaths (15). The expected total death was considered as the sum of death probability for each hospitalized patient. The Logistic regression model was used to calculate the expected deaths. For each of the 72 diagnosis groups, which accounted for 80% of total hospital deaths, a logistic regression model was fitted with different predictors, including LOS, admission type, comorbidity level, sex, and age.

The ALOS was calculated by dividing the number of bed days by total number of discharges in all hospitals during the study year. In this study, the number of beds, number of hospital specialties, number of physicians per bed, teaching status of the hospital, hospital revenue, patients' number, regional population, and the expected average length of stay (EALOS) were considered as control variables.

Expected length of stay (ELOS) was calculated using a regression model, in which the log of LOS was expressed as a linear function of case-mix group (CMG), age factor, comorbidity factor, sixteen flagged intervention factor, intervention event factor, and possible interactions (16). Initially, the ELOS of each inpatient was first estimated, then EALOS it was calculated for each hospital. The EALOS was used as a control variable in the analysis.

In view of the different scales of independent and control variables, they were standardized before linear regression was used. Variables measured at different scales did not contribute equally to the analysis and might end up creating a bias. Data standardization procedures were equalized to the range and data variability. The Skewness of the data were handled by logarithm transformation, and the dependent variable was log-transformed.

Pearson correlation coefficient was used to determine the association between independent and control variables, which revealed a strong association. The variance inflation factor (VIF) was used to identify the degree of multicollinearity in the multiple regression model. The variable of the number of specialties in the hospital had a high value of VIF (i.e., > 10); therefore, this variable was removed to correct multicollinearity.

4. Results

4.1. Descriptive Results

There was a wide range of differences in the utilization of CTs and MRIs among the hospitals in 2017 per 100 discharges, ranging from 0.39 to 149.35 and 0.24 to 80.23, respectively. As such, the ALOS ranged from 3 to 8.46 days among studied hospitals. The HSMR in the hospitals ranged from 76.8% to 146% (Table 1). For about half of the studied hospitals, the number of observed deaths was higher than the expected value (Figure1). In one-third of the hospitals, the ALOS was higher than the EALOS (Figure 2).

Table 1. Descriptive Statistics of Inpatient Use of CT and MRI Devices, Mortality and LOS, 2017

Variable	Max	Min	Mean	SD
Total no. of discharges	38328	7475	22327	8933
No. of CT scans per 100 discharges	149.35	0.39	50.98	41.83
Number of MRI scans per 100 discharges	80.23	0.24	15.76	21.11
Hospital standardized mortality ratio, %	146.04	76.80	99.16	19.04
Crude mortality rate, %	4.82	1.13	2.92	1.19
Avg. length of stay	8.46	3	5.14	1.69
Expected avg. length of stay	6.86	4.77	5.50	0.49

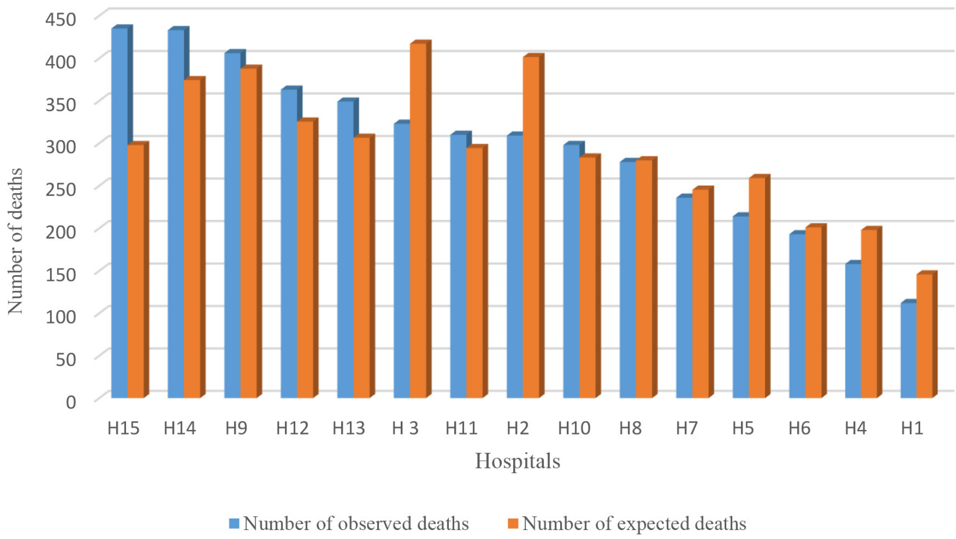

Figure 1. Hospital standardized mortality ratio of studied general university hospitals, 2017.

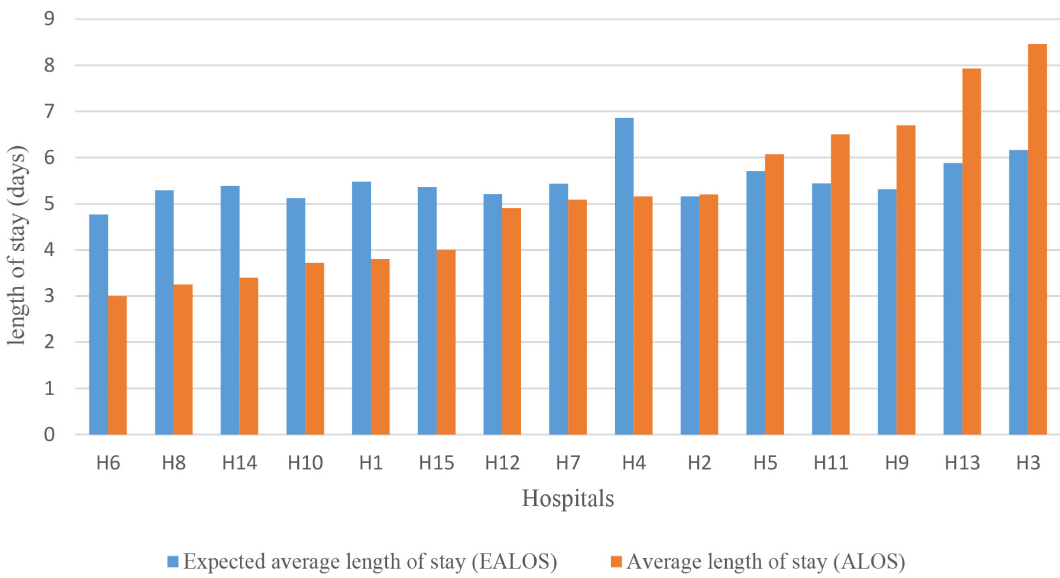

Figure 2. Average length of stay and expected average length of stay in Tehran general university hospitals, 2017.

4.2. Regression Analysis Results

Multiple linear regression analysis was used to investigate the effect of MRI and CT utilization on the HSMR (Table 2). According to the findings, the use of MRI and CT had no significant effect on the HSMR. There was also no significant difference in the HSMR in terms of the regional population and the structural characteristics of the hospital, including the number of beds, number of specialties in the hospital, teaching status, number of patients, number of physicians per bed, and hospital revenue (P-Value > 0.05). No significant association was observed between the ALOS and the use of MRI and CT in hospitals (Tables 3). Furthermore, none of the control variables, including regional population, EALOS, hospital revenue, number of patients, number of physicians per bed, number of specialties in the hospital, and number of beds, had a significant effect on the ALOS.

Table 2. Results of Regression Analysis for the Effect of CT and MRI Use on the HSMR, 2017

Variables	Estimate (B)	SE	P-Value
Intercept	95.213	12.892	0.000
Number of CT per 100 discharges	0.001	0.001	0.377
Number of MRI per 100 discharges	-0.002	0.002	0.492
Number of beds	-13.452	15.907	0.430
Number of Physicians per bed	1.455	12.221	0.909
Number of beds	-13.452	15.907	0.430
Number of patients	1.402	8.350	0.872
Hospital revenue	0.768	10.138	0.942
Teaching status	-12.844	24.082	0.613
Regional population	6.125	13.544	0.667

Table 3. Results of Regression Analysis for the Effect of CT and MRI Use on the ALOS, 2017

Variables	Estimate (B)	SE	P-Value
Intercept	1.56154	0.07901	< 0.001
Number of CT per 100 discharges	-0.02763	0.17096	0.8769
Number of MRI per 100 discharges	0.16575	0.15959	0.3390
Number of Physicians per bed	0.06247	0.08978	0.5126
Regional population	0.12655	0.10221	0.2619
Revenue hospital	0.15072	0.08468	0.1254
Teaching status	0.20114	0.28143	0.5016
Number of patients	0.02696	0.10530	0.8065
EALOS	0.19996	0.09237	0.0736

5. Discussion

Given the valuable information provided by diagnostic services for clinical decision-making and their high cost, the current study intended to investigate the effect of using advanced imaging devices (e.g. CT and MRI) on the key care outcomes. There was a large variation in the inpatient CT and MRI utilization between the studied hospitals, which might partly be associated with the differences in the accessibility and socioeconomic factors (17). It can also be attributed to differences in demographic factors such as age and regional population as well as reimbursement policies (18). For instance, a survey in Taiwan showed that supply-side factors such as hospital-based physician and the insurance payment can affect the CT and MRI utilization more than demand factors like population ratio, female ratio, and family income (19). This variation in the utilization rate may not certainly reflect the inappropriate use of CT and MRI. in order to determine what constitutes overuse and underuse, data on variation must be linked to information on indications, clinical outcome, risks, and costs (17).

Also, according to the findings, the use of CT and MRI devices did not have a significant effect on outcomes, including HSMR and ALOS, in the studied hospitals. As HSMR and ALOS are key indicators of health care quality and efficiency, it can be argued that increased utilization of AIMT did not cause any improvement in study outcomes, which is consistent with results of previous studies (10, 20, 21). A similar argument can be noted for hospitals without AMIT, which usually refer their patients to other centers to receive CT and MRI-related services. Furthermore, in hospitals with at least one MRI and CT scanner, there was also no significant association between the use of CT and MRI and the ALOS of stroke patients, nor with the mortality rate and the ALOS of patients with respiratory disease (10). In the same vein, a study on patients admitted to the emergency department of a hospital in Ireland reported that patients who received MRI had a significantly higher rate of mortality and LOS. For each unit increase in waiting time for MRI, the LOS increased by 1.12 days (20). We found no association between non-invasive cardiac imaging in patients with suspected myocardial infarction and readmission rate in the hospital, as an indicator for care outcome, was established (21).

However, few studies reported that higher use of AMIT in hospitals may result in improved quality of healthcare services (i.e., less mortality) and higher efficiency (shorter LOS) (2, 10, 22). A study conducted at Ontario (Canada) hospitals that in hospitals with at least one CT and MRI device, a 10% increase in CT use resulted in reduced mortality by about 1% among medical (non-surgical) patients, and 1% increase in the use of MRI was associated with decreased deaths among patients with stroke by 1% - 2.4%, depending on the number of available devices. This Canadian study is performed on 127 hospitals and three groups of patients, including medical patients and two groups of medical patients with respiratory diseases and stroke (10).

In another study on 102 hospitals in the USA, the more utilization of CT and MRI ended up in less mortality and lower costs (2). Both studies defined the hospital as the unit of analysis and have investigated more than 100 hospitals. On the other hand, the present study only included general university hospitals due to limitations related to data availability, which probably have declined the statistical power of the models to detect the potential differences. Another study on patients admitted to a tertiary care hospital indicated that early imaging with MRI and CT scanners on the day before or the day of admission was significantly associated with shorter LOS (22). Several studies on patients in specific diagnosis groups showed the positive effect of CT and MRI on the quality of life and survival of patients (23, 24).

According to the best knowledge of the authors, no previous study has considered the hospital as the unit of analysis. That is, mostly considered patients in specific diagnosis groups in a hospital. Therefore, they had a greater ability to control confounders. Meanwhile, in the present study, the hospital was defined as the unit of analysis. The confounding factors were substantially controlled by categorizing patients in 72 diagnosis groups, calculating the HSMR, and controlling the effect of patients' clinical and demographic characteristics on mortality, in addition to considering the hospital characteristics and environmental factors as control variables.

Conceptually, the appropriate use of imaging technologies should result in better outcomes (25). Appropriateness of diagnostic imaging services can be evaluated using controlled randomized trials (RCTs) or concepts such as quality-adjusted life years (QALYs) (25), as well as research and development (RAND) methodology (7, 8). Although we could not directly evaluate the appropriateness of provided CT and MRI services for Inpatients, but the appropriateness of advanced imaging services for inpatients was evaluated indirectly. As the utilization of AIMT did not show statistically positive results, the inappropriate and unnecessary use of these services might be highlighted. Other studies conducted in Iran also pointed to the unnecessary and inappropriate use of CT and MRI services (6-8). For instance, about half of patients referred for low back pain (LBP) had no indication for imaging, and about 37% of patients with mild head trauma (MHT) who were referred to the emergency department had no indication for CT scan (6). Furthermore, in the same vein, another study reported that 65% of provided MRI services to LBP patients were inappropriate (7). Also, about half of patients with knee pain underwent an unnecessary MRI in some hospitals in the country (8). Studies conducted in the USA reported that 20% - 50% of advanced imaging services were inappropriate and unnecessary in terms of providing valuable information for either diagnosis or treatment of patients (4). According to a report issued in 2011, 35% of provided MRI services in the USA were unnecessary (5). Negative effects of unnecessary use of advanced imaging services on the quality and cost of healthcare services, including undesirable exposure to radiation, false positive and negative results, delayed diagnosis, and inefficient resource allocation, have been widely recognized in the literature (10).

In Iran, the MoH is the key player in regulating the distribution of ADI equipment. However, this role remains limited mostly to issuing the purchase and/or import licenses of such equipment (13). It is noteworthy that health insurance funds do not play a significant role in this process. In other words, due to the poor referral system, lack of well-developed clinical guidelines, and problems related to the payment system, there is no control over the use of MRI and CT services in Iran (13).

5.1. Study Limitations

It is necessary to mention some limitations and biases of our study. First, we only investigated general university hospitals in the city of Tehran (fifteen hospitals), which has reduced the statistical power of developed models to detect differences. Second, there were variations between hospitals, which probably has led to systematic differences in processes between hospitals that in turn resulted in systematic HSMR variations.

5.2. Conclusions

This study demonstrated a large variation in the utilization of CT and MRI services across investigated hospitals. In addition, increased utilization of such technologies was not necessarily associated with reduced LOS and mortality. This study also indirectly evaluated the appropriateness of providing such services for inpatients. It can be argued that inappropriate and unnecessary use of these services has influenced the study results. Effective utilization management of AMIT, such as CT and MRI scanners, requires transparent regulations with an assertive commitment towards the diffusion and use of these technologies.

Moreover, not only it is necessary to revise the currently deployed payment system, but also the development of appropriate reimbursement mechanisms and effective service coverage is of crucial importance. Moreover, particular emphasis should be given to the development of clinical guidelines with the support and cooperation of health insurance funds. HSMR is a powerful tool to evaluate the quality of care across hospitals and for a particular hospital over time, which was calculated for university hospitals in the present study. The study results are anticipated to help healthcare managers, and policymakers effectively manage the use of such equipment, improve the efficiency and quality of hospital care, and enhance access to such services.

References

1. Heidenreich PA. Assessing the value of a diagnostic test. *Arch Intern Med.* 2009;**169**(14):1262-4. doi:10.1001/archinternmed.2009.208. [PubMed:19636026].
2. Lee DW, Foster DA. The association between hospital outcomes and diagnostic imaging: early findings. *J Am Coll Radiol.* 2009;**6**(11):780-5. doi:10.1016/j.jacr.2009.08.007. [PubMed:19878885].
3. Hillman BJ, Goldsmith JC. The uncritical use of high-tech medical imaging. *N Engl J Med.* 2010;**363**(1):4-6. doi:10.1056/NEJMp1003173. [PubMed:20573920].
4. America's Health Insurance Plans. *Ensuring quality through appropriate use of diagnostic imaging.* Washington, DC: AHIP; 2008.
5. Flynn TW, Smith B, Chou R. Appropriate use of diagnostic imaging in low back pain: a reminder that unnecessary imaging may do as much harm as good. *J Orthop Sports Phys Ther.* 2011;**41**(11):838-46. doi:10.2519/jospt.2011.3618. [PubMed:21642763].
6. Zargar Balaye Jame S. Evidence informed policy making in selection, importing and use of advanced medical technologies and factors affecting in. Tehran University of Tehran Medical of Science; 2013.
7. Salari H, Ostovar R, Esfandiari A, Keshtkaran A, Akbari Sari A, Yousefi Manesh H, et al. Evidence for Policy Making: Clinical Appropriateness Study of Lumbar Spine MRI Prescriptions Using RAND Appropriateness Method. *Int J Health Policy Manag.* 2013;**1**(1):17-21. doi:10.15171/ijhpm.2013.04. [PubMed:24596832]. [PMC3937931:PMC3937931].
8. Ebrahimipour H, Mirfeizi S, Vejdani M, Vafaee-najar A, Kachooei A, Ariamanesh A. Evaluation of Medical costs resulting from Magnetic Resonance Imaging inappropriate prescriptions for Knee joint, using RAND Method in Ghaem Hospital-2013. *Hakim Res J.* 2015;**17**(4).
9. Baker LC, Atlas SW, Afendulis CC. Expanded use of imaging technology and the challenge of measuring value. *Health Aff (Millwood).* 2008;**27**(6):1467-78. doi:10.1377/hlthaff.27.6.1467. [PubMed:18997202].
10. Garcés G. Adoption and use of high dent tech medical imaging in Ontario hospitals: the determinants of adoption and the relationship between use and inpatient mortality and length of stay. Canada: University of Toronto; 2014.
11. Hearld LR, Alexander JA, Fraser I, Jiang HJ. Review: how do hospital organizational structure and processes affect quality of care?: a critical review of research methods. *Med Care Res Rev.* 2008;**65**(3):259-99. doi:10.1177/1077558707309613. [PubMed:18089769].
12. Lipitz-Snyderman A, Steinwachs D, Needham DM, Colantuoni E, Morlock LL, Pronovost PJ. Impact of a statewide intensive care unit quality improvement initiative on hospital mortality and length of stay: retrospective comparative analysis. *BMJ.* 2011;**342**:d219. doi:10.1136/bmj.d219. [PubMed:21282262]. [PMC3031651:PMC3031651].
13. Abedini Z, Sari AA, Foroushani AR, Jaafaripooyan E. Diffusion of advanced medical imaging technology, CT, and MRI scanners, in Iran: A qualitative study of determinants. *Int J Health Plann Manage.* 2019;**34**(1):e397-e410. doi:10.1002/hpm.2657. [PubMed:30289584].
14. OECD/EU. Health at a Glance: Europe 2016 - State of Health in the EU Cycle OECD Publishing Paris. 2016; Available from: https://www.oecd.org/els/health-systems/Health-at-a-Glance-Europe-2016-CHARTSET.pdf.
15. Canadian Institute for Health Information (CIHI). Hospital Standardized Mortality Ratio. Technical Notes. 2016; Available from: https://www.cihi.ca/sites/default/files/document/hsmr-tech-notes-sept-2019-en-web.pdf.
16. Canadian Institute for Health Information. DAD Resource Intensity Weights and Expected Length of Stay for CMG+ 2009. Case Mix. Ottawa, Ontario: CIHI; 2009; Available from: https://www.cihi.ca/en/resource-indicators-dad-resource-intensity-weights-and-expected-length-of-stay.
17. Lysdahl KB, Borretzen I. Geographical variation in radiological services: a nationwide survey. *BMC Health Serv Res.* 2007;**7**:21. doi:10.1186/1472-6963-7-21. [PubMed:17302970]. [PMC1805434:PMC1805434].
18. Olsson S. Diffusion, utilisation and regional variations in the use of CT and MRI in Sweden. *Comput Methods Programs Biomed.* 2001;**66**(1):129-35. doi:10.1016/s0169-2607(01)00155-9. [PubMed:11378235].
19. Kung PT, Tsai WC, Yaung CL, Liao KP. Determinants of computed tomography and magnetic resonance imaging utilization in Taiwan. *Int J Technol Assess Health Care.* 2005;**21**(1):81-8. doi:10.1017/s0266462305050105. [PubMed:15736518].
20. Cournane S, Creagh D, O'Hare N, Sheehy N, Silke B. MRI in acutely ill medical patients in an Irish hospital: influence on outcomes and length of hospital stay. *J Am Coll Radiol.* 2014;**11**(7):698-702. doi:10.1016/j.jacr.2014.01.014. [PubMed:24993535].
21. Safavi KC, Li SX, Dharmarajan K, Venkatesh AK, Strait KM, Lin H, et al. Hospital variation in the use of noninvasive cardiac imaging and its association with downstream testing, interventions, and outcomes. *JAMA Intern Med.* 2014;**174**(4):546-53. doi:10.1001/jamainternmed.2013.14407. [PubMed:24515551]. [PMC5459406:PMC5459406].
22. Batlle JC, Hahn PF, Thrall JH, Lee SI. Patients imaged early during admission demonstrate reduced length of hospital stay: a retrospective cohort study of patients undergoing cross-sectional imaging. *J Am Coll Radiol.* 2010;**7**(4):269-76. doi:10.1016/j.jacr.2009.11.024. [PubMed:20362942].
23. Brandt M, Walluscheck KP, Jahnke T, Graw K, Cremer J, Muller-Hulsbeck S. Endovascular repair of ruptured abdominal aortic aneurysm: feasibility and impact on early outcome. *J Vasc Interv Radiol.* 2005;**16**(10):1309-12. doi:10.1097/01.RVI.0000175332.44635.49. [PubMed:16221900].
24. Varlotto JM, Flickinger JC, Niranjan A, Bhatnagar A, Kondziolka D, Lunsford LD. The impact of whole-brain radiation therapy on the long-term control and morbidity of patients surviving more than one year after gamma knife radiosurgery for brain metastases. Int *J Radiat Oncol Biol Phys.* 2005;**62**(4):1125-32. doi:10.1016/j.ijrobp.2004.12.092. [PubMed:15990018].
25. Sistrom CL. The appropriateness of imaging: a comprehensive conceptual framework. *Radiology.* 2009;**251**(3):637-49. doi:10.1148/radiol.2513080636. [PubMed:19474372].