Medical Accidents Related to Ferromagnetic Objects Brought into the MRI Room: Analysis of the National Multicenter Database by Orthopedic Surgeons

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Abstract:

Introduction: Magnetic resonance imaging (MRI) is widely used in orthopedics, but orthopedic surgeons, including spine surgeons, do not have detailed knowledge of MRI-related accidents. We, as orthopedic surgeons, investigated the details of medical accidents related to ferromagnetic objects brought into the MRI room using a national multicenter database.

Methods: We conducted an exploratory analysis of accidents involving MRI ferromagnets based on the Japanese database of adverse medical occurrences. From a total of 104,659 accident reports over nine years, 172 involving the presence of ferromagnetic objects in the MRI room were extracted and analyzed.

Results: The accident reports frequently involved children and the elderly. Nurses filed the highest number of reports (44.8%) by occupation, which was more than twice as many as physicians (19.8%). The most common ferromagnetic devices brought into the MRI rooms were pacemakers (n = 22). There were also large magnetic objects such as oxygen cylinders (n = 12) and IV stands (n = 7). In the field of orthopedics, ankle weights (n = 4), pedometers (n = 3), and artificial limbs (n = 2) were brought in. “Failure to check” was the most common cause of accidents (69%). Actual harm to patients occurred in 9% of cases, with no fatalities.

Conclusions: Manuals and checklists should be developed and continuous education provided to prevent accidents involving magnetic objects brought into the MR scanner room. As orthopedic surgeons, including spine surgeons, we should be cautious with emergency, geriatric, and pediatric patients because their information and medical history may not be accurate. We should not overlook equipment commonly found in orthopedic practice such as ankle weights and pedometers.

Keywords:

MRI, patient safety, ferromagnetic objects, reporting system

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Introduction

Magnetic resonance imaging (MRI) is widely used for diagnostic imaging because it is minimally invasive and carries no risk of radiation exposure. MRI is particularly essential in orthopedic practice, especially in the spine, because it can assess soft tissues such as nerves and ligaments.

Because of the inherent dangers of high magnetic fields with MRI, various measures are taken to prevent accidents. In fact, among all medical accidents, MRI accidents are less frequent[1]. Each facility and region has a reporting system for medical accidents to analyze and prevent their recur-

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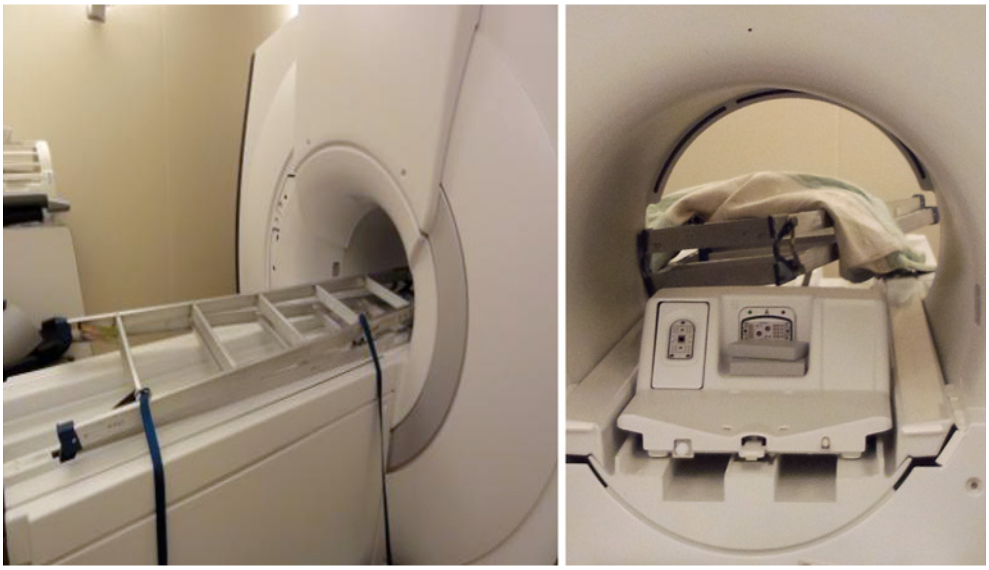

Figure 1. Our accident case.
On a holiday, a cleaning staff brought a stepladder into the MRI room for an air conditioning inspection. The stepladder was pulled into the MRI gantry, causing no damage to personnel.

rence. Incident reporting systems are critical for recording incidents, understanding their causes, and taking immediate action to minimize future accidents, while also reducing hospital costs[2-5].

Although rare, MRI-related accidents have been reported (Fig. 1), some of which have had serious consequences[6]. Japan has about seven times as many MRI scanners as the world average, and the highest number of MRI units per capita worldwide[7]. Orthopedic surgery is one of the departments that use MRI most frequently. The greatest factor influencing the number of serious incidents is reported to be the total number of MRI examinations performed at a single facility[8]. Therefore, understanding the background and details of such accidents through incident reports is vital for orthopedic surgeons.

Unfortunately, orthopedic surgeons' knowledge of MRI incidents is limited due to their rarity and the inadequacy of single-center analysis. The purpose of this study is to examine the details of medical accidents related to ferromagnetic objects that were brought into the MRI room using a national multicenter database and from the perspective of orthopedic surgery practice.

Materials and Methods

This analysis-based study used cases registered in the Japanese national public database of adverse medical events. In 2004, Japan made the reporting of adverse medical events mandatory for some large medical institutions such as university and national hospitals. At the time, the Japan Council for Quality Health Care (registered with the Minister of Health, Labor and Welfare) conducted the medical near-miss/Adverse Event Information Project. The project's website provides public access to medical adverse events and medical near-miss data in the Japanese language[9]. As of March 31, 2021, 1559 facilities are participating in this project. In the past, an adverse event analysis study in pediatrics using this database was reported[10].

The public database contains 104,659 medical near-miss/adverse events over nine years (January 1, 2010, to December 31, 2019), and reports can be searched by entering keywords. The search strategy for near-miss/adverse cases regarding ferromagnetic objects that were brought into MRI rooms was "(MRI) AND (suction) OR (attraction) OR (metals) OR (ferromagnetic objects) OR (accidents)" in Japanese. Then, from the extracted reports, cases related to the presence of magnetic materials that were brought into the MRI room were manually checked and categorized by two orthopedic surgeons. We included not only cases in which ferromagnetic materials were actually brought into the MRI room but also near-miss cases in which an incident was prevented.

The search flow diagram is shown in Fig. 2. The database search identified a total of 415 cases. Subsequent screening excluded 243 cases not related to ferroelectric objects in the MRI room. Finally, 172 cases were included in the analysis. The survey items included the gender and age of the patient, the date and time of the occurrence, the occupation and years of work experience of the staff involved, the details of the medical treatment, the details of the ferromagnetic object, the cause of the event, and the severity of the harm caused to the patient by the incident. Table 1 summarizes the definitions and examples for each severity category.

The descriptive statistics were conducted using SPSS software (IBM SPSS 25, Armonk, NY, USA). A Pearson's chi-square test was used to compare the ratios between the groups. Written informed consent was obtained from the patients to report cases. No identifiable information about the participants was included in the manuscript. The Institutional Review Board of our hospital approved this study

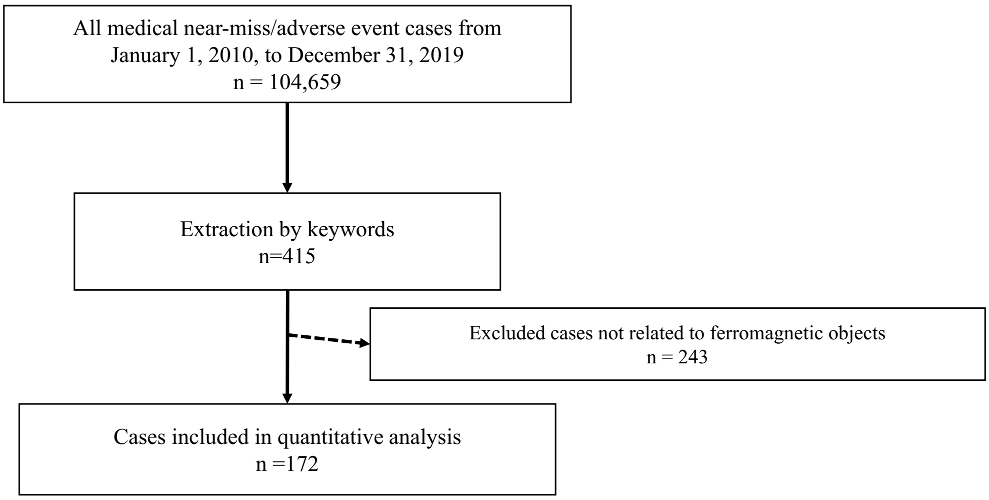

Figure 2. Flow diagram showing the case selection protocol.

Table 1. Cases of Different Severity Levels as Examples.

Severity	Example case
Level 0 (no harm, near-miss event)	A doctor ordered an MRI of the thoracic spine on a patient with external fixation of the lower extremity. Before performing the MRI, the nurse noticed that the patient had external fixation and canceled the examination.
Level 1 (affected but no harm)	A doctor ordered a lumbar MRI for a patient with back pain; after the MRI, the staff found out that the patient had a cardiac pacemaker. A cardiologist examined the patient and, fortunately, the patient was unaffected.
Level 2 (temporary or minor harm)	A lumbar MRI was performed to investigate pyogenic spondylitis. The temperature sensor lead of the urinary catheter got caught in the patient's back and burned his back.
Level 3 (permanent or serious harm)	A neurosurgeon ordered a head MRI for a patient. The radiologist verbally confirmed that the patient did not have any ferromagnetic material but failed to notice that he had ankle weights under his pants. The patient's leg was absorbed into the MRI gantry when the examination started and rescuing the patient from the MRI gantry took about 10 minutes. An orthopedic surgeon then diagnosed a fracture of the left ankle.
Level 4 (death)	No applicable cases

protocol.

Results

The characteristics of the 172 cases are shown in Table 2. Concerning age, the number of reported cases was high among the elderly, with the age ranging from 60 to 89 years old, and children under nine years old. Of the reports, 62.2% were inpatients, and 37.8% were outpatients. Regarding the time of occurrence, 73.3% of the accidents occurred in the daytime and 26.7% at night. Of the 172 patients, 52.3% required medical treatment.

By occupation, nurses (44.8%) were the most commonly involved, followed by radiological technologists (31.4%) and doctors (19.8%) (Fig. 3). The staff work experience ranged from 0 to 42 years, with an average of 10.7 ± 9.6 years. About 30% of the reports involved staff with less than five years of experience and about 20% involved staff with 5 to 10 years of experience (Table 3).

The ferromagnetic objects brought or about to be brought into the MRI room included cardiac pacemakers (n = 22), oxygen cylinders (n = 12), and IV splints (n = 8), as well as hearing aids, IV stands, and thermometers (n = 7). Seven patients with cardiac pacemakers underwent MRI, and no patients experienced adverse effects. With regard to orthopedic devices, ankle weights (n = 4), pedometers (n = 3), and artificial limbs (n = 2) were the basis for the described incident (Fig. 4).

The classification of accident causes is indicated in Fig. 5. "Failure to check" was the most common cause (69%), "lack of knowledge" was 16%, "patient's unawareness of ferromagnetic objects" was 5%, and "under unusual psychological conditions" was 4%. Examples of the accident causes are shown in Table 4.

Fig. 6 indicates the severity of accidents. Of all cases, 26% were level 0 (no harm, near-miss event), 65% were level 1 (affected, but no harm), 6% were level 2 (temporary, or minor harm), 3% were level 3 (permanent, or serious harm), and none were level 4 (death). In summary, only 9% of all the incidents (level 2 or higher) caused actual harm to the patient. In the 34 instances where doctors were involved, 18% were level 2 or higher. In the 138 cases of non-doctor involvement, 7% were level 2 or higher. The percentage of serious accident cases (level 2 or higher) involving doctors

(17.6%) was significantly higher than that of non-doctors (6.5%) (P=0.039). Approximately half of the cases required medical treatment (Table 2), but most had no significant adverse outcomes (Fig. 6).

The following five cases required intensive care: intracranial hypotension syndrome due to ventriculoperitoneal shunt

Table 2. Characteristics of Reports (n=172).

Characteristics		
Patient		
Age (years)		
	0–9 (n)	21
	10–19 (n)	5
	20–29 (n)	3
	30–39 (n)	7
	40–49 (n)	8
	50–59 (n)	11
	60–69 (n)	25
	70–79 (n)	50
	80–89 (n)	35
	90–99 (n)	5
	unknown (n)	2
Sex (male vs. female)		98:72
Category of patient		
Inpatient (n)		107
Outpatient (n)		65
Staff years of work experience (years)		10.7±9.6
Time of occurrence		
Daytime (n)		126
Nighttime (n)		46
Medical treatment		
Required (n)		91
Not required (n)		81

Data are expressed as means±standard deviation.
Daytime, 8:00~15:59; Night time, 0:00~7:59, 16:00~23:59.

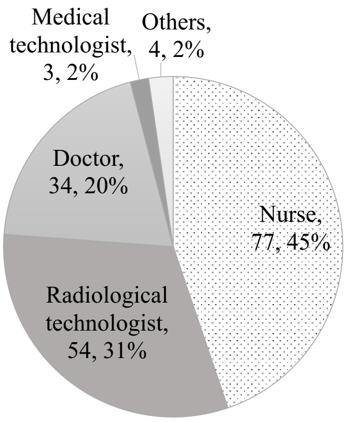

Figure 3. Occupation of the staff involved.
Nurses were the most common, followed by radiologists and doctors.

Table 3. Relationship between Years of Work Experience and Number of Incidents.

Year	n
0–4	57
5–9	38
10–14	25
15–19	23
20–24	12
25–29	9
30–34	3
35–39	3
40≤	2
Total	172

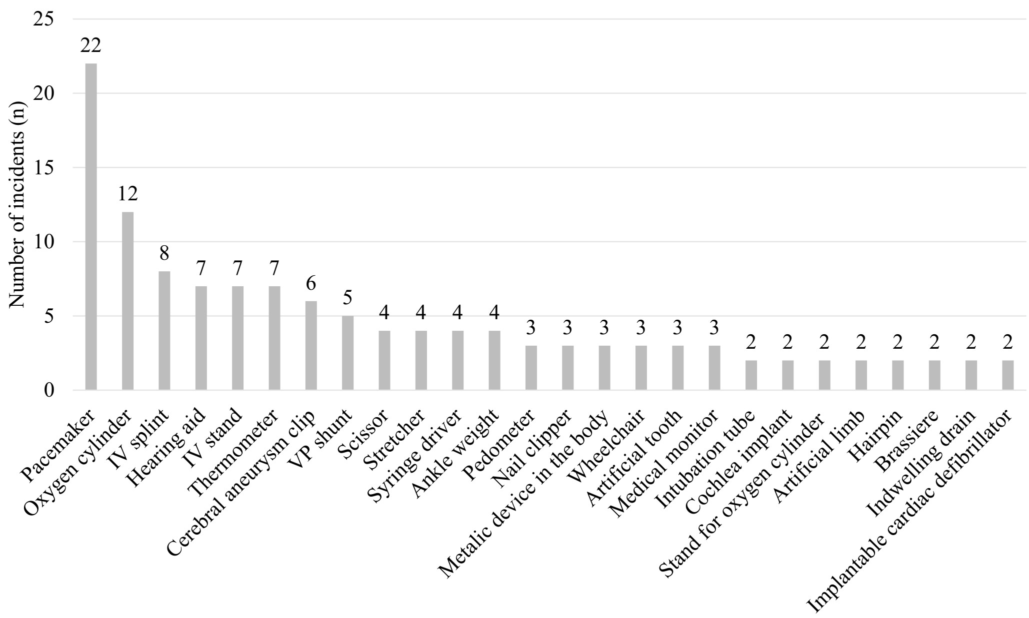

Figure 4. Ferromagnetic materials brought or about to be brought into the MRI room (n≥2).

(n = 2), a skull fracture and intracranial hemorrhage caused by a stretcher, an ankle fracture caused by an ankle weight, and a burn injury caused by the temperature sensor of a urinary catheter.

Discussion

Our study found that nurses were involved in most incidents when analyzing the incidents by occupation, more than twice as doctors (Fig. 3). In fact, nurses are more likely to be involved in bringing patients into the MRI room for scanning than doctors. Moreover, we speculate that this difference is because nurses are more aware of the incident reporting system than physicians. Reportedly, nurses were more likely than doctors to know how to access an incident report[11].

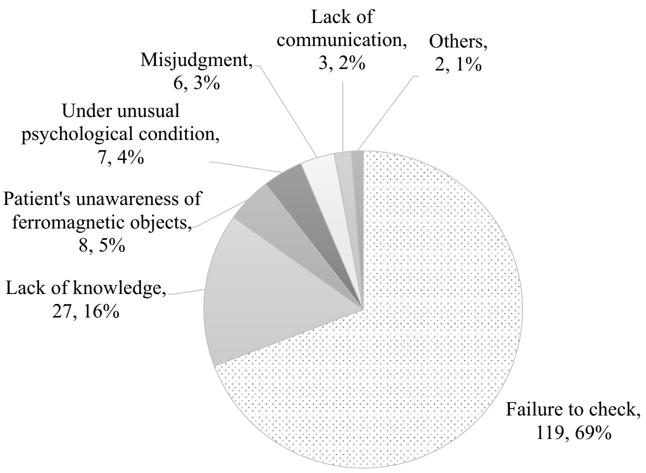

Figure 5. Classification of accident causes.
"Failure to check" was the most common cause, accounting for 69% of all causes.

Our analysis showed that 33% of the reports were from staff with less than five years of experience (Table 3). This means that less experienced staff are more likely to cause accidents, which is consistent with past reports[12]. Many accidents with level 2 or higher outcomes were reported in the cases in which doctors were involved (Fig. 6). The reason could be that doctors are not as familiar with MRI room protocols and lack knowledge about magnetic materials in implants.

The present study found that the most common reason for reporting incidents was "failure to check," which accounted for approximately 70% of the reports (Fig. 5). A study in the United States found that the most common reasons for reporting MRI-related incidents were diagnostic test orders, adverse drug reactions, and medication/IV safety[1]. Due to different classification definitions in the databases, and because our study was limited to incidents involving magnetic objects, we could not directly compare our results with those of previous studies.

In this survey, no fatalities from MR accidents were found. However, since many accidents involving large ferromagnetic objects such as stretchers, IV stands, and oxygen tanks have been reported, fatalities could have occurred. We expected that the accidents involving pacemakers would have disastrous consequences, but contrary to our prediction, the outcomes involving pacemaker accidents were not serious. In 2000, a patient with a cardiac pacemaker died during an MRI examination at a teaching hospital in Victoria, Australia[6]. Although there were no fatalities in our study, we should not forget that accidents leading to death can and do occur.

Based on the results of our analysis, we propose three preventive measures. First, facilities should maintain and utilize manuals and checklists to prepare for accidents involving magnetic objects and MRI. According to a survey of

Table 4. Cause of the Incident and Examples.

Cause of the incident	Example case
Failure to check	The technician nearly performed an MRI on a patient with a cardiac pacemaker because the doctor had not asked the patient for a detailed medical history.
Lack of knowledge	Six months prior, a former doctor took a brain MRI to check for lung cancer metastasis. When the neurosurgeon re-examined the brain MRI, he found a subdural hematoma. Therefore, he performed a hematoma removal procedure since the patient had a ventriculoperitoneal (VP) shunt. The hematoma was probably caused by intracranial hypotension as a result of the prior MRI.
	The doctor who ordered the head MRI six months prior did not know that the VP shunt was ferromagnetic.
Patient's unawareness of ferromagnetic materials	A doctor ordered an MRI for a dementia patient with a cardiac pacemaker. The doctor had taken a detailed history of the patient but had not informed the radiologist about the pacemaker. When the radiologist reviewed the chest X-ray before the examination, he noticed the pacemaker and the MRI was canceled.
Under unusual psychological condition	In the MRI room, the doctor was concentrating on securing the peripheral venous route of the patient, whose blood vessels were fragile, for a contrast-enhanced MRI. As soon as the doctor secured the veinous line, he rushed to connect the route and placed the puncture needle on the table. The needle was sucked into the MRI gantry.
Misjudgment	When a radiology technician was taking a patient to the MRI room, he mistakenly used a regular IV stand instead of one specially designed for the MRI room.
	The IV stand was sucked into the MRI gantry, but, fortunately, the patient was not injured.
Lack of communication	A patient with a cardiac pacemaker presented to the cardiologist with a headache. A brain CT scan showed a subdural hematoma, so the cardiologist consulted a neurosurgeon. The neurosurgeon mistakenly believed that a brain MRI had been ordered. The MRI was performed, but, fortunately, did not injure the patient.

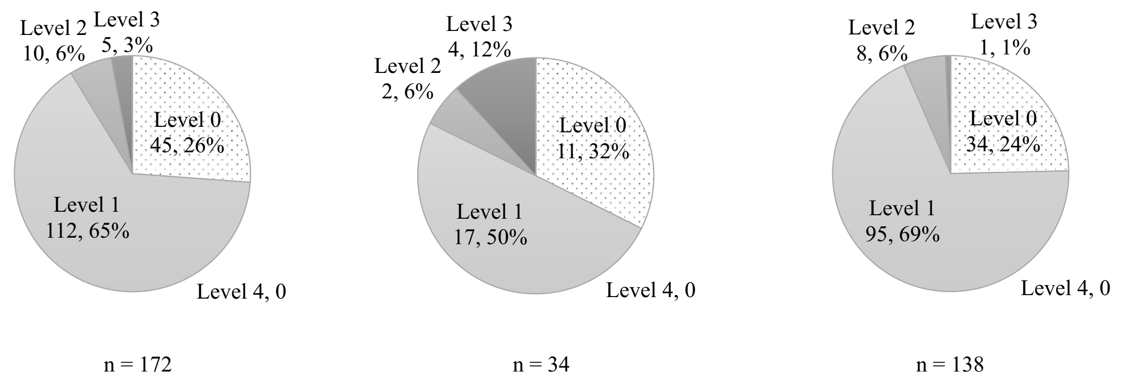

Figure 6. Severity of accidents A: All cases, B: Doctors' cases, C: Non-doctors' cases.

Table 5. Checklist for MR Safety in Orthopedic Patients.

Checklist for MR safety in orthopedic patients	
Pay attention to the following patients	
• emergency trauma patients	
• patients with dementia	
• elderly patients	
• pediatric patients	
• sports patients	
Examples of ferromagnetic objects that require attention	
1. Metallic device in the body	5. Others
❒ Pacemaker	❒ Oxygen cylinder
❒ Cerebral aneurysm clip	❒ IV splint
❒ VP shunt	❒ IV stand
2. Otolaryngology	❒ Thermometer
❒ Hearing aid	❒ Stretcher
❒ Cochlea implant	❒ Syringe driver
3. Dentistry	❒ Wheelchair
❒ Artificial tooth	
4. Orthopedic devices	
❒ Ankle weight	
❒ Pedometer	
❒ Artificial limb	

safety management for MRI facilities in Japan, many MRI facilities do not have adequate measures in place to guarantee MRI safety[8]. We developed a checklist for orthopedic patients based on the results of the present study (Table 5). Second, continued safety education, particularly for new staff, is essential. In the analysis of work experience, less employee experience corresponded to more reported accidents. "Lack of knowledge" is the second most common cause of accidents. These results suggest the importance of education for accident prevention. Third, orthopedic surgeons should be reminded that patients do not always correctly answer questions about issues that may affect MRI safety. It may be necessary to proactively confirm the safety of the MRI with the patient's medical data, and review conventional imaging information such as radiographs, prior to the MRI.

There are some limitations to this study. First, this type of survey is not entirely inclusive, and there is always the possibility of selection bias. Second, some of the reports lacked detail, making an in-depth analysis difficult. Third, the person who reported the incident was considered the person involved in the database, but the person who caused the incident might be different from that who reported it. Nonetheless, this study will provide helpful information for orthopedic surgeons, including spine surgeons.

In conclusion, less experienced medical staff were involved in a greater number of accidents. "Failure to check" was the most common cause of accidents. Based on these results, manuals and checklists need to be developed and continuous education provided to prevent future accidents involving magnetic objects in the MRI room. As orthopedic surgeons, we should be cautious with emergency, geriatric, and pediatric patients because of the potential unreliability of their information, and we should not overlook equipment commonly found in orthopedic practice such as ankle weights and pedometers.

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Author Contributions: Kayo Inaguma and Toshiaki Kotani wrote and prepared the manuscript, and all of the authors participated in the study design. All authors have read, reviewed, and approved the article.

Ethical Approval: This study was approved by the Institutional Review Board of the Seirei Sakura Citizen Hospital (Approval code: 2021025).

Informed Consent: Written informed consent was obtained from the patients to report cases. No identifiable information about the participants was included in the manuscript.

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