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Risk factors for imaging abnormalities in patients with dizziness complaints: an algorithm for ordering brain imaging

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AIM: The diagnostic detection of abnormal findings with head imaging is low for dizziness. This study aimed to investigate the risk factors associated with abnormal computed tomography (CT) or magnetic resonance imaging (MRI) findings for patients with dizziness.

MATERIALS AND METHODS: Medical records of patients who had CT or MRI examinations for dizziness complaints between January 1, 2019, and December 31, 2020, were retrospectively reviewed. Imaging outcomes were grouped as normal or abnormal findings. Risk factors, including demographics, dizziness pattern, symptoms, comorbidities, and medical history were assessed. A Chi-square automatic interaction detection decision tree model was used to classify abnormal imaging findings based on risk factors identified through multivariable analyses.

RESULTS: A total of 2,342 scans were examined. Detection of abnormal findings was 4.8% (n = 96), including acute cerebral infarction (n = 33), acute cranial hemorrhage (n = 15), cancer/tumor-like lesions (n = 27), and inner ear abnormalities (n = 21). The risk factor most indicative of abnormal findings were loss of consciousness and neurologic deficit (Odds Ratio 55.57, $p < 0.001$). The likelihood of abnormality indicating acute brain lesions was 44.4% for patients with loss of consciousness and neurologic deficits. Loss of consciousness and neurologic deficits, hearing loss, nausea/vomiting, and comorbid malignancy distinguished abnormal findings from negative imaging findings (AUC 0.729; 95%CI 0.672–0.785; $p < 0.001$). Patients with unspecific dizziness complaints were less likely to have abnormal imaging findings.

CONCLUSION: These findings highlighted the significance of specific risk factors in recognizing individuals with dizziness complaints who may have abnormal imaging findings indicative of serious diseases. Further studies are warranted to verify the findings.

Abbreviations: AUC, area under the receiver operating characteristic curve; CI, confidence intervals; ED, emergency department.

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Introduction

Dizziness and vertigo are among the most common symptoms in those presenting to both emergency and ambulatory care, accounting for more than 3.9 million visits to US emergency departments (ED) in 2011.[1] In Japan, more than 50,000 patients with dizziness were transported to the ED in an ambulance during 2018–2020 in one prefecture alone.[2] Based on 20.6 million outpatient visits for dizziness between 2013 and 2016, the prevalence of dizziness is 8.8 per 1,000 visits.[3] The causes of dizziness and vertigo range from peripheral and otologic to central and acute. In the ED, benign paroxysmal positional vertigo, acute unilateral vestibulopathy/vestibular neuritis, and ischemic attack are the most frequent diagnoses for patients presenting with dizziness and vertigo.[4] The incidence of dizziness/vertigo and peripheral vestibular disorder in Japanese primary care patients with lifestyle-related diseases is 194.7 and 115.7 per 1,000 person-years, respectively.[5]

To identify dizziness indicating life-threatening conditions such as stroke, head computed tomography CT and magnetic resonance imaging (MRI) are often ordered. In a Medicare database, 56.1% of the billed head CT examinations were ordered in the ED, most commonly for dizziness and giddiness.[6] Around 36–42% of patients with dizziness and vertigo presenting to the ED undergo MRI or CT[1,7,8]; in outpatient clinics, the percentage is around 5.5–15%.[3,8] Patient factors associated with neuroimaging for dizziness include older age, comorbidity, ED presentation, and outpatient clinician specialty.[8,9] However, the diagnostic yield of CT for dizziness is below 5%[7,9,10]; MRI is slightly higher at 12%.[7] In real-world clinical practice, there has been concerns over unnecessary imaging tests performed for patients, as well as the need to timely inspect radiology reports of CT and MRI in order to increase the usefulness of the image findings, especially in Japan.[11]

To reduce the number of unnecessary CTs/MRIs, improve the diagnostic yield, and triage patients needing urgent intervention in both the ED and outpatient setting, this study aimed to investigate the risk factors associated with abnormal CT or MRI findings for dizziness. We sought to develop an algorithm to aid decision-making when ordering head imaging for patients presenting with dizziness or vertigo using patient demographics, medical history, and presenting symptoms.

Materials and methods

Our hospital institutional review board approved the study protocol (IRB number: E22-0243). Patient informed consent was waived by our institutional review board for this retrospective study, and the investigation adhered to the Declaration of Helsinki principles. This study was conducted as part of a joint research course between our university and a biomedical laboratory company.

Study design and patients

This retrospective study analyzed consecutive patient records at a Japanese tertiary university hospital. The radiology reports of patients who had brain CT and/or MRI scans for dizziness or vertigo between January 1, 2019, and December 31, 2020 were reviewed. Patients who had imaging scans specifically ordered to examine the pituitary gland, internal auditory canal, temporal bone (without full brain coverage), or CT angiography only, were excluded.

Outcomes and variables of interest

The radiological outcomes were grouped into five categories by two radiologists independently (38 year- and 23 year-experience): Group 1: No abnormality, defined as having no new abnormalities that would account for acute dizziness, including old cerebral infarction, old cranial hemorrhage, chronic ischemic change, brain atrophy, brain tumor follow-up; Group 2: acute cerebral infarction; Group 3: acute cranial hemorrhage; Group 4: brain tumor or tumor-like disease, including new lesion or tumor growth; and Group 5: inner ear abnormality. In patients who received >1 imaging test during the study period, the last retrievable imaging outcome was used for regression analysis and decision tree development.

Variables collected included patient demographics, dizziness pattern (dizziness, vertigo, feeling of unsteadiness, or unspecified), reported symptoms (nausea/vomiting, headache, nystagmus, and hearing loss), loss of consciousness, and neurologic deficits (including motor nerve paralysis and paresthesia), the clinical department ordering the imaging test, comorbidities (hypertension, diabetes mellitus, hyperlipidemia, heart disease [including angina pectoris, myocardial infarction, atrial fibrillation, valvular disease, arrhythmia, and heart failure], cancer or malignancy [lymphoma, sarcoma, brain tumor]), and past medical history (including prior cerebral infarction or cranial hemorrhage).

In this study, the categorization of the dizziness pattern was based on patient's complaints in the electronic medical record data rather than clinical examination findings. Within the Japanese context, when patients complain of "memai", it generally has a broad spectrum of interpretations, encompassing descriptions such as "vertigo," "dizziness" or the "feeling of unsteadiness" To establish clarity in this study, we operationally defined "vertigo" as rotational vertigo and "dizziness" as floating vertigo. Instances where categorization could not be ascertained from the medical records were categorized as "unspecified dizziness."

Statistical analysis

Age was reported in years using means and standard deviations. The differences between those without and with abnormal findings were tested for significance with an independent two samples t-test, and the differences between the five subgroups were tested using one-way analysis of

variance with Bonferroni correction in the post-hoc comparisons of the four abnormal groups versus the group without abnormality. Categorical data were presented using count and percentage. Fisher's exact test was used to test the differences between those with vs. without abnormal findings, and the differences among the five subgroups. The Z-test for proportions with Bonferroni correction was performed for the multiple comparisons between the four abnormal groups vs. the group with no abnormality.

Logistic regression analyses were performed in three steps to find independent risk factors and odds associated with each of the abnormal imaging diagnoses. First, the univariable logistic regression model for each possible variable was performed. Second, the variables with p-value less than 0.1 in the univariable logistic regression models were considered as possible independent factors of diagnosis and were included in the process of model selection. Finally, an optimized final model was determined based on the conditional backward method. The variables in the final model with p-values less than 0.05 were considered as independent factors influencing diagnosis. Receiver operating characteristic analysis (ROC) was then performed to evaluate the ability of these variables in relation to identifying the specified outcomes. Odds ratios (OR) with 95% confidence intervals (CI) were shown for the tested variables. A higher area under the receiver operating characteristic curve (AUC) indicated a higher diagnostic ability of the model.

Based on the risk factors included in the multivariable logistic models, two models of a chi-square automatic interaction detector decision tree were constructed to classify different outcome subgroups. The number of parent nodes and child nodes were set as 30 and 10, respectively. The misclassification cost of false negatives was set at 20 for acute brain lesion, tumor-like disease, and inner-ear abnormality; the other misclassification costs were set as 1.

All hypothesis tests were two-sided with a significance level of 0.05. The statistical and decision tree analyses were performed using SPSS Statistical software, version 25.0 (IBM Corporation, Inc., Armonk, NY, USA).

Results

Patient demographics

A total, 2,342 CT or MRI examination records were included from 2,002 patients (mean age: 59.3 ± 18.4 years) (Fig 1). Table 1 outlines patient demographics, dizziness patterns, symptoms, comorbidities, and medical histories. MRI was used in 71.5% of cases. Dizziness patterns included vertigo (37.3%), dizziness (20.4%), and feeling of unsteadiness (13.2%). The predominant symptoms were nausea and vomiting (31.1%) and headache/heavy headedness (15.9%). Hypertension was present in 25% of patients, and 3.8% had a history of cerebral infarction.

MRI examinations were prevalent in otorhinolaryngology (42.6%), while CT scans were common in neurology (32.5%). Otorhinolaryngology (42.6%) and rheumatology (4.3%) ordered more MRI, whereas neurology (32.5%) and the ER (17.0%) ordered more CT (all $p < 0.001$, Table S1).

Ninety-six patients (4.8%) had abnormal findings on CT or MRI examinations: 33 with acute cerebral infarction, 15 with acute cranial hemorrhage, 27 with brain tumor or tumor-like disease, and 21 with inner ear abnormality. The group with no abnormality (Group 1) differed from the groups with abnormal findings in several demographic attributes (Table 1). Loss of consciousness and neurologic deficits were more common in groups with abnormal findings (21.2%, 6.7%, 11.1%, and 4.8%) compared to those without abnormalities (Group 1: 0.3%, $p < 0.001$). Over 50% of the patients with an acute cerebral infarction or acute cranial hemorrhage had hypertension (54.5% and 60.0%, respectively), exceeding the patients without abnormalities, brain tumor, or inner-ear abnormality (24.5%, 14.8%, and 9.5%, respectively, $p < 0.002$). One-third of patients with acute cerebral infarction had hyperlipidemia, significantly higher than those without abnormal findings (33.3% vs. 13.2%, $p = 0.001$). Similarly, one-third of patients with brain-tumor-like abnormalities had cancer or other malignancies, significantly higher than those without abnormal findings (33.3% vs. 9.9%, $p < 0.001$) (Table 1).

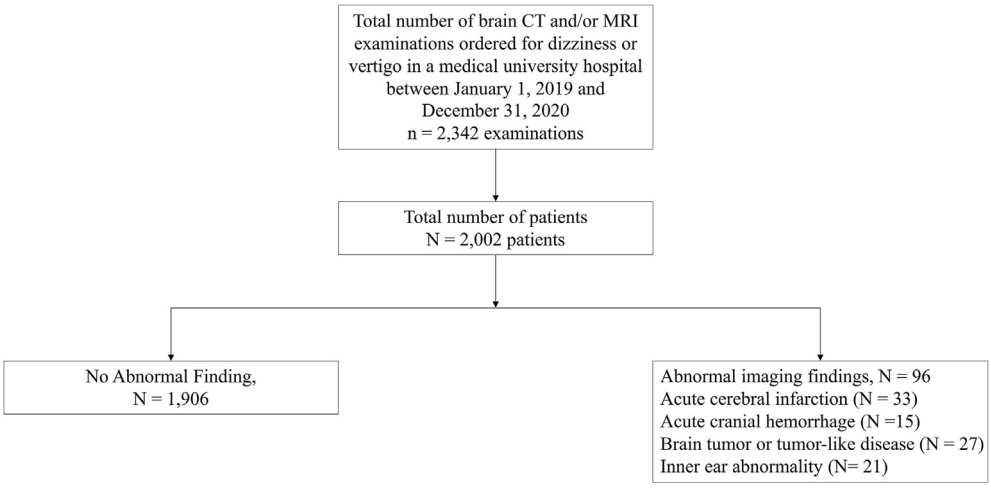

Figure 1 Study flow chart.

Table 1
Demographic and baseline characteristics of subjects with brain CTs and MRIs ordered to investigate the possible causes for dizziness/vertigo according to the clinical outcome.

	Total (N = 2,002)	Group 1: No abnormality (N = 1,906)	Group 2-5: With abnormal findings (N=96)	P-value	With abnormal findings (N = 96)				P-value
					Group 2: ACI (N = 33)	Group 3: ACH (N = 15)	Group 4: BT (N = 27)	Group 5: IEA (N = 21)	
Age (years)	59.3 (18.4)	59.0 (18.5)	64.8 (16.3)	0.001[e]	67.7 (16.4)	68.8 (11.5)	68.3 (12.8)	52.9 (18.3)	<0.001[f]
Age ≧ 65 years	888 (44.4%)	834 (43.8%)	54 (56.3%)	0.020[e]	22 (66.7%)[a,d]	8 (53.3%)	18 (66.7%)[d]	6 (28.6%)	0.005[f]
Sex				0.024[e]					0.021[f]
Female	1,210 (60.4%)	1,163 (61.0%)	47 (49.0%)		11 (33.3%)	7 (46.7%)	16 (59.3%)	13 (61.9%)	
Male	792 (39.6%)	743 (39.0%)	49 (51.0%)		22 (66.7%)[a]	8 (53.3%)	11 (40.7%)	8 (38.1%)	
Imaging modality				0.008[e]					0.001[f]
CT	570 (28.5%)	554 (29.1%)	16 (16.7%)		2 (6.1%)	7 (46.7%)	6 (22.2%)	1 (4.8%)	
MRI	1,432 (71.5%)	1,352 (70.9%)	80 (83.3%)		31 (93.9%)[a]	8 (53.3%)[b,d]	21 (77.8%)	20 (95.2%)	
Dizziness Pattern									
Dizziness	409 (20.4%)	389 (20.4%)	20 (20.8%)	0.897	7 (21.2%)	5 (33.3%)	4 (14.8%)	4 (19.0%)	0.709
Vertigo	747 (37.3%)	711 (37.3%)	36 (37.5%)	>0.999	11 (33.3%)	4 (26.7%)	12 (44.4%)	9 (42.9%)	0.780
Feeling of unsteadiness	265 (13.2%)	245 (12.9%)	20 (20.8%)	0.030[e]	7 (21.2%)	4 (26.7%)	6 (22.2%)	3 (14.3%)	0.118
Unspecified	617 (30.8%)	597 (31.3%)	20 (20.8%)	0.031[e]	8 (24.2%)	2 (13.3%)	5 (18.5%)	5 (23.8%)	0.287
Other symptoms									
Nausea, vomiting	622 (31.1%)	584 (30.6%)	38 (39.6%)	0.071	14 (42.4%)	9 (60.0%) [d]	12 (44.4%)	3 (14.3%)	0.012[f]
Headache, heavy headedness	318 (15.9%)	306 (16.1%)	12 (12.5%)	0.394	0 (0.0%)	1 (6.7%)	8 (29.6%)	3 (14.3%)	0.010[f]
Nystagmus	146 (7.3%)	135 (7.1%)	11 (11.5%)	0.109	0 (0.0%)	6 (40.0%)[a,b,d]	5 (18.5%)	0 (0.0%)	<0.001[f]
Hearing loss	57 (2.8%)	46 (2.4%)	11 (11.5%)	<0.001[e]	1 (3.0%)	1 (6.7%)	2 (7.4%)	7 (33.3%) [a,b]	<0.001[f]
Loss of consciousness & neurologic deficits	18 (0.9%)	6 (0.3%)	12 (12.5%)	<0.001[e]	7 (21.2%) [a]	1 (6.7%) [a]	3 (11.1%)[a]	1 (4.8%) [a]	<0.001[f]
Comorbidities									
Hypertension	500 (25.0%)	467 (24.5%)	33 (34.4%)	0.039[e]	18 (54.5%)[a,c,d]	9 (60.0%)[a,c,d]	4 (14.8%)	2 (9.5%)	<0.001[f]
Diabetes	207 (10.3%)	193 (10.1%)	14 (14.6%)	0.168	6 (18.2%)	3 (20.0%)	3 (11.1%)	2 (9.5%)	0.313
Hyperlipidemia	272 (13.6%)	252 (13.2%)	20 (20.8%)	0.046[e]	11 (33.3%)[a]	4 (26.7%)	4 (14.8%)	1 (4.8%)	0.009[f]
Cancer, other malignancies	211 (10.5%)	189 (9.9%)	22 (22.9%)	<0.001[e]	7 (21.2%)	3 (20.0%)	9 (33.3%)[a]	3 (14.3%)	0.001[f]
Heart disease	221 (11.0%)	210 (11.0%)	11 (11.5%)	0.867	6 (18.2%)	3 (20.0%)	1 (3.7%)	1 (4.8%)	0.249
Past Medical History									
Cerebral infarction	76 (3.8%)	70 (3.7%)	6 (6.3%)	0.176	4 (12.1%)	1 (6.7%)	1 (3.7%)	0 (0.0%)	0.115
Cranial hemorrhage	14 (0.7%)	12 (0.6%)	2 (2.1%)	0.143	1 (3.0%)	1 (6.7%)	0 (0.0%)	0 (0.0%)	0.074

ACI: acute cerebral infraction; ACH: acute cranial hemorrhage; BT/TLD: Brain tumor or tumor-like disease; IEA: inner ear abnormality; CT, computed tomography; MRI, magnetic resonance imaging.
[a] Indicates a significant difference as compared to those without abnormal findings (Group 1).
[b] Indicates a significant difference as compared to group ACI.
[c] Indicates a significant difference as compared to group BT.
[d] Indicates a significant difference as compared to group IEA.
[e] Indicates a significant difference between the subjects without abnormal findings (Group 1) and those with abnormal findings (Groups 2-5). The subjects with abnormal findings were further classified into 4 diagnosis groups.
[f] Indicates significant differences among the 5 groups (Groups 1-5).

Risk factor analysis by logistic regression

In univariable analysis, the risk factors associated with increased odds of abnormal findings were age ≥65 years; male sex, dizziness pattern of feeling of unsteadiness, symptoms of hearing loss, loss of consciousness and neurologic deficits, and the comorbidities of hypertension, hyperlipidemia, or cancer/malignancy (with ORs and 95% CI > 1). Conversely, an unspecified dizziness pattern was less likely to result in abnormal findings (OR = 0.58) (Table S2). The multivariable analysis identified four independent risk factors for abnormal imaging results: loss of consciousness and neurologic deficits (OR = 55.57), hearing loss (OR = 8.75), nausea/vomiting (OR = 1.76), and cancer/malignancy comorbidity (OR = 2.57). Conversely, the unspecified dizziness pattern was less likely to show abnormal findings (OR = 0.52) (all $p < 0.05$). Receiver operating characteristic analysis showed that the predicted probability of the model for any abnormal imaging results had an AUC of 0.729 (95% CI 0.672, 0.785, $p < 0.001$) (Fig 2a).

Separate logistic regression models were conducted for patients with different types of abnormalities. Male sex (OR = 1.97), loss of consciousness and symptoms of neurologic deficits (OR = 36.45), nausea/vomiting (OR = 2.64), hypertension (OR = 3.50), and cancer/malignancy (OR = 2.16) were independent risk factors associated with acute brain lesions (acute cerebral infarction and acute cranial hemorrhage) (all $p < 0.05$, Table 2. The predicted probability of the model had an AUC of 0.788 (95% CI 0.717, 0.859, $p < 0.001$) (Fig 2b).

The independent risk factors for brain tumor or tumor-like abnormality were symptoms of headache and heavy headedness (OR = 3.16), nystagmus (OR = 4.62), loss of consciousness and neurologic deficits (OR = 22.30), and

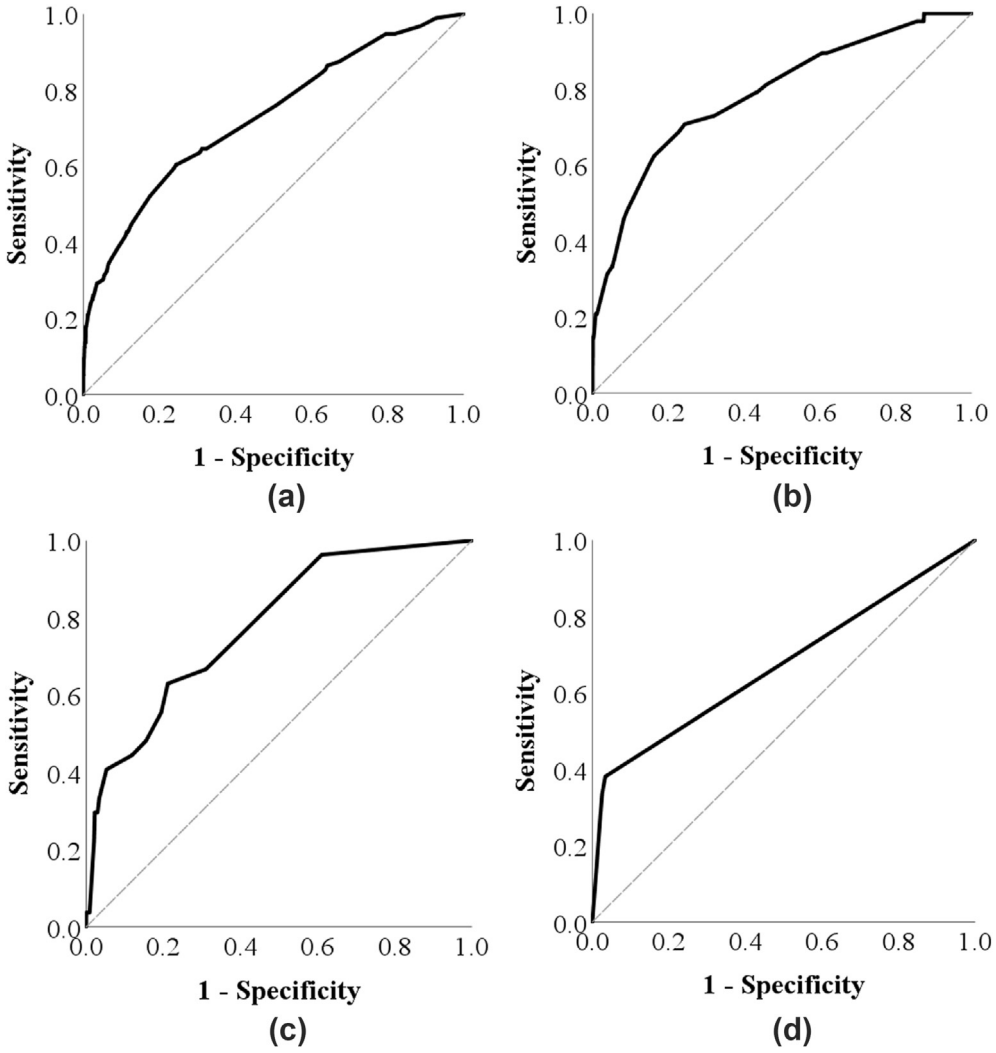

Figure 2 Receiver operating characteristic (ROC) analysis based on the predicted probability of finding: (a) All abnormalities (Groups 2–5), with an area under the curve (AUC) of 0.729 (95% CI 0.672, 0.785, $p < 0.001$); (b) acute brain lesions (Groups 2 and 3), with an AUC of 0.788 (95% CI 0.717, 0.859, $p < 0.001$); (c) brain tumor or tumor-like disease, AUC of 0.779 (95% CI 0.694, 0.864, $p < 0.001$) and (d) inner-ear abnormalities, AUC of 0.674 (95% CI 0.534, 0.815, $p = 0.006$).

cancer/malignancy (OR = 3.76) (all $p < 0.05$, Table 3). The predicted probability of the model had an AUC of 0.779 (95% CI 0.694, 0.864, $p < 0.001$) (Fig 2c).

The risk factors for inner-ear abnormality were symptoms of hearing loss (OR = 20.61), loss of consciousness, and neurologic deficits (OR = 8.66, all $p < 0.05$, Table 4). The predicted probability of the model had an AUC of 0.674 (95% CI 0.534, 0.815, $p < 0.001$, Fig 2d).

Decision tree analysis

Two algorithms were built to distinguish dizzy patients with abnormal imaging findings using patient demographics, symptoms, and comorbidities, and past medical history. The decision tree model for classifying no abnormality vs. any abnormality contained 14 nodes (Fig 3a and b). The decision tree model for classifying different abnormality subgroups contained 10 nodes (Fig 4a and b).

The likelihood of having abnormal imaging findings was 66.7%, 19.3% (Fig 3a), and 8.8% (Fig 3b) for patients with loss of consciousness and neurologic deficit, hearing loss, or cancer, respectively, higher than in those without these symptoms (4.2%, 3.8%, 3.2%, respectively, all $p < 0.001$, Fig 3a and b). The likelihood of the abnormality indicating acute brain lesions was 44.4% (vs. no neurologic deficits, 2.0%, Fig 4a).

For patients without loss of consciousness and neurologic deficits, those with the following combination of symptoms had a higher likelihood of also having abnormal imaging findings: cancer comorbidity with headache, 22.6% (vs. no headache, 6.4%) (Fig 3b); nystagmus with nausea symptoms, 12.1% (vs. no nausea, 1.6%, Fig 3b). The likelihood of having acute brain lesions was higher in those with both hypertension and nausea symptoms, 8.6% (vs. no nausea, 2.3%. Fig 4b).

The decision tree obtained an overall correct prediction rate of 82.9% for finding any abnormal imaging result

Table 2
The factors associated with acute brain lesions (Groups 2 and 3).

	Univariable analysis		Final multivariable model II	
	Odds ratio (95% CI)	*P*-value	Odds ratio (95% CI)	*P*-value
Demographics				
Age ≧ 65 years	2.13 (1.18, 3.85)	0.012[a]		
Sex: male to female	2.61 (1.44, 4.71)	0.001[a]	1.97 (1.05, 3.69)	0.033[a]
Dizziness pattern				
Dizziness	1.31 (0.67, 2.54)	0.428		
Vertigo	0.76 (0.41, 1.41)	0.381		
Feeling of unsteadiness	1.99 (1.00, 3.95)	0.049[a]		
Unspecified	0.58 (0.29, 1.18)	0.134		
Other symptoms				
Nausea, vomiting	2.08 (1.17, 3.70)	0.012[a]	2.64 (1.42, 4.89)	0.002[a]
Headache, heavy headedness	0.11 (0.02, 0.80)	0.029[a]	0.15 (0.02, 1.11)	0.063
Nystagmus	1.85 (0.77, 4.43)	0.167		
Hearing loss	1.50 (0.36, 6.34)	0.581		
Loss of consciousness & Neurologic deficits	38.88 (14.58, 103.70)	<0.001[a]	36.45 (12.45, 106.73)	<0.001[a]
Comorbidities				
Hypertension	4.03 (2.26, 7.19)	<0.001[a]	3.50 (1.89, 6.48)	<0.001[a]
Diabetes	2.05 (0.98, 4.29)	0.058		
Hyperlipidemia	3.00 (1.61, 5.60)	0.001[a]		
Cancer, other malignancies	2.30 (1.13, 4.68)	0.022[a]	2.16 (1.01, 4.61)	0.046[a]
Heart disease	1.90 (0.91, 3.97)	0.090		
Past medical history				
Cerebral infarction	3.08 (1.19, 8.02)	0.021[a]		
Cranial hemorrhage	7.04 (1.53, 32.34)	0.012[a]		

CI: Confidence Interval.
[a] Indicates a significant influence on the odds of finding acute brain lesions.

(Table S3), and 81.8% for abnormality subgroups (Table S4). Positive prediction rates were 41.7% for acute brain lesions, 25.9% for tumor-like disease, and 33.3% for inner ear abnormalities (Table S4).

Out of 274 patients with multiple imaging results within a year (Table S5), the majority (93.8%, n = 257) had consistent findings for both examinations. In total, 90.9% had no abnormal findings on both occasions; 4.7% (n = 13)

Table 3
The factors associated with brain tumor or tumor-like disease (Group 4).

	Univariable analysis		Final multivariable model III	
	Odds ratio (95% CI)	*P*-value	Odds ratio (95% CI)	*P*-value
Demographics				
Age ≧ 65 years	2.54 (1.14, 5.68)	0.023[a]	2.29 (0.97, 5.41)	0.059
Sex: male to female	1.05 (0.49, 2.28)	0.900		
Dizziness pattern				
Dizziness	0.67 (0.23, 1.96)	0.469		
Vertigo	1.35 (0.63, 2.90)	0.442		
Feeling of unsteadiness	1.89 (0.76, 4.73)	0.172		
Unspecified	0.51 (0.19, 1.34)	0.171		
Other symptoms				
Nausea, vomiting	1.79 (0.83, 3.85)	0.136		
Headache, heavy headedness	2.26 (0.98, 5.21)	0.055	3.16 (1.32, 7.56)	0.010[a]
Nystagmus	2.96 (1.10, 7.92)	0.031[a]	4.62 (1.65, 12.93)	0.004[a]
Hearing loss	2.79 (0.65, 12.09)	0.169		
Loss of consciousness & neurologic deficits	16.33 (4.44, 60.13)	<0.001[a]	22.30 (5.57, 89.21)	<0.001[a]
Comorbidities				
Hypertension	0.52 (0.18, 1.51)	0.228		
Diabetes	1.09 (0.32, 3.64)	0.895		
Hyperlipidemia	1.11 (0.38, 3.23)	0.851		
Cancer, other malignancies	4.39 (1.95, 9.90)	<0.001[a]	3.76 (1.57, 9.00)	0.003[a]
Heart disease	0.31 (0.04, 2.27)	0.247		
Past medical history				
Cerebral infarction	0.97 (0.13, 7.28)	0.980		
Cranial hemorrhage	NA			

NA: the odds ratio is not available due to too few or no subjects in Group 4 having cranial hemorrhage.
CI: Confidence Interval.
[a] Indicates a significant influence on the odds of finding a brain tumor or tumor-like disease (Group 4).

Table 4
The factors associated with inner ear abnormality (Group 5).

	Univariable analysis		Multivariable analysis	
	Odds ratio (95% CI)	*P*-value	Odds ratio (95% CI)	*P*-value
Demographics				
Age ≧ 65 years	0.50 (0.19, 1.29)	0.151		
Sex: male to female	0.94 (0.39, 2.28)	0.890		
Dizziness pattern				
Dizziness	0.92 (0.31, 2.74)	0.875		
Vertigo	1.26 (0.53, 3.01)	0.598		
Feeling of unsteadiness	1.09 (0.32, 3.74)	0.887		
Unspecified	0.70 (0.26, 1.92)	0.487		
Other symptoms				
Nausea, vomiting	0.37 (0.11, 1.25)	0.109		
Headache, heavy headedness	0.88 (0.26, 3.01)	0.840		
Nystagmus	NA			
Hearing loss	19.31 (7.47, 49.92)	<0.001[a]	20.61 (7.89, 53.88)	<0.001[a]
Loss of consciousness & neurologic deficits	5.78 (0.73, 45.52)	0.096	8.66 (1.07, 69.97)	0.043[a]
Comorbidities				
Hypertension	0.31 (0.07, 1.35)	0.120		
Diabetes	0.91 (0.21, 3.94)	0.902		
Hyperlipidemia	0.32 (0.04, 2.36)	0.261		
Cancer, other malignancies	1.42 (0.42, 4.86)	0.576		
Heart disease	0.40 (0.05, 3.00)	0.373		
Past medical history				
Cerebral infarction	NA			
Cranial hemorrhage	NA			

NA: the odds ratio is not available due to too few or no subject in Group 5 having nystagmus, cerebral infarction, or cranial hemorrhage.
CI: Confidence Interval.
[a] Indicates a significant influence on the odds of finding inner ear abnormality (Group 5).

initially showed no abnormalities but were later diagnosed with acute cerebral infarction and tumor-like abnormalities; four cases (1.5%) initially diagnosed with acute cerebral infarction (n = 2), tumor-like disease (n = 1), or inner-ear abnormality (n = 1) showed no abnormal findings in the last image examination. No significant association was observed between the image diagnosis results and the imaging modality.

Discussion

In this study, a review of all patients receiving brain CT or MRI ordered for dizziness was conducted in a tertiary hospital. The risk factors associated with abnormal imaging findings included loss of consciousness and neurologic deficits, hearing loss, the comorbidities of hypertension and cancer, and the symptoms of nausea/vomiting, headache/heavy headedness, and nystagmus. Conversely, an unspecified dizziness complaint was inversely associated with an abnormal finding. A decision tree algorithm considering these risk factors was derived to support clinical judgment for patients needing CT or MRI when presenting with dizziness or vertigo complaints.

Among the underlying causes of dizziness, stroke is a life-threatening condition that should be prioritized for timely diagnosis and intervention. Compared to patients with benign paroxysmal positional vertigo who receive neuroimaging for vertigo or dizziness in the ED, stroke patients in the same clinical scenario were more likely to have historical risk factors for stroke, neurologic symptoms, and positive neurologic exam results.[12] Several studies have attempted to establish triage algorithms to discern the type of dizzy patient most likely to benefit from brain imaging. However, most have focused on the utilities of brain imaging in the ED. One study developed scoring algorithms that included focal neurologic deficit, altered mentation, nausea/vomiting, coagulopathy, cancer history, and age to increase the diagnostic yield of noncontrast head CT in nontrauma patients presenting in the ED. In that study, the AUC for the proposed algorithms was 0.73–0.83.[13] In a nomogram that considered albumin level, inorganic phosphate level, previous ischemic stroke, presyncope, and nystagmus, the AUC for predicting patients needing diffusion-weighted MRI when presenting to the ED with isolated dizziness was 0.731.[14] To triage ED patients presenting with dizziness for brain imaging, clinicians can use extensive neurophysical tests; a clinical pathway examining the transient and triggerable nature of the dizziness; the presence of nystagmus; head impulse; the ABCD^{2}score and nystagmus scheme,-high blood pressure was considered score; the Dix-Hallpike test; and the head impulse, nystagmus, and test of skew examination.[15]

Consistent with the literature, our study also identified neurologic deficits, nausea and vomiting, cancer history, and the presence of nystagmus as risk factors for abnormal image findings. We also found that having hypertension and symptoms of headache/heavy headedness could be used to predict patients needing brain CT or MRI. In patients without loss of consciousness and neurologic deficits, those

with hypertension presenting with nausea/vomiting or those with cancer and headache/heavy headedness were more likely to need imaging than those having single risk factors. In a recent study by Bi and Cao (2022), which proposed a new nomogram-based online service tool that outperformed the score based on five parameters Age, Blood pressure, Clinical features, Duration of symptoms, and presence of Diabetes (ABCD^2) score and nystagmus scheme, high blood pressure was considered among the three most important factors (together with sex and the finger-to-nose test) for predicting stroke detectable by CT or MRI in ED patients with acute dizziness.[16]

A variety of diagnostic index tests—including the head impulse, nystagmus, and test of skew examination (HINTS), ABCD^2, posterior circulation infarct score (PCI), and SponTAneous and positional nystagmus, the evaluation of the Nystagmus Direction, the head impulse test, and the evaluation of equilibrium (standiNG)—have been proposed for the diagnosis of acute vestibular disorders.[17] Machine learning techniques have also been adopted to aid in diagnosis of vertigo and dizziness.[18] Using extensive data mining of examination and demographic data of patients with balance disorders, investigators have developed diagnostic decision support systems that strongly recommend neuroimaging for the diagnosis of vestibular paroxysmia, but not for the other balance disorders investigated.[19] More recently, a Catboost model considering nonwhirling type dizziness, male sex, older age, and previous stroke as risk factors was established, demonstrating an AUC of 0.74 in diagnosing central dizziness in patients receiving diffusion-weighted imaging.[20] However, many of these algorithms were designed to facilitate the differentiation of vestibular causes of dizziness rather than improving the diagnostic yield of neuroimaging, and they usually require a range of bedside examinations, neurophysical examinations, and sometimes also laboratory measurements. Our study used common comorbidities, presenting symptoms, and past medical history to identify risk factors for abnormal imaging findings among patients with dizziness in Japan.

This study has limitations, including its single-center retrospective design and the potential for patient selection bias arising from the use of the radiology reporting system. Patients with dizziness complaints whose referring physicians did not order imaging tests were not available in the radiology reporting system. The radiology reporting system also did not have records on the primary diagnosis, duration of dizziness, and laboratory results, thus details of some of the important clinical factors, for example,

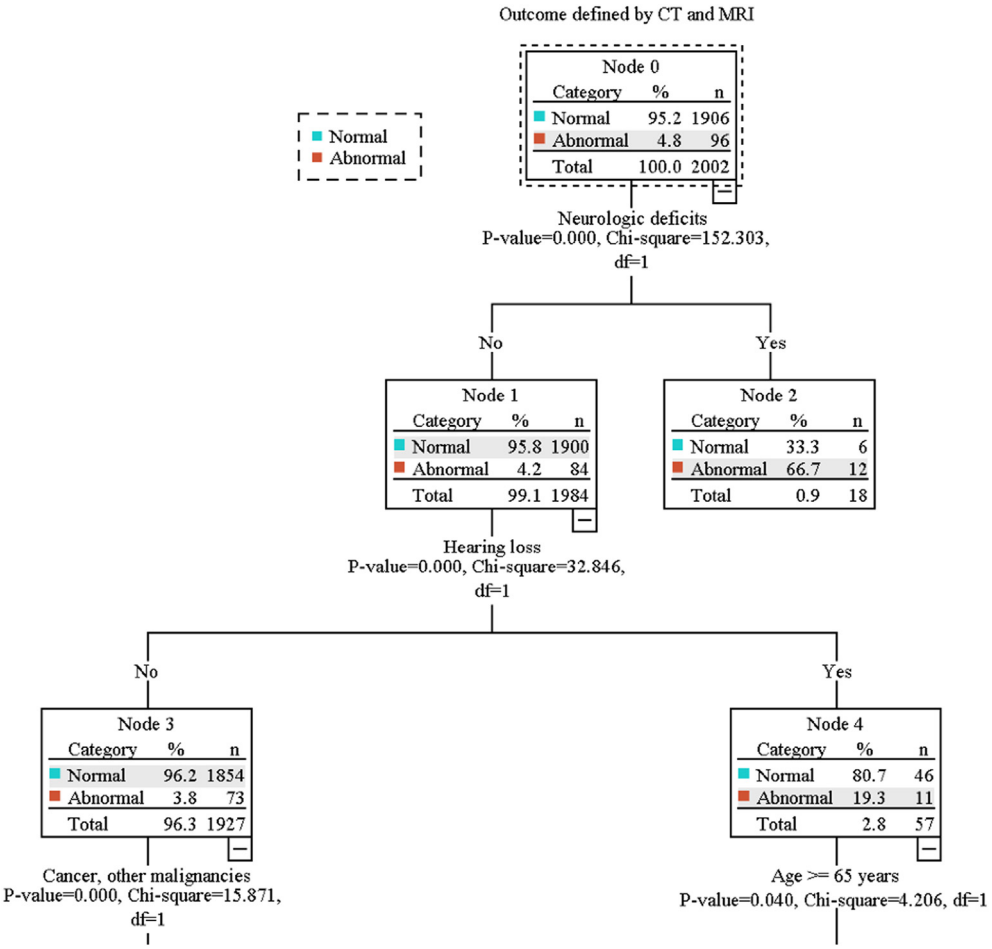

Figure 3 The Chi-square automatic interaction detection (CHAID) decision tree was used to classify subjects by the presence or absence of abnormal imaging findings. Note: Due to space limitations, the figure was split into part a and part b, the two parts belong to the same decision tree.

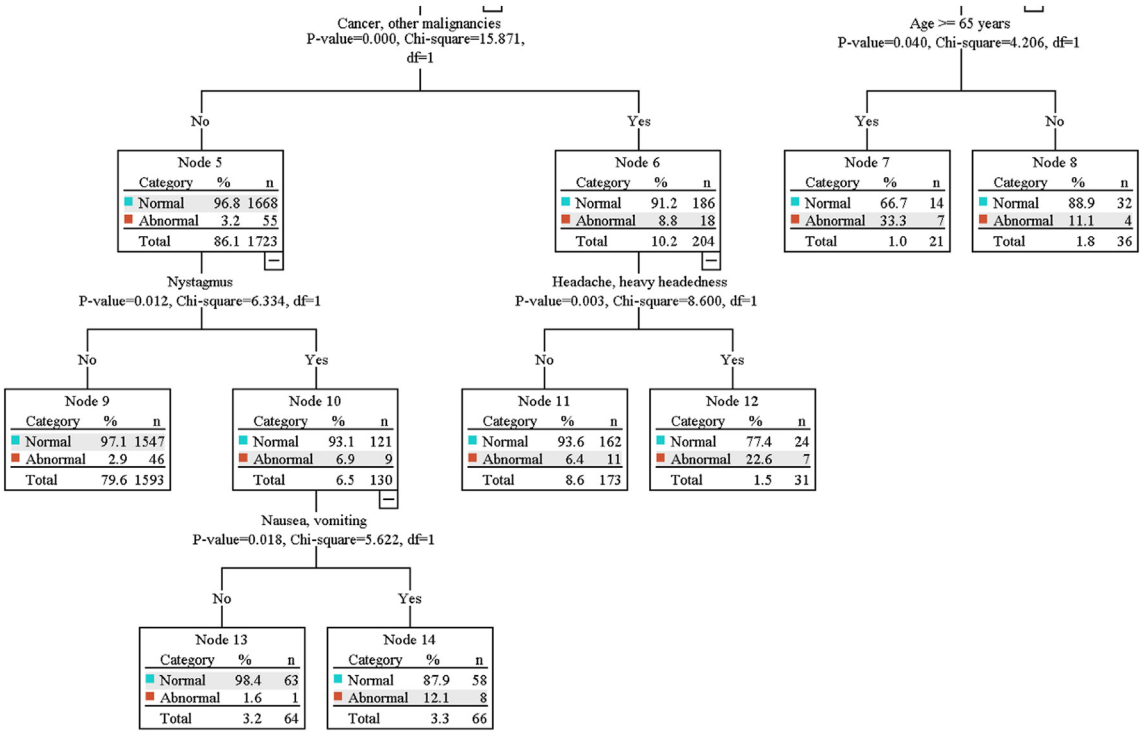

Figure 3 (*continued*).

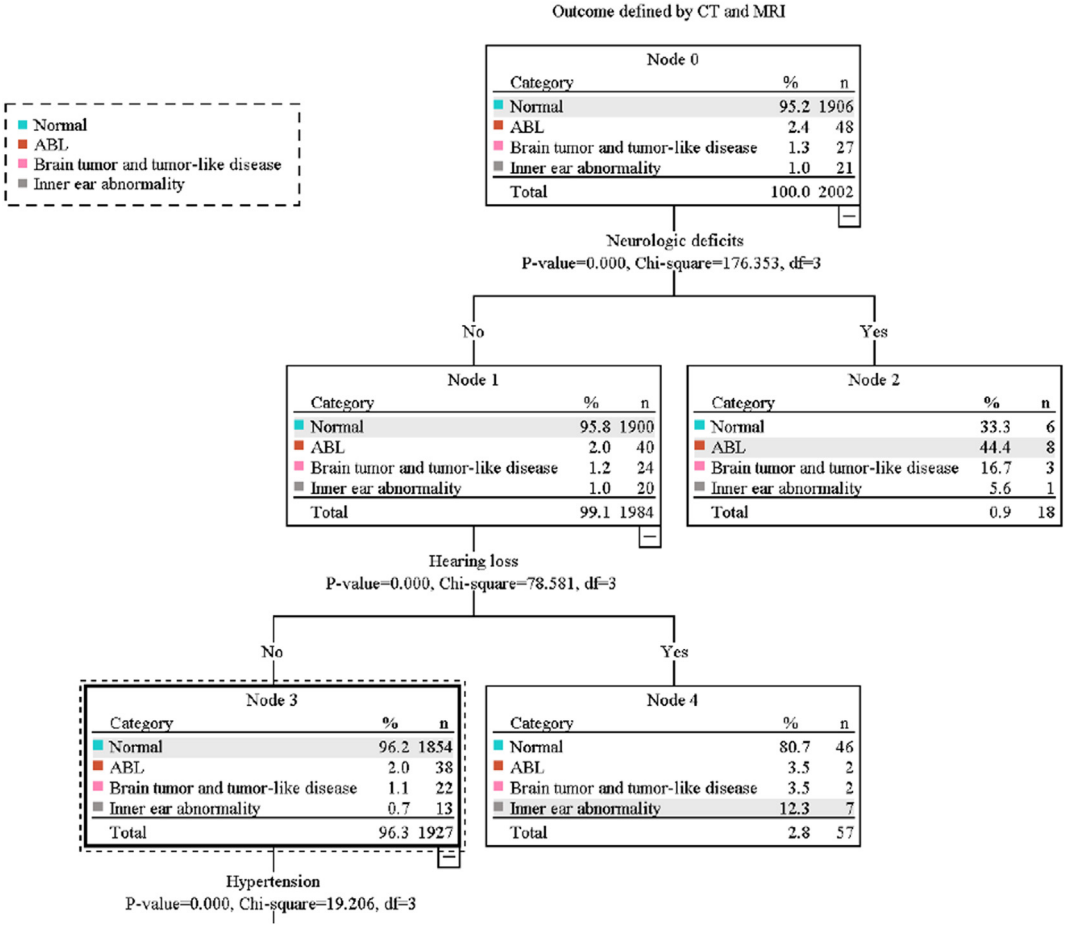

Figure 4 The Chi-square automatic interaction detection (CHAID) decision tree was used to classify subjects with four imaging outcomes (normal, acute brain lesions [ABL], brain-tumor or tumor-like disease, and inner ear abnormality). Note: Due to space limitation, the figure was split in to part a and part b, the two parts belong to the same decision tree.

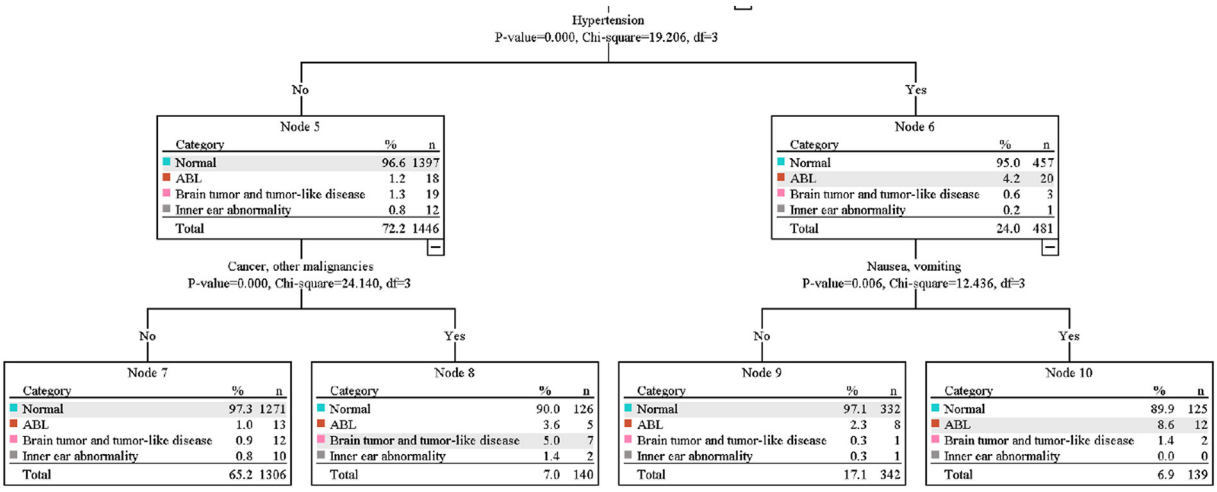

Figure 4 (*continued*).

differentiating stroke with or without large vessel occlusion were not available for investigation in this study. Additionally, only the most recent retrievable imaging results were analyzed. However, the impact on results was likely minimal, as only four patients had abnormal findings on their initial imaging and normal findings on subsequent scans. These cases included two acute cerebral infarctions (MRI first by CT second) internal auditory canal tumors (detectable primarily by MRI), and a stable brain tumor case (considered “normal,” meaning no additional abnormality in subsequent scans). Furthermore, this study focused on imaging findings rather than the final diagnosis, leaving the possibility of neuroimaging false negatives and that ”no abnormality” should only be regarded as no lesion detectable by CT and/or MRI. Future longitudinal studies utilizing the radiology reporting system and hospital electronic medical records are needed to understand how these clinical factors improve the diagnostic yield as well as the risk threshold and cost-effectiveness in emergent settings.

Conclusion

This study attempted to develop a medical history and symptom-based algorithm to support clinical decision-making in patients with dizziness complaints. Our study found neurologic deficits as a significant risk factor for abnormal imaging in dizziness patients. Furthermore, hypertension or cancer with specific symptoms like headache, nausea, or nystagmus also increased the likelihood of abnormal CT/MRI results. Prioritizing brain scans for these individuals could improve diagnostic yield for dizziness. To validate these findings, further investigation through longitudinal studies is necessary.

Ethical

The Juntendo University hospital institutional review board approved the study protocol (No: E22-0243). Patient informed consent was waived by Juntendo University hospital institutional review board for this retrospective study, and the investigation adhered to the Declaration of Helsinki principles.

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Author contribution

1 guarantor of integrity of the entire study: RK.
2 study concepts and design: NS and RK.
3 literature research: NS, 4 clinical studies: NS.
5 experimental studies/data analysis: TH.
6 statistical analysis: TH.
7 manuscript preparation: NS.
8 manuscript editing: TH, RK.

All authors contributed to project administration and approved the final manuscript.

Conflict of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ryohei Kuwatsuru reports financial support was provided by Shin Nippon Biomedical Laboratories Ltd. Takahiro Hirano reports statistical analysis was provided by Clinical Study Support, Inc. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data generated or analyzed during the study are included in the published paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crad.2024.08.003.

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