Original Article

Magnetic resonance (MR) evaluation of deep venous thrombosis of 338 discharged viral pneumonia patients

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Background: Viral pneumonia (VP) often leads to the development of deep vein thrombosis (DVT) in hospitalized patients. The aim of the study was to investigate the incidence of DVT in discharged patients with VP, and whether new and old DVT differ in transverse relaxation time.

Methods: In this prospective cohort study in Wuhan, China, 338 consecutive discharged VP patients from February 2021 to March 2023 who underwent T2 weighted Sampling Perfection with Application Optimized Contrast Evolution (SPACE) were recruited to detect DVT. T2 mapping and T2* mapping were performed for the patients with DVT detected by magnetic resonance imaging (MRI). The minimum, maximum, mean of T2 time and T2* time of DVT were recorded as T2min, T2max, T2mean, T2*min, T2*max, and T2*mean, respectively. Clinical data and laboratory findings were compared between new and old DVT cases, which were defined based on the examination results before and after discharge. A Mann-Whitney test was used to compare transverse relaxation time parameters between new and old DVT.

Results: Twelve percent of VP patients (40/338) developed new DVT after discharge. Thirty-three out of 104 DVTs did not resolve after discharge. Compared with patients with new DVT, patients with old DVT were older (67 *vs.* 59 years, P=0.003); and had a higher proportion of bedridden time >72 hours (72.7% *vs.* 37.0%, P<0.001). Patients with old DVT had a lower lymphocyte count (0.67×10^9/L *vs.* 0.97×10^9/L, P=0.01), higher C-reactive protein (59 *vs.* 35 mg/L, P=0.019), and higher levels of D-dimer (6.7 *vs.* 0.9 μg/mL, P<0.001) than patients with new DVT. Patients with old DVT received more invasive mechanical ventilation (30.3% *vs.* 7.4%, P<0.001) and had a higher proportion of acute respiratory distress syndrome (75.8% *vs.* 51.9%, P<0.001), and a higher proportion of cardiac injury (39.4% *vs.* 14.8%, P=0.033) than patients with new DVT. T2min, T2max, T2mean, and T2*max of new DVT were significantly greater than old DVT (17.6±10.4 *vs.* 13.2±5.9 ms, 94.9±44.9 *vs.* 42.3±23.6 ms, 46.8±24.0 *vs.* 25.0±12.6 ms, 22.5±12.4 *vs.* 10.7±3.5 ms, P<0.05 for all). There was no significant difference in T2*min or T2*mean between new and old DVT (3.2±0.4 *vs.* 3.1±0.4 ms, 8.2±4.9 *vs.* 5.5±1.5 ms, P>0.05 for both).

Conclusions: T2 weighted SPACE magnetic resonance (MR) is valuable in the follow-up of thrombosis of discharged VP patients. T2 mapping distinguishes between new and old DVT.

Keywords: Deep venous thrombus; methemoglobin; magnetic resonance (MR); transverse relaxation time

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Introduction

Viral pneumonia (VP) is well-established to induce a hypercoagulable state, often leading to the development of deep vein thrombosis (DVT) in hospitalized patients (1-5). Many cases of DVT have been identified in VP patients during hospitalization, with some cases persisting after discharge (referred to as old DVT). Additionally, some VP patients may develop new DVT after discharge. Distinguishing between old and new DVT holds significant clinical importance, potentially impacting treatment decisions. Therefore, it is crucial to determine whether thrombosis resolves after discharge, a task facilitated by follow-up examinations.

Currently, ultrasound is the primary modality for evaluating lower extremity DVT due to its accessibility and cost-effectiveness. However, magnetic resonance imaging (MRI) serves as an alternative to ultrasound and has been reported to be highly accurate in detecting DVT (6). MRI offers advantages over ultrasound, including the ability to utilize multiple sequences (such as T1 mapping, T2 mapping, diffusion-weighted imaging), providing additional parameters (such as relaxation time), some of which are closely associated with thrombosis age (7).

While MRI techniques have been explored in a limited number of studies for assessing thrombus age (8,9), there is a gap in the literature regarding whether there are differences in T2 relaxation time between new and old DVT. Wu *et al.* demonstrated that T1 mapping and diffusion-weighted MRI can aid in determining thrombus age, but the specific role of T2 relaxation time in distinguishing between new and old DVT remains unexplored (10,11). The T2 value mainly reflects the spin relaxation time of the organization in a uniform magnetic field state. This parameter is fixed and not affected by the non-uniformity of the external magnetic field. The T2* value refers to the fact that in actual MRI, due to factors such as magnetic field non-uniformity and gradient magnetic field, the actual transverse relaxation time is shorter than the inherent T2 time of the tissue. The T2* value is not only affected by the spin interaction, but also by the non-uniformity of the external magnetic field, so it is not a fixed value, but varies with the uniformity of the main magnetic field. The influencing factors of transverse relaxation time mainly include internal and external factors. The larger the molecular size, the smaller T2. The tighter the molecular binding, the smaller T2. The transverse relaxation time of thrombosis is of importance, especially in the determination of thrombus age, since microstructure, water content, density, molecular movement speed, and uniformity of the magnetic field all vary with time. Therefore, our study aims to utilize MRI for the follow-up of DVT in discharged VP patients and investigate the following:

(I) The proportion of DVT resolving after discharge.
(II) The proportion of patients developing new DVT post-discharge.
(III) Whether new and old DVT exhibit differences in T2 relaxation time.

We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-23-1607/rc).

Methods

Patients

This prospective cohort study was conducted in accordance with the Declaration of Helsinki (as revised in 2013), with approval from the Ethics Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China (No. TJ-IRB20230937). Informed consent was obtained from each patient prior to inclusion. The standard deviation of T2 relaxation time of thrombus was about 20ms, with an expected error not exceeding 6. Considering 10% loss to follow-up, using PASS software (version: 15.0), the study was conducted on 60 individuals.

We reviewed electronic medical records of VP patients

discharged from our center between February 2021 and March 2023. Patients who had undergone lower extremity ultrasound to screen for DVT were contacted by telephone and offered free lower extremity examinations for thrombosis follow-up. While both ultrasound and MRI are accurate in detecting thrombosis, we opted for MRI follow-up because it allows for the assessment of transverse relaxation time, which ultrasound cannot provide. Standard lower extremity deep venous ultrasound examinations (compression and color Doppler analysis) were performed during hospitalization, while follow-up MR was conducted after discharge.

MR follow-up was not performed for patients with contraindications to MR examinations, such as claustrophobia. Cases without DVT on follow-up MR were excluded from further analysis, while those with DVT underwent additional investigation using T2 mapping and T2* mapping to confirm thrombosis presence and measure its transverse relaxation time.

In this study, new and old DVT were defined by comparing the findings of initial ultrasound and follow-up MR. Cases with thrombosis identified only on follow-up MR were classified as new DVT, whereas those identified on both initial ultrasound and follow-up MR were classified as old DVT.

Clinical data during hospitalization, including age, gender, symptoms, and laboratory findings, were recorded for both new and old DVT cases. The study did not investigate the treatment of DVT.

MR examinations

All MR examinations were conducted using a 3T whole-body scanner (Magnetom Skyra, Siemens Healthcare, Erlangen, Germany). Patients were placed in a supine position, feet-first, and both the 18-element body coil and 36-element dedicated peripheral coil were utilized to cover the entire lower extremity.

A fast-view scout with a 1,300 mm × 400 mm field of view (FOV) was initially performed to localize the entire extremity in coronal, sagittal, and transverse planes, taking approximately 22 seconds. Subsequently, a T2-weighted three-dimensional (3D) Sampling Perfection with Application optimized Contrast Evolution (SPACE) sequence was executed in the coronal plane using the following parameters: repetition time (TR)/echo time (TE), 3,000/100 ms; matrix size, 320; FOV, 44 cm; slice thickness, 3 mm; echo train length, 120; phase direction, head-foot; phase oversampling, 80%; slice number, 50–60. This sequence provided intrinsically high signal intensity for deep veins, while thrombi generally exhibited low signal intensity (likely due to low water content). The T2 SPACE sequence was performed in three continuous stations from foot to head: calf, thigh, and pelvis, with a 5mm FOV overlap between neighboring stations. The total acquisition time for the 3-station SPACE was 12–15 minutes.

Following this, T2 mapping and T2* mapping were conducted in the transverse plane, covering the central segment of DVT. The main parameters for T2 mapping were as follows: TR =1,140 ms; TE =13.8, 27.6, 41.4, 55.2, 69.0 ms; matrix size, 384×384; FOV, 20 cm × 20 cm or greater to fit leg size; slice thickness, 3 mm; slice number, 12–20; data acquisition time, 3–5 minutes. For T2* mapping, the main parameters were: TR =445 ms; TE =3.60, 9.62, 15.64, 21.66, 27.68 ms; matrix size, 384×384; FOV, 20 cm × 20 cm or greater to fit leg size; slice thickness, 3 mm; slice number, 12–20; data acquisition time, 2–4 minutes.

Data analysis

T2 maps and T2* maps were automatically generated by the scanner. Two radiologists, each with 10 and 11 years of experience in imaging diagnosis of peripheral vascular diseases, were blinded to clinical data. They independently measured the T2 time and T2* time of DVT by delineating a region of interest (ROI) on the T2 map and T2* map, respectively. Circular ROIs were drawn at the site of thrombosis on five consecutive slices. The diameter of the ROI was slightly shorter than that of the thrombosis to avoid including its border. For each ROI, the mean value, as well as the minimum and maximum values, were recorded.

The maximum, minimum, and mean T2 time for a DVT were denoted as T2max, T2min, and T2mean, respectively. Similarly, the maximum, minimum, and mean T2* time for a DVT were denoted as T2*max, T2*min, and T2*mean, respectively. Thus, a total of six parameters were obtained for each DVT in the study.

Statistical analysis

All statistical analyses were performed using SPSS (version 22.0, IBM, NY, USA). Continuous variables were expressed as mean ± standard deviation. Categorical variables were expressed as percentages [n (%)]. The normality of continuous variables was confirmed with Shapiro-Wilk

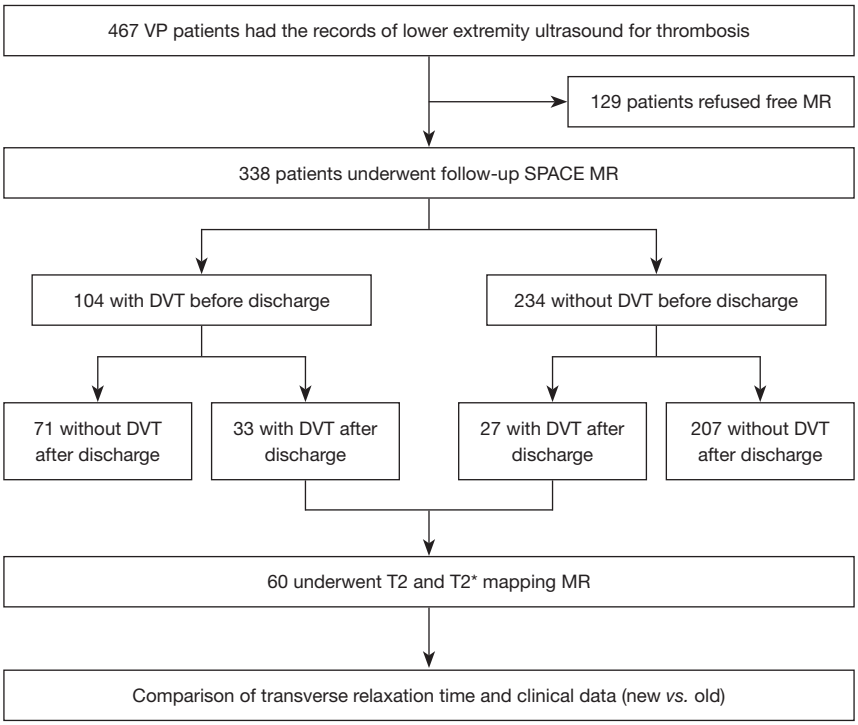

Figure 1 The flowchart of patient selection for T2 mapping MR. VP, viral pneumonia; MR, magnetic resonance; SPACE, Sampling Perfection with Application Optimized Contrast Evolution; DVT, deep vein thrombosis.

tests, and the homogeneity of variance was evaluated using Levene's test. We assessed differences between new and old DVT cases using the two-sample *t*-test for normally distributed data or the Mann-Whitney U test for non-normally distributed continuous variables. Categorical variables were analyzed using the Chi-squared test or Fisher's exact test. Correlations among normally distributed continuous data were analyzed using Pearson's correlation coefficient and simple linear regression. Non-normal continuous data and categorical variables were evaluated using Spearman's correlation and the Chi-squared test. The intra-class correlation coefficient (ICC) was calculated to determine the inter-reader reproducibility in the measurement of T2 time and T2* time parameters (12). An ICC greater than 0.7 was considered indicative of excellent inter-reader reproducibility, while an ICC less than 0.4 indicated poor reproducibility. ICC values between 0.4 and 0.7 were considered acceptable. Statistical significance was set at P values less than 0.05. All statistical tests were two-sided.

Results

We reviewed the electronic medical records of 523 VP patients discharged from our center between February 2021 and March 2023. Among them, 467 underwent lower extremity ultrasound for DVT screening. DVT was identified in 113 out of 467 patients (24%) by ultrasound, while it was not observed in the remaining 354 patients. We attempted to contact all 113 patients with ultrasound-confirmed DVT, as well as the 354 patients without DVT, offering free follow-up MR for study purposes. At last, 338 patients were recruited in the next study, 129 patients were not recall or refusing to study.

A total of 338 patients (104 with DVT before discharge, 234 without DVT before discharge) underwent follow-up MRI. The follow-up SPACE MR identified DVT in 60 out of 338 cases (18%). T2 mapping and T2* mapping were performed for these 60 cases. *Figure 1* presents the flowchart of patient selection.

Among the 338 participants, 104 had DVT before discharge, with 33 out of 104 DVT (32%) still existing in the follow-up MR, while the remaining 71 resolved. Among the 234 participants without DVT before discharge, new DVT was identified in 27 cases (12%) during the follow-up MR, with the remaining 207 still free of DVT. Thus, the follow-up MR identified a total of 33 old DVT and 27

new DVT.

Tables 1,2 compare new and old DVT cases regarding clinical data. Laboratory findings before discharge were compared because follow-up laboratory tests were not performed for participants. Patients with old DVT were older, had a higher proportion of bedridden time >72 hours, lower lymphocyte counts, higher inflammation-related indices (C-reactive protein and procalcitonin), and higher D-dimer levels compared to patients with new DVT (P<0.05 for all comparisons). Additionally, patients with old DVT received more high-flow oxygen, invasive mechanical ventilation, had a higher proportion of acute respiratory distress syndrome, cardiac injury, and intensive care unit (ICU) admissions compared to patients with new DVT (P<0.05 for all comparisons).

We measured the transverse relaxation time for 60 DVT (27 new and 33 old) using T2 mapping and T2* mapping. B1 inhomogeneity artifacts were observed in 14 out of 60 cases but without substantial image quality degradation. Arterial pulsation artifacts were observed in 6 out of 60 cases, with ROI assessment still possible. The ICC ranged from 0.81 to 0.88 for T2 time and T2* time parameters.

The mean T2 time of new DVT was significantly greater than that of old DVT (46.8±24.0 *vs.* 25.0±12.6 ms, P<0.05). T2min and T2max were significantly greater in new DVT than in old DVT (17.6±10.4 *vs.* 13.2±5.9 ms, 94.9±44.9 *vs.* 42.3±23.6 ms, P<0.05). T2*max was significantly greater in new DVT than in old DVT (22.5±12.4 *vs.* 10.7±3.5 ms, P<0.05, *Table 3*). However, there was no significant difference in T2*min or T2*mean between new and old DVT (P>0.05, *Table 3*).

Figure 2 shows that the signal intensity of DVT decreased with increasing TE in the T2 and T2* mapping. *Figure 3* displays a typical DVT that was substantially different from adjacent muscles on T2 map or T2* map, and ROI assessment of the DVT. *Figure 4* shows the comparisons of T2 and T2* time parameters between new and old DVT, with significant difference in all T2 time parameters. *Figure 5* is a case of comparison between new and old DVT, showing significant difference in T2max and similarity in T2*min.

Discussion

We used MR for follow-up of thrombosis in discharged VP patients. The most important findings were: (I) 32% of thrombosis did not resolve after discharge; (II) 12% of VP patients developed new DVT after discharge; (III) new and old DVT differed in T2 time.

There are plenty of publications investigating thrombosis in VP patients. However, data regarding the follow-up of thrombosis of discharged VP patients are still lacking. Few publications reported that there was a proportion of patients with continuing DVT after discharge or a proportion of VP patients developing new DVT after discharge. We think that it is necessary to reveal the evolution of thrombosis in discharged VP patients, which is important for health management.

We found that about one-third of DVTs did not resolve in the follow-up MR, which should be considered as

Table 1 The comparison of clinical data between new and old DVT cases

Characteristic	Total (n=60)	Old DVT (n=33)	New DVT (n=27)	P value
Age (years)	63±14	67±12	59±16	0.003
Male	31 (51.7)	18 (54.5)	13 (48.1)	0.635
Body mass index (kg/m^2)	23.5±3.0	23.5±2.9	23.5±3.1	0.941
Onset of symptoms				
Fever	53 (88.3)	29 (87.9)	24 (88.9)	0.926
Dry cough	42 (70.0)	22 (66.7)	20 (74.1)	0.435
Fatigue	41 (68.3)	24 (72.7)	17 (63.0)	0.203
Dyspnea	36 (60.0)	20 (60.6)	16 (59.3)	0.684
Diarrhea	10 (16.7)	7 (21.2)	3 (11.1)	0.226
Headache	4 (6.7)	2 (6.1)	2 (7.4)	0.235

Table 1 (*continued*)

Table 1 (*continued*)

Characteristic	Total (n=60)	Old DVT (n=33)	New DVT (n=27)	P value
Vital signs				
Temperature (℃)	38.5±1.2	38.6±1.3	38.4±1.1	0.096
Respiratory rate (breaths/min)	25±5	25±5	24±4	0.661
Heart rate (beats/min)	89±12	89±12	88±11	0.884
Systolic blood pressure (mm Hg)	131±11	130±10	132±12	0.616
Diastolic blood pressure (mm Hg)	81±9	80±8	82±10	0.015
Comorbidities				
Current smoker	5 (8.3)	3 (9.1)	2 (7.4)	0.793
Hypertension	23 (38.3)	14 (42.4)	9 (33.3)	0.539
Diabetes mellitus	10 (16.7)	6 (18.2)	4 (14.8)	0.691
Coronary artery disease	8 (13.3)	5 (15.2)	3 (11.1)	0.650
Cerebral infarction	2 (3.3)	1 (3.0)	1 (3.7)	1.000
Malignancy	4 (6.7)	2 (6.1)	2 (7.4)	1.000
Edema of lower extremity	8 (13.3)	5 (15.2)	3 (11.1)	0.576
Leg pain	2 (3.3)	2 (6.1)	0	0.038
Bedridden time (h)				<0.001
>72	34 (56.7)	24 (72.7)	10 (37.0)	
≤72	26 (43.3)	9 (27.3)	17 (63.0)	
Disease severity status				0.341
General	6 (10.0)	3 (9.1)	3 (11.1)	
Severe	10 (16.7)	5 (15.2)	5 (18.5)	
Critical	44 (73.3)	25 (75.8)	19 (70.4)	
Symptom onset to hospital admission (days)	11±6	10±5	12±6	0.123
Admission to intensive care unit	7 (11.7)	6 (18.2)	1 (3.7)	0.006
High-flow oxygen	34 (56.7)	23 (69.7)	11 (40.7)	0.004
Invasive mechanical ventilation	12 (20.0)	10 (30.3)	2 (7.4)	<0.001
Noninvasive mechanical ventilation	7 (11.7)	4 (12.1)	3 (11.1)	0.944
Complications				
Acute respiratory distress syndrome	39 (65.0)	25 (75.8)	14 (51.9)	<0.001
Acute kidney injury	10 (16.7)	6 (18.2)	4 (14.8)	0.411
Cardiac injury	17 (28.3)	13 (39.4)	4 (14.8)	0.033
Coagulation dysfunction	22 (36.7)	14 (42.4)	8 (29.6)	0.096

Continuous data are presented as means ± SDs. Categorical data are numerators; data in parentheses are percentages. DVT, deep venous thrombosis; SD, standard deviation.

Table 2 The comparison of laboratory findings between new and old DVT cases

Characteristic	Total (n=60)	Old DVT (n=33)	New DVT (n=27)	P value
Hematologic and infection-related indices				
White blood cells (×10^9/L)	7.6 (5.2, 10.6)	8.5 (6.3, 10.8)	6.5 (4.9, 9.4)	0.001
Lymphocytes (×10^9/L)	0.81 (0.52, 1.28)	0.67 (0.48, 1.13)	0.97 (0.67, 1.36)	0.010
Neutrophils (×10^9/L)	6.2 (3.9, 9.4)	7.1 (5.6, 9.9)	4.5 (3.7, 7.8)	<0.001
Neutrophils/lymphocytes	7.3 (3.7, 14.4)	10.4 (5.5, 16.7)	5.0 (3.1, 11.3)	0.001
Platelets (×10^9/L)	211.0 (142.3, 277.5)	175.5 (130.3, 279.0)	219.0 (160.5, 275.8)	0.093
Hemoglobin (g/L)	118.4±30.0	117.4±17.7	119.3±21.8	0.683
C-reactive protein (mg/L)	45.1 (10.2, 85.3)	59.0 (22.9, 103.8)	35.0 (8.5, 66.7)	0.019
Procalcitonin (ng/mL)	0.12 (0.07, 0.28)	0.19 (0.11, 0.39)	0.08 (0.06, 0.20)	< 0.001
Coagulation function index				
D-dimer (μg/mL)	2.8 (0.7, 7.9)	6.7 (2.6, 8.1)	0.9 (0.5, 3.4)	<0.001
Prothrombin time (s)	13.7 (12.7, 14.9)	14.3 (13.4, 15.5)	12.9 (12.4, 14.0)	<0.001
Activated partial thromboplastin time (s)	34.9 (30.9, 39.4)	37.2 (32.2, 42.9)	35.4 (31.2, 39.0)	0.221
Liver function index				
Total protein (g/L)	62.0±7.9	61.9±7.8	62.1±8.0	0.841
Albumin (g/L)	28.6±5.4	27.8±5.3	29.1±5.4	0.180
Aspartate aminotransferase (U/L)	32.0 (23.5, 32.0)	34.0 (26.5, 51.8)	28.0 (21.5, 37.5)	0.009
Alanine aminotransferase (U/L)	35.0 (25.0, 55.0)	40.0 (30.0, 65.0)	31.0 (20.5, 46.0)	0.006
Total bilirubin (μmol/L)	13.1 (10.1, 17.8)	14.8 (10.2, 18.5)	12.5 (9.4, 16.7)	0.215
Direct bilirubin (μmol/L)	4.3 (2.9, 6.2)	5.6 (4.2, 7.6)	3.6 (2.7, 5.4)	0.018
Lactic dehydrogenase (U/L)	315.0 (206.0, 477.5)	399.0 (265.5, 597.3)	247.0 (190.0, 386.0)	<0.001
Kidney function index				
Blood urea nitrogen (mmol/L)	5.8 (4.1, 9.3)	7.7 (4.4, 10.4)	5.1 (3.7, 7.1)	0.003
Serum creatinine (μmol/L)	62.1 (53.0, 78.7)	62.4 (53.5, 78.4)	61.8 (52.0, 79.2)	0.635
K+ (mmol/L)	4.0±0.5	4.0±0.6	3.9±0.5	0.619
Na+ (mmol/L)	139.5 (136.8, 142.5)	139.3 (137.2, 143.2)	139.7 (136.5, 142.1)	0.637
Cardiac injury index				
High-sensitivity troponin I (ng/L)	5.6 (2.3, 44.2)	15.0 (4.1, 80.6)	3.4 (1.6, 13.7)	0.024
Creatinine kinase-myocardial band (U/L)	10.1 (4.1, 15.1)	11.1 (6.9, 16.1)	9.1 (0.9, 13.1)	0.027
B-type natriuretic peptide (pg/mL)	50.5 (24.6, 99.5)	66.4 (27.8, 123.4)	49.6 (21.5,79.8)	0.088

Continuous data are presented as means ± SDs or median (upper quartile, lower quartile). DVT, deep venous thrombosis; SD, standard deviation.

chronic thrombosis. Many discharged VP patients might suffer from chronic DVT, as the number of discharged VP patients is astronomical. We found that about one-tenth of discharged VP patients developed new DVT after discharge. The mechanism behind this phenomenon is worth further investigation. One possible explanation is that the hypercoagulate state caused by VP continues after discharge, but anticoagulant thromboprophylaxis

discontinues in some discharged cases. The in-hospital incidence of thrombosis was 24% for VP patients undergoing ultrasound in the study, which seemed rather high.

T2 SPACE MR was used instead of ultrasound to detect thrombosis in the follow-up. The two methods have been reported to have similar diagnostic accuracy. MR is generally less available than ultrasound. However, in the author's center, the availability of MR scanners is similar to that of ultrasound. We could offer free MR to participants. By using long-echo-train T2 SPACE, the acquisition time for imaging the whole lower extremity deep veins was less than 15 minutes, which was also similar to that of ultrasound. However, MR is superior to ultrasound in the aspect of quantitative parameters that reflect the intrinsic characteristics of thrombosis. For example, the transverse relaxation time of thrombosis can be easily obtained with MR, which reflects the water content of DVT to some extent. MR is also less operator-dependent compared to ultrasound. In a word, MR was preferred by us in the study. By using SPACE MR, we successfully identified sixty thromboses.

Table 3 T2/T2* time parameters were compared between new and old DVT using a Mann-Whitney test

Characteristic	ICC	New DVT	Old DVT	P value
T2min	0.85	17.6±10.4	13.2±5.9	0.04
T2max	0.87	94.9±44.9	42.3±23.6	0.002
T2mean	0.88	46.8±24.0	25.0±12.6	0.02
T2*min	0.81	3.2±0.4	3.1±0.4	0.72
T2*max	0.83	22.5±12.4	10.7±3.5	0.03
T2*mean	0.84	8.2±4.9	5.5±1.5	0.08

For T2 and T2* time values, the units are milliseconds. DVT, deep venous thrombus; ICC, intra-class correlation coefficient.

Due to elevated levels of paramagnetic substance and decreased levels of water, thrombosis is substantially different from venous blood on T2/T2* mapping images. It is thus easy to identify DVT from blood with these sequences, which helps confirm thrombosis initially detected with SPACE MR. By measuring T2/T2* time of thrombosis, the diagnosis of thrombosis could be further validated, as DVT transverse relaxation is significantly lower than that of blood. In a word, the combination of SPACE MR and T2/T2* mapping is highly reliable in the detection of DVT.

Many studies have attempted to determine the age of DVT using imaging techniques (13-16). However, there are few studies investigating whether new and old DVT differ in transverse relaxation time. The content of paramagnetic methemoglobin within thrombosis increases with

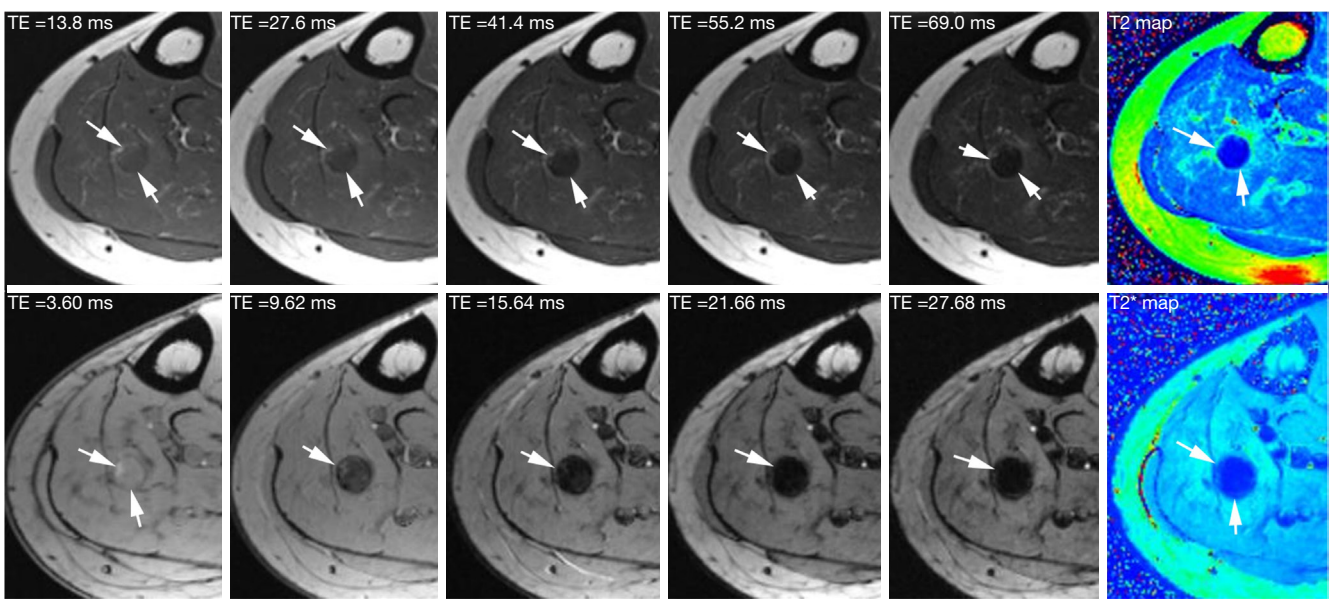

Figure 2 DVT (arrows) shown in T2 mapping (top row) and T2* mapping (bottom row). The signal intensity of DVT decreased with increasing TE. TE, echo time; DVT, deep vein thrombosis.

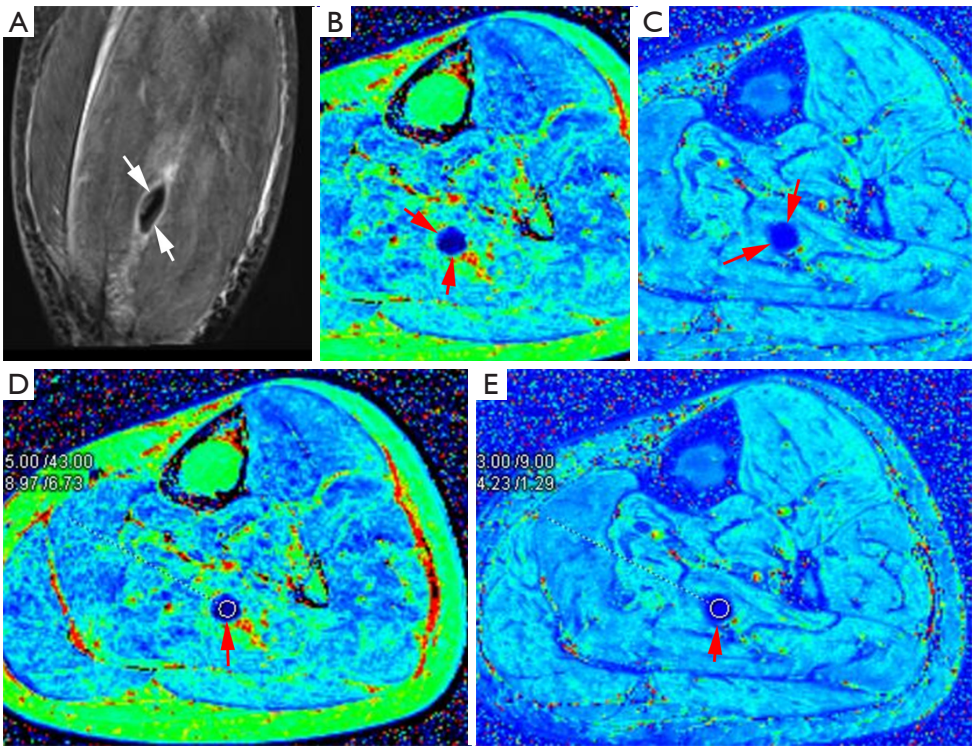

Figure 3 DVT ROI assessment. The DVT was hypointense on FSE image [(A) arrows], and was substantially different from adjacent muscles on T2 map [(B) arrows] or T2* map [(C) arrows]. Circular ROI were drawn at thrombus on T2 map and T2* map [(D) and (E), arrows], with minimum, maximum and mean values obtained. DVT, deep vein thrombosis; ROI, region of interest; FSE, fast spin echo.

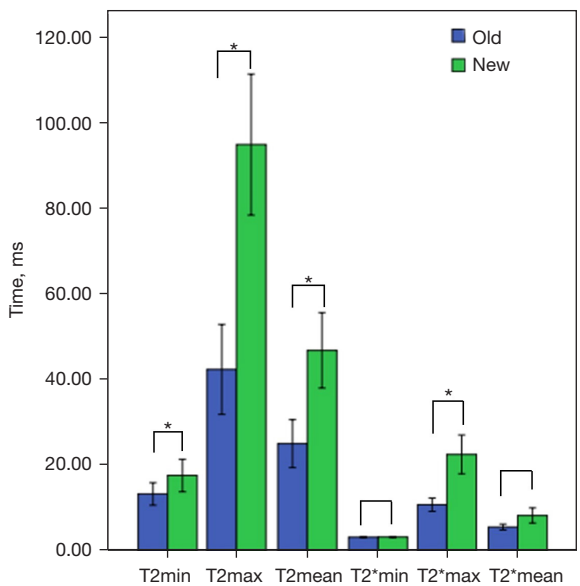

Figure 4 Comparisons of T2 and T2* time parameters between new and old DVT. Overlap of 95% confidence interval could be seen in T2min, but not in T2max. *, statistically significant difference. DVT, deep vein thrombosis.

thrombosis age, peaking at about 7–10 days, then decreases with age (17,18). Methemoglobin shortens the T2 time of DVT to some extent. However, the effect of water on the determination of T2 time is generally greater relative to methemoglobin. It is well-established that water content decreases with thrombus age. Rich-in-water new thrombosis should have a longer T2 time than old thrombus that is poor in water. Our data supported this hypothesis.

T2* time is more influenced by paramagnetic substance compared with T2 time. The effect of methemoglobin for the determination of T2* time is greater relative to water. Either new or old DVT has a moderate content of methemoglobin, which significantly shortens T2* time. Thus, both new and old DVT have low T2* time. Our data supported this hypothesis. It is not surprising that new and old DVT did not differ in mean T2* time in the study. Although new and old DVT differ in water content, they might have similar content of methemoglobin in the study. T2* time differed among voxels, due to the inhomogeneous distribution of water and methemoglobin within thrombosis. The voxel with maximum T2* time must have

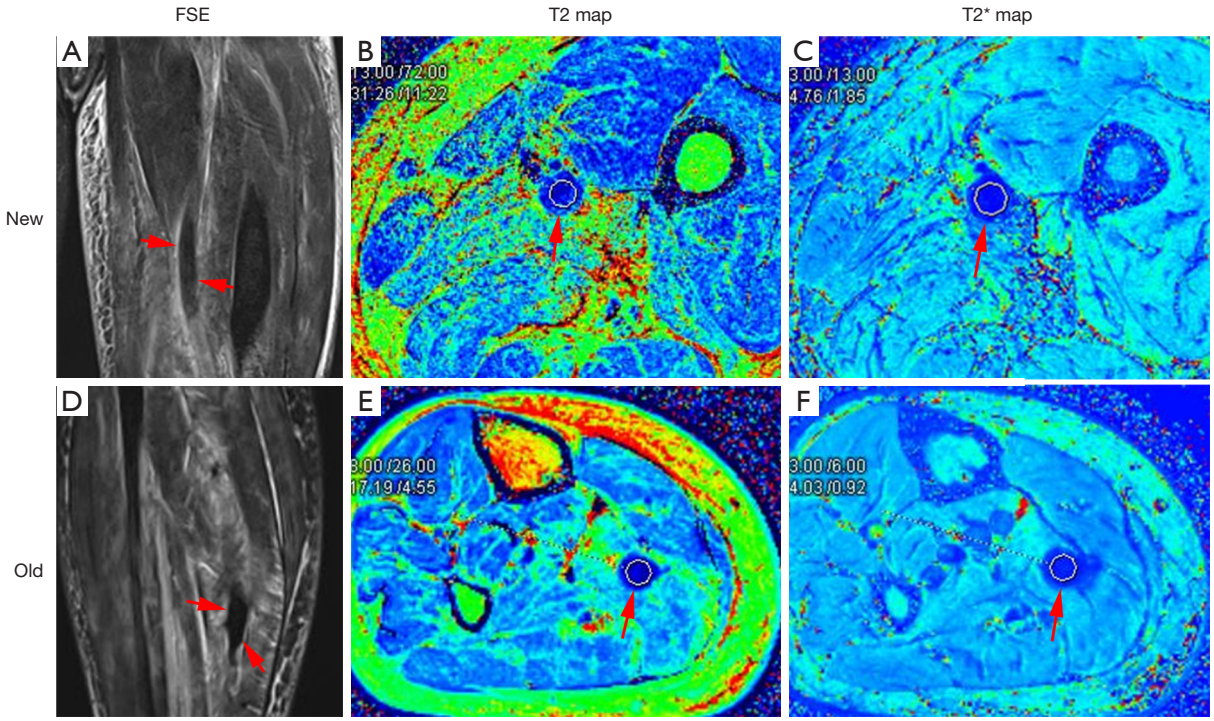

Figure 5 A case of comparison. New (first row) and old DVT (second row) were both hypointense on FSE images (first column, arrows). T2min, T2max, T2mean, T2*min, T2*max, and T2*mean were obtained through ROI assessments. T2mean was 31 ms for new DVT, versus 17 ms for old DVT (see second column). New and old DVT differed greatly in T2max (72 versus 26, see second column). T2*min was the same for the two DVT (see third column). (A) FSE image of new DVT; (B) T2map of new DVT; (C) T2*map of new DVT. (D) FSE image of old DVT; (E) T2map of old DVT; (F) T2*map of old DVT. Arrows pointed to the DVT. DVT, deep vein thrombosis; FSE, fast spin echo.

more water and less methemoglobin compared to other voxels. T2*max is thus less influenced by methemoglobin but more influenced by water. This is why new and old DVT still differed in T2*max.

Based on the comparison of laboratory findings, old DVT cases were in worse conditions in the hospital compared to new DVT cases. Old DVT cases corresponded with the patients having DVT in the hospital, while new DVT cases corresponded with the patients without DVT in the hospital. Thus, VP patients with DVT were in more serious conditions than those without DVT.

There are several limitations in this study. First, this is a single-center study with a moderate sample size. Although we performed MR for more than 300 participants, only 60 DVT cases were collected. Larger-sample, multi-center studies are required to validate our conclusion. Second, ultrasound was not used in the follow-up. We aimed to obtain the transverse relaxation time of thrombosis, so MR was used instead of ultrasound. Ultrasound might identify thrombosis that is missed by MR. Third, thrombectomy was not performed for any patient studied, so DVT could not be pathologically assessed to establish the actual water and methemoglobin content. Thus, the mechanism for transverse relaxation time within a thrombus remains speculative. The microstructural analysis of clots relative to transverse relaxation time is best studied in animal models (19). Fourth, we only performed T2/T2* mapping for the participants but did not use diffusion-weighed MR or T1 mapping in consideration of scanning time. We focused on the difference in transverse relaxation in the study. Fifth, we did not perform follow-up laboratory tests for the participants. We failed in the breakdown of VP (causative virus) in the study because an antibody test was not performed for all patients. Thus, we could not answer whether new and old DVT cases differ in laboratory findings after discharge, which should be investigated in further study.

In conclusion, SPACE MR is valuable in the follow-

up of thrombosis of discharged VP patients. T2 mapping distinguishes between new and old DVT.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-23-1607/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-1607/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This prospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China (No. TJ-IRB20230937). Informed consent was obtained from each patient prior to inclusion in the study.

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