A Multicenter Survey on the Trend of Chest CT Scan Utilization: Tracing the First Footsteps of COVID-19 in Iran

Amir Reza Radmard, MD;1 Ali Gholamrezanezhad, MD;2; Seyyed Ali Montazeri, MD, MPH;1 Amir Kasaeian, PhD;1 Nemat Nematollahy, MD;2 Roghieh Molaei Langrudi, MD;2 Reza Javad Rashid, MD;2 Alireza Dehghan, MD;2 Ali Hekmatnia, MD;2 Ali Shakourirad, MD;2 Masoud Pezeshki Rad, MD;2 Reza Nafisi Moghadam, MD;2 Hashem Sharifian, MD;2 Ahmad Enhesari, MD;2 Marzieh Aalinezhad, MD;2 Ghazaleh Jalalipour Soufi, MD;2 Alireza Shakibaifar, MD;2 Maryam Mohammadzadeh, MD;2 Reza Jalli, MD;2 Mehrdad Bakhshayeshkaram, MD;2 Tarefagh Faghifi Langrudi, MD;2 Masoomeh Raoufi, MD;2 Alireza Abdishahi, MD;2 Pooneh Dehghan, MD;2; Hooman Bahrami-Motlagh, MD;2; Hassan Hashemi, MD;2; Morteza Sanei Taheri, MD;2*

1Department of Radiology, Shahid Beheshti University of Medical Sciences, Tehran, Iran
2Department of Biostatistics and Epidemiology, Hematology-Oncology and Stem Cell Transplantation Research Center, Shahid Beheshti Hospital, Tehran University of Medical Sciences, Tehran, Iran
3Department of Radiology, 5 Azar Hospital, Golestan University of Medical Sciences, Gorgan, Iran
4Diagnostic Radiology Department, Poursina Hospital, Guilan University of Medical Sciences, Rasht, Iran
5Department of Radiology, Imam Reza hospital, Tabriz University of Medical Sciences, Tabriz, Iran
6Department of Radiology, Namazi Hospital, Shiraz University of Medical Sciences, Shiraz, Iran
7Radiology Department, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran
8Department of Radiology, Sina Hospital, Tehran University of Medical Sciences, Tehran, Iran
9Department of Radiology, Imam Reza Hospital, Mashhad University of Medical Sciences, Mashhad, Iran
10Department of Radiology, Shahid Sadoughi Hospital, Tabriz University of Medical Sciences, Tabriz, Iran
11Department of Radiology, Imam Reza Hospital, Mashhad University of Medical Sciences, Mashhad, Iran
12Department of Radiology, Shahid Sadoughi Hospital, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
13Department of Radiology, Amir Al'Am Hospital, Tehran University of Medical Sciences, Tehran, Iran
14Clinical Research Unit, Afzalipour Hospital, Kerman University of Medical Sciences, Kerman, Iran
15TABA Medical Imaging Center, Shiraz, Iran
16Chronic Respiratory Diseases Research Center, National Research Institute of Tuberculosis and Lung Diseases (NRITLD), Shahid Beheshti University of Medical Sciences, Tehran, Iran
17Department of Radiology, Shahid Modarres Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
18Department of Radiology, Imam Hossein Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
19Department of Radiology, Taleghani Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
20Department of Radiology, Loghman Hakim Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
21Advanced Diagnostic and Interventional Radiology Research Center (ADIR), Tehran University of Medical Sciences, Tehran, Iran
22Department of Radiology, Shohada-E-Tajrish Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran

Abstract
Background: Chest computed tomography (CT) scan has been used widely to diagnose COVID-19 in Iran.
Objectives: To trace the footsteps of COVID-19 in Iran by exploring the trend in using chest CT scans and its economic impact on radiology departments.
Methods: In this cross-sectional study, the number of imaging examinations from 33 tertiary radiology departments in 9 large cities of Iran was collected from September 23, 2019 to March 20, 2020 (Months 1 to 6) and the corresponding months in 2018–2019.
Results: A 50.2% increase was noted in the chest CT scan utilization in 2019–2020 compared to 2018–2019. This increase was +15%, +15%, +27%, +2%, +1% in Months 1–5 of 2019–2020, respectively. In Month 6 of 2019–2020, a 251% increase in the acquisition of chest CT scans was observed compared to the Month 6 of 2018–2019. Following negative balance of revenue from Month 1 to 5 with respect to the inflation rate, the total income in Month 6 was further 1.5% less than the same Month in 2018–19.
Conclusion: The observed peak in chest CT utilization in Month 3 prior to the surge in Month 6 could be explained by the seasonal influenza. However, unawareness about an emerging viral disease, i.e. COVID-19, might have underutilized chest CT in Months 4 and 5 before the official announcement in Month 6. The unbalanced increase in the workload of radiology departments in the shortage of cardiotoracic radiologists with the simultaneous decrease in income initiated a vicious cycle that worsened the economic repercussions of the pandemic.
Keywords: COVID-19, Hospital, Multicenter Study, Multidetector computed tomography, Radiology department, Public health
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Introduction
The coronavirus disease 2019 (COVID-19) pandemic has caused 593,000 deaths in 13.9 million infected individuals as of July 17, 2020, which has resulted in an unprecedented increasing workload for the healthcare system. The need for accurate and rapid tests to diagnose the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is crucial for optimal clinical management of the patients and effective control of the COVID-19 pandemic.

Iran was one of the first countries struggling with surging numbers of COVID-19 patients. At the time of writing, more than 269,000 individuals have been diagnosed with the disease and 13,000 have died in Iran. Although these numbers appear to be significantly underestimated, Iran suffers from the highest burden of the disease in the Middle East.

Limited availability of the reverse-transcriptase polymerase-chain-reaction (RT-PCR) test kits for SARS-CoV-2 and the reportedly higher sensitivity of chest computed tomography (CT) in patients with a high pretest probability of the disease forced the healthcare system to implement chest CT in the initial diagnostic workup of patients with suspect COVID-19. Therefore, tracing the number of chest CT studies since early fall 2019 could potentially give us the footsteps of the disease.

The implementation of chest CT in the initial workup of patients with respiratory symptoms has been a valuable step in controlling the pandemic. A notable shift to the imaging of chest with a possible drop in imaging of other organs, however, may raise concerns on the job security for the radiologists who have been involved in other subspecialties without enough experience in thoracic imaging. The economic consequences could also be a matter of concern for the radiology departments, which have already been influenced by economic sanctions and currency depreciations in Iran.

This study aimed to explore the trend and pattern of utilization of imaging modalities in 2019–2020 and compared to that in 2018–2019. A Heat map was depicted. The income of radiology departments was calculated by the total number of the imaging studies multiplied by the official tariffs set by the Iranian health authorities in 2018–2019 and 2019–2020. Then, the costs of all imaging studies were summed up per Month in 2019–2020 and compared to that in 2018–2019. A Heat

Materials and Methods
Data Source
For this cross-sectional study, data were obtained from health information systems and picture archiving and communication systems at 33 radiology departments/ imaging centers in 9 large cities in Iran, as capitals of the provinces. These centers were tertiary main referral imaging centers in their corresponding provinces including radiology departments of 28 university teaching hospitals and three major private imaging centers (Table 1). The names and populations of these cities are as follows: Tehran (8,737,510), Mashhad (3,372,660), Isfahan (2,243,249), Shiraz (1,869,001), Tabriz (1,733,033), Rasht (956,971), Kerman (738,724), Yazd (656,474), and Gorgan (480,541). With a total population of 20,788,163, these cities constitute 5 out of the 6 most populated cities and more than 26% and 35% of total and urban population in Iran, respectively.

Patient and Public Involvement
The public were not involved in the design, or conduct, or recruitment the data for this study. The results of this study will be disseminated to the public according to the journal’s policies.

Data Classification
The number of obtained imaging modalities was collected on a monthly basis per two 6-month periods, which correspond to the flu season. The first period, i.e. 2018–2019, started from September 2018 to March 2019 and the second, i.e. 2019–2020, covers September 2019 to March 2020. Due to the difference in the Persian (Solar Hijri) and Gregorian calendars, the data from each Month are depicted in the numerical order. For example, the month of Mehr in Persian Calendar year 1397 corresponds to September 23 to October 22, 2018 in Gregorian Calendar, which was considered as “Month 1” in this study. Accordingly, Month 2 (Aban) = October 23 to November 21; Month 3 (Azar) = November 22 to December 21; Month 4 (Dey) = December 22 to January 20; Month 5 (Bahman) = January 21 to February 19; and Month 6 (Esfand) = February 19 to March 20. The same order applies to the second 6-month period (2019–2020) from September 23, 2019 to March 20, 2020.

The data were categorized as: 1. Chest CT scan (CT with or without IV contrast, high-resolution CT angiography of the pulmonary arteries, etc.); 2. Brain CT scan [with or without IV contrast, CT angiography (CTA), CT venography (CTV), etc.]; 3. Abdominopelvic CT scan [with or without IV contrast, CTA, CTV, CT Urography, etc.]; and 4. Others (facial, orbital, paranasal sinuses, temporal bone CT, spine, and extremities). The total number of magnetic resonance imaging (MRI) studies, regardless of the body part, was also collected.

Data Analysis
STATA statistical software, Release 14, StataCorp LLC, was used. The trend in utilization of each imaging modality was depicted. The income of radiology departments was determined as follows. The cost per each modality was calculated by the total number of the imaging studies multiplied by the official tariffs set by the Iranian health authorities in 2018–2019 and 2019–2020. Then, the costs of all imaging studies were summed up per Month in 2019–2020 and compared to that in 2018–2019. A Heat
map figure was used to illustrate the ratio of two odds according to the following formula:

$$\text{Chest odds ratio} = \frac{\text{odds of ordered chest CT to the ordered CT scans for all other organs in month 6 of 2019–2020}}{\text{odds of ordered chest CT to the ordered CT scans for all other organs in month 6 of 2018–2019}}$$

| Center/Hospital | City, Province | Center/Hospital Type | General Beds/ICU Beds | CT Scanners No. | MRI Machines No. | General Radiologists | Fellowship-Trained Radiologist | In Training Residents |
|-----------------|----------------|---------------------|-----------------------|----------------|----------------|----------------------|-----------------------------|---------------------|
| Shariati Hospital | Tehran, Tehran | Teaching | 520/73 | 2 | 1 | 7 | 2 | 28 |
| Sina Hospital | Tehran, Tehran | Teaching | 486/51 | 2 | 1 | 7 | 1 | 27 |
| Amir Alam Hospital | Tehran, Tehran | Teaching | 280/28 | 1 | 1 | 3 | 1 | 20 |
| Shohada-E-Tajrish Hospital | Tehran, Tehran | Teaching | 485/39 | 2 | 1 | 7 | 2 | 25 |
| Masih Daneshvari Hospital | Tehran, Tehran | Teaching | 330/33 | 1 | 0 | 6 | 0 | 4 |
| Shahid Modarres Hospital | Tehran, Tehran | Teaching | 265/38 | 1 | 0 | 3 | 2 | 5 |
| Shahid Labbafinejad Hospital | Tehran, Tehran | Teaching | 225/10 | 1 | 0 | 3 | 0 | 5 |
| Taleghani Hospital | Tehran, Tehran | Teaching | 481/20 | 1 | 0 | 3 | 0 | 10 |
| Loughman Hakim Hospital | Tehran, Tehran | Teaching | 365/32 | 1 | 0 | 4 | 0 | 15 |
| Imam Hossein Hospital | Tehran, Tehran | Teaching | 605/22 | 1 | 1 | 4 | 0 | 25 |
| Morid Hospital | Tehran, Tehran | Teaching | 219/12 | 1 | 0 | 1 | 0 | 0 |
| Mahdieh Hospital | Tehran, Tehran | Teaching | 134/7 | 1 | 0 | 2 | 0 | 6 |
| Akhtar Hospital | Tehran, Tehran | Non-teaching (Public) | 114/8 | 1 | 0 | 1 | 0 | 0 |
| Torfeh Hospital | Tehran, Tehran | Non-teaching (Public) | 110/0 | 1 | 0 | 1 | 0 | 0 |
| Mofatteh Hospital | Tehran, Tehran | Non-teaching (Public) | 148/7 | 1 | 1 | 1 | 0 | 0 |
| Pakdasht Hospital | Tehran, Tehran | Non-teaching (Public) | 157/7 | 1 | 0 | 1 | 0 | 0 |
| Darvand Hospital | Tehran, Tehran | Non-teaching (Public) | 108/0 | 1 | 0 | 1 | 0 | 0 |
| Shohada Gormam Hospital | Tehran, Tehran | Non-teaching (Public) | 120/0 | 1 | 0 | 1 | 0 | 0 |
| Imam Reza Hospital | Mashhad, Khorasan-e-Razavi | Teaching | 1028/97 | 1 | 1 | 6 | 2 | 44 |
| Amin Hospital | Isfahan, Isfahan | Teaching | 160/39 | 1 | 0 | 3 | 0 | 80 |
| Ayatollah Keshani Hospital | Isfahan, Isfahan | Teaching | 220/30 | 2 | 1 | 3 | 1 | 80 |
| Sepahan Imaging Center | Isfahan, Isfahan | Private | N/A | 1 | 2 | 3 | 1 | N/A |
| Namazi Hospital | Shiraz, Fars | Teaching | 824/91 | 3 | 2 | 11 | 5 | 87 |
| TABA Imaging Center | Shiraz, Fars | Private | N/A | 1 | 1 | 8 | 1 | N/A |
| Imam Reza Hospital | Tabriz, Azarbayjan-e-Sharghi | Teaching | 800/129 | 3 | 1 | 11 | 2 | 60 |
| Razi Hospital | Rasht, Guilan | Teaching | 300/10 | 1 | 0 | 3 | 0 | 10 |
| Poursina Hospital | Rasht, Guilan | Teaching | 263/29 | 2 | 1 | 3 | 0 | 9 |
| Afzalipour Hospital | Kermanshah, Kerman | Teaching | 505/120 | 1 | 0 | 6 | 0 | 16 |
| Sadoughi Hospital | Yazd, Yazd | Teaching | 520/48 | 1 | 1 | 4 | 2 | 32 |
| Rahnuma Hospital | Yazd, Yazd | Teaching | 220/36 | 1 | 1 | 2 | 0 | 6 |
| S Azar Hospital | Gorgan, Golestan | Teaching | 400/30 | 2 | 0 | 6 | 0 | 13 |
| Golestan Imaging Center | Gorgan, Golestan | Private | N/A | 1 | 1 | 3 | 0 | 9 |
| Sayyad Shirazi Hospital | Gorgan, Golestan | Teaching | 340/35 | 1 | 0 | 4 | 2 | 13 |

Results
Total Number of Imaging Modalities in 2019–2020 and 2018–2019
The total number of CT and MRI studies in the second period decreased by 0.3% compared to the previous period: 430 617 and 431 817 in 2019–2020 and 2018–2019, respectively. A more than 50.2% increase was seen in the total number of chest CT scans in 2019-2020 compared to 2018-2019 (Figure 1).

Trend in the Number of CT scans
The total number (percentage) of chest CT increased by 1274 (+14.6%), 1243 (+15.1%), 2443 (+27.3%), 191 (+1.9%), 62 (+0.7%) and 21848 (+251.5%) in the 1st to 6th Months, respectively, in the 2019-2020 period,
compared to the chest CT scans in the corresponding Months in 2018–2019 (Figure 2). The lowest chest odds ratios were 2.15 and 2.64, which corresponded to Fars and East Azerbaijan provinces, respectively. The highest chest odds ratios were 18.83 and 18.74, which were seen in Gorgan (Golestan province) and Rasht (Guilan province), respectively (Figure 3). In 2018–2019, brain CT was the most common CT imaging study used, followed by others, chest, and abdominopelvic exams. This pattern was unchanged until Month 6, when a substantial increase was noted in the percentage of chest CT scans.

The number of abdominopelvic CT scans was higher in Months 1, 2, and 3 in 2019–2020 than in the same Months of 2018–2019. A substantial decrease in the number of abdominopelvic CT scans was seen in Month 6 in 2019–2020 compared to the same Month in 2018–2019. Similar patterns were seen in brain and other CT scans in 2019–2020 compared to 2018–2019 (Figure 4).

Trend in the Number of MRI Examinations
The total number of MRI examinations was 4712 in Month 6 of 2019–2020 period, which showed a 63.9% decrease compared to the same Month of the previous year.

Analysis of the Income
The total income of all radiology departments and imaging centers was IRR 32.1 and IRR 31.6 billion in 2018–2019.
and 2019–2020, respectively. This income was increased in Months 1 to 5 of 2019–2020 compared to the same period in 2018–2019. The last Month, however, showed a decrease in the income by 1.5% (Figure 5).

**Discussion**

**Catching the First Glimpse of Pandemic**

The outbreak of COVID-19 in China was first reported in late December 2019. Some reporters, however, recently figured out that the patient zero might be traced back to November 17, 2019. Although the first case of COVID-19 in Iran was confirmed on February 19, 2020, tracing the actual first patient has been cumbersome because it was an unknown respiratory disease outbreak during the flu season. One way to trace the first signs of the outbreak is to look for the number of diagnostic tests ordered in the referral hospitals. It has been very difficult to monitor the disease outbreak in the large cities of Iran, due to the limited number of available molecular diagnostic assays and RT-PCR kits. Therefore, a chest CT scan was initially implemented in the diagnostic workup of the patients with respiratory signs and symptoms in Iran. 

In this survey, the total number of chest CT acquisitions in the 2019–2020 period was 50% higher than the same period of 2018–2019. This increase consisted of 15%–27% rise in the first three Months of 2019–2020 compared to the previous period, followed by a two-month trend of unchanged volume. A substantial 251% increase in the number of CT scans was seen in Month 6 of 2019–2020 compared to Month 6 of 2018–2019. This pattern could be explained by two hypotheses: first, higher incidence of seasonal influenza-associated pneumonia with the highest peak in Month 3. Seasonal waves of influenza are commonly expected every year, which may present a complex spatiotemporal pattern depending on the biological, sociodemographic, and environmental factors. The second hypothesis based on the higher peak of chest CT utilization in Month 3 might be attributed to the other causes of acute respiratory diseases like unknown viruses (e.g. COVID-19). However, unawareness of the healthcare system, especially physicians, about the presence of a confirmed new virus in Iran might have led to a relative decrease in chest CT utilization in Months 4 and 5 before a considerable surge in Month 6. On the other hand, a part of notable overutilization of chest CT in Iran in 6 was derived from the panic of being infected by COVID-19, which resulted in significantly increased requisitions without sufficient clinical indications. Nevertheless, the hypothesis of earlier COVID-19 spread to Iran could have been supported if the earlier peak in Month 3 had been continuously extended to Months 4 and 5, then to the highest peak in Month 6.

**The Pattern of Utilization of Imaging Studies and Economic and Workload Consequences**

In contrast to chest CT scans, radiology departments have faced a remarkable reduction in the number of brain CT, abdominopelvic CT, other CT scans, and MRI examinations in 2019–2020 compared to 2018–2019. In a large healthcare system in New York, the United States, a substantial decline, i.e. 28%, was reported in all imaging volumes. Mammography, MRI, nuclear medicine, and ultrasound witnessed the largest decrease in acquisition. However, more detailed information was not provided about the change in the volume of imaging for each body part, e.g. chest CT. In another study in the United States, the number of brain imaging declined by as much as 50% during the pandemic.
These changes have substantial economic consequences for the radiology departments. The economic impact has been warned in Germany, Austria, and Switzerland where the nuclear medicine services were notably reduced 3 weeks after the SARS-CoV-2 pandemic. In the United States, a huge reduction of 50%-70% has been anticipated in imaging volumes for at least 3–4 months. This reduction will be most prominent in outpatient practices. In the present study, the total income of the radiology departments in 2019–2020 from CT and MRI was only partially offset in the first five Months by the increased total number of chest CTs. The worst economic impact of the pandemic on the radiology departments was observed in Month 6 of 2019–2020. In this Month, although the 1.5% decrease in the income of these departments may seem insignificant, radiology departments have faced a significant drop in their revenue considering the inflation rate of 35% in Iran.

The quality of providing service was already compromised when the maintenance service for the imaging equipment had been reduced due to the economic sanctions and Iranian currency (IRR) depreciation, with a 12-month inflation rate of 34.8% ending in Month 6 (i.e. Esfand), 2019–2020. The apparently increased income of the radiology departments from Month 1 to Month 5 (Figure 5) in 2019–2020 compared to the same period in the previous year must be interpreted and adjusted according to the heavy impact of the high inflation rate. This declining trend of income was further accentuated in Month 6 of 2019–2020 when the curve dropped to a negative value. The international community sent humanitarian aids to Iran including diagnostic kits, medicine, and protective equipment while no aids were sent to support the equipment of radiology centers. Needless to say, this negative economic impact may significantly threaten the survival of imaging centers and overutilization may shorten the availability of the CT scanners for the rest of the fight against the pandemic.

The Pros and Cons of Radiology Subspecialization in Iran

With the significant increase in the workload of radiologists, the radiology departments in Iran were not fully capable of dealing with the pandemic. A couple of reasons might explain this deficit: first, the number of cardiothoracic imagers available is not sufficient to meet the increased demand in a pandemic of such respiratory diseases in Iran, where there is no dedicated cardiothoracic imaging fellowship program. Second, many radiologists in Iran are working as sonographers without any experience or involvement in cross-sectional imaging. Therefore, health authorities must be prepared for any possible future pandemic by investment and planning for training subspecialized cardiothoracic radiologists as well as other healthcare staff necessary for these situations. This specific shortage of fellowship-trained radiologists in thoracic imaging adds to the already described shortage of medical providers in the country. Although small cities, non-academic centers, and rural and underserved areas may experience the shortages more severely, the need for subspecialty-trained radiologists is felt everywhere.

The downside of subspecialization can be highlighted by looking at the odds of chest CT studies to all other CTs in Month 6, 2019–2020 compared to the same odds in Month 6 of 2018–2019 (odds ratio 2–19; Figure 4). This shows how other subspecialties like abdominal, neuro-, or musculoskeletal radiologists may suffer from job insecurity.

Several limitations should be considered when interpreting the results. First, we did not have data from the other 22 provinces of Iran to conduct a comprehensive national survey. However, covering more than 35% of the urban population could provide important information about the trend and pattern of imaging utilization. Second, three enrolled private centers were excluded from income analysis because of the different tariffs they use for imaging. This exclusion could not significantly skew our results since most of the individuals were referred to the teaching (public) hospitals thanks to the benefits of insurance coverage. Finally, although it was not the
primary question of this study, data from patients referred to hospitals due to respiratory symptoms could provide more granular data regarding the onset and footprint of COVID-19 in Iran.

In conclusion, the results of this study could provide a valuable overview of the trend and pattern of imaging utilization in a wide multi-province setting during the COVID-19 outbreak in Iran. Compared to the same period in 2018–2019, a significant increase was identified in the acquisition of chest CT studies in March 2019–2020 (two months before official announcement of SARS-CoV-2 in Iran) without a persistent increase in months 4 and 5. This might be attributed to the seasonal waves of influenza or lack of healthcare system awareness about presence of an emerging viral infection, i.e. COVID-19. This might have caused the underutilization of chest CT in months 4 and 5. The increased burden on the radiology workforce initiated a vicious cycle in which the resulting burnout, financial hardship, and lack of maintenance service worsened the economic repercussions of the pandemic. The shortage of thoracic radiologists and job insecurity for non-thoracic radiologists (including those who strictly focus on ultrasonography) in Iran should also alert the health authorities to choose wiser policies in the future.

Further studies are warranted on a wider scale and a higher temporal resolution of data collection focusing on the imaging and clinical findings to better track COVID-19 footsteps in different countries in more details.

Authors’ Contribution
AR and AG contributed equally as co-first authors. They were involved in the study design, conduct, data gathering, analysis of the data, and writing and editing the manuscript. SAM was involved in statistical analysis, manuscript writing and editing. AK was involved in the statistical analysis. NN, RML, RJR, AD, AH, ASR, MW, RJR, AD, AH, ASR, MPR, RNM, NN, RML, RJR, AD, AH, ASR, MPR, RNM, and AA, PD, HBM, and HH provided data and participated in manuscript writing and editing. MST was involved in study design and conduct, data management and audit, and manuscript editing.

Conflict of Interest Disclosures
All authors have nothing to disclose.

Ethical Statement
The study was approved by the ethics committee of the National Institute for Medical Research Development in Iran (ID: IR.NIMAD.REC.1399.011).

Data Sharing Statement
Data will be available upon request to the corresponding author.

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