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Acute type B aortic intramural hematoma: the added prognostic value of a follow-up CT

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Abstract

Objectives To investigate prognostic significance of follow-up CT findings for initially medically treated type B aortic intramural hematoma (IMH).

Methods We performed a retrospective pooled analysis of individual patient data, including baseline and follow-up CT characteristics. All enrolled patients were followed up for adverse aorta-related events, defined as a composite of aortic disease–related death and surgical or endovascular aortic repair.

Results A total of 238 patients (73.9% men) were included, with a mean age of 58.1 ± 9.8 years. During follow-up, 83 patients (34.9%) experienced adverse aorta-related events, most of the events (83.1%) occurred within 1 month after follow-up CT imaging ($n = 69$). In the Cox regression model for predicting adverse aorta-related events, baseline maximal aortic diameter (MAD) (HR = 1.05, $p = 0.008$), ulcer-like projection (ULP) (HR = 2.47, $p < 0.001$), changes of maximal hematoma thickness (MHT) (HR = 1.22, $p < 0.001$), newly developed ULP (HR = 4.44, $p < 0.001$), and newly developed pleural effusion (HR = 2.46, $p = 0.002$) were powerful independent predictors. In combined predictive model for 1-month aortic events, baseline MHT ≥ 11.8 mm (OR = 4.39, $p = 0.001$), ULP (OR = 3.98, $p < 0.001$), changes of MHT (OR = 1.46, $p < 0.001$), newly developed ULP (OR = 9.27, $p = 0.002$), and newly developed pleural effusion (OR = 3.45, $p = 0.015$) were independent predictors. Besides, in patients with pleural effusion at baseline, resorption of pleural effusion was associated with adverse aorta-related events (HR = 0.36, $p = 0.027$) and 1-month aortic events (OR = 0.23, $p = 0.026$).

Conclusions Follow-up CT findings provide strong and incremental prognostic information for initially medically treated type B IMH, which are helpful for risk estimates and decisions-making.

Key Points

- *Follow-up CT provides strong and incremental prognostic information for initially medically treated type B aortic intramural hematoma.*
- *Follow-up CT is highly recommended for type B intramural hematoma in patients who did not receive urgent invasive therapy.*
- *Follow-up CT is helpful for risk estimates and decisions-making.*

Keywords Aortic diseases · Hematoma · Prognosis · Computed tomography angiography

Abbreviations

AAS	Acute aortic syndrome
BMI	Body mass index
CI	Confidence interval
CT	Computed tomography
HR	Hazard ratio

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IBP Intramural blood pool
IMH Intramural hematoma
MAD Maximal aortic diameter
MHT Maximal hematoma thickness
OR Odds ratio
ROC Receiver operating characteristic
ULP Ulcer-like projection

Introduction

Acute type B aortic intramural hematoma (IMH) is a unique entity within the spectrum of acute aortic syndrome. It shares similar clinical symptoms and in-hospital mortality risk to those of type B aortic dissection [1–3]. Type B IMHs are more likely to regress than progress; however, a variety of adverse aorta-related events can arise during follow-up like progression to aortic dissection, aneurysm formation, rupture, and other complications [4–6]. Initial medical therapy under careful surveillance is recommended for uncomplicated type B IMH, and repetitive imaging is indicated [3]. It appears that some imaging features including ulcer-like projection (ULP), enlarging aortic diameter, increased hematoma thickness, and ascending aortic involvement are associated with progression to complications [7–13]. Nevertheless, there is still controversy regarding these so-called high-risk imaging characteristics [14–16]. Most studies include relatively small samples, underpowered for confirming correlation between these imaging findings and complications. Besides, follow-up imaging findings should have significant clinical implications in predicting prognosis and subsequent management decisions, and they may have incremental prognostic value for initially medically treated type B IMH; this merits further in-depth analysis in a sizable series of patients.

In the present study, we investigated incremental prognostic value of follow-up CT in patients with initially medically treated type B IMH.

Methods

Study population

This retrospective cohort study was approved by the institutional review board and the need for informed consent was waived. Inclusion criteria included the following: (1) from September 2009 to June 2018, patients who were diagnosed as acute type B aortic IMH by their initial CT examination and (2) patients who received initial medical treatment and were followed up by CT. Exclusion criteria included the following: (1) CT images were not available for analysis and (2) patients who were lost to follow-up.

All enrolled patients received initial medical therapy including pain relief and tight blood pressure control under careful surveillance according to the standard clinical regimen. Follow-up CT imaging was performed during hospitalization within 1 month or after discharge within 6 months. Subsequently, the decision whether to perform endovascular aortic repair or surgery was made by the surgeons according to the evolution of disease and patient's willingness. Timed invasive therapy was performed in the case of disease progression.

Clinical data collection and follow-up

Baseline clinical data about patient characteristics and clinical course were obtained retrospectively from the medical records. Relevant patient information included patient age, sex, body mass index (BMI), cardiovascular risk factors, and therapeutic regimen. Follow-up data (survival information, cause of death, interventions) were collected through clinical visits or telephone contact with the patient or relatives. All reported events were verified by reviewing hospital records or contact with the attending physicians. The endpoints during follow-up were adverse aorta-related events, defined as a composite of aortic disease–related death and surgical or endovascular aortic repair [17]. The follow-up period ended in September 2018, or when the patient died or underwent aortic invasive treatment.

Serial CT scans and image analysis

All the initial CT scans were performed at admission within 2 days of the onset of chest or back pain. MDCT angiography was performed using a variety of scanners across different years including 64-row spiral CT scanner (Light Speed VCT, GE Healthcare), Discovery CT750 HD scanner (GE Healthcare), Revolution CT (GE Healthcare), Brilliance iCT (Philips), and SOMATOM Definition or SOMATOM Definition Flash (Siemens Healthineers). The scan range extended from the level of the thoracic inlet to femoral head. A 120-kV tube potential was used for patients with a BMI > 30 kg/m^2, 100-kV tube potential for BMIs 20–30 kg/m^2, and 80-kV tube potential for BMIs < 20 kg/m^2. X-ray tube current was adjusted individually for each patient, depending on BMI. Contrast-enhanced acquisition was performed with an intravenous bolus injection of iodinated contrast medium (iopromide [Ultravist] 370 mg I/ml, Bayer Healthcare) at a volume of 1 ml/kg body weight with a saline chaser of 40 ml at a rate of 4–5 ml/s. CT images were reconstructed with a section thickness of 0.625 mm. The raw data of the scans were transferred to workstation (Advantage Workstation Ver.4.6, GE Healthcare) for three-dimensional image reconstruction. Median effective radiation dose was 6.1 mSv (range 3.2–15.6 mSv) for the present study.

All the CT images acquired at the time of diagnosis and during follow-up were used for analysis. Presence and location of IMH, presence of special imaging features including ULP, and presence of intramural blood pool (IBP) were identified. Maximal hematoma thickness (MHT) and maximal aortic diameter (MAD) were measured by CT using transverse planes. The MAD was the largest diameter of the outer contour of the affected aorta. Site of maximal aortic diameter and wall thickness was selected by using visual inspection. Measurement of MHT and MAD was expressed in millimeters. Specific interest was taken to evaluate ULP and IBP, which were explicitly distinguished from each other. ULP, also described as focal intimal disruption, is defined as a localized blood-filled pouch protruding into the opacified aortic lumen with an orifice diameter > 3 mm, as previously described [4]. IBP is another type of localized blood-filled pool without obvious communication with the true lumen and may correspond with artery branch ostia, typically with small connection orifices ≤ 3 mm in diameter. An orifice of the pool could also be observed, which is usually as tiny as the diameter of the corresponding branch artery [18]. In addition, the aorta was simply divided into three segments for a simplified evaluation of the longitudinal extent of type B IMH. These three segments were the transverse arch, descending thoracic aorta, and abdominal aorta. Other imaging characteristics such as associated pleural/pericardial effusion as well as presence of aortic aneurysm were also recorded.

The evolution of IMH was assessed by comparing the initial and follow-up CT images. Follow-up CT findings were recorded, including changes of MHT and MAD, newly developed ULP, IBP, aortic aneurysm, dissection, and pericardial and pleural effusion. Besides, resorption of IBP, pericardial effusion, and pleural effusion were also recorded, including incomplete and complete resorption. Two experienced radiologists (with 5 and 6 years of experience in cardiovascular imaging, respectively), who were blinded to the clinical status and unaware of follow-up results, independently evaluated all CT images. A final consensus read was performed to resolve discrepancies between the two observers according to the definitions described above.

Statistical analysis

Statistical analysis was performed with SPSS version 16.0 (SPSS Inc.). Continuous variables were expressed as mean ± SD or median (interquartile range), and categorical variables were expressed as absolute numbers and percentages. Continuous variables that were normally distributed were compared using independent samples *t* test, non-normally distributed variables using the Mann-Whitney *U* test. The χ^2 test or Fisher exact test, as appropriate, was used for categorical variables. The Cox proportional hazard model was applied to identify factors associated with the development of adverse aorta-related events. The Kaplan-Meier method was applied for survival analysis, and log-rank test was performed. Receiver operating characteristic (ROC) analysis was used to define the optimal cutoff values of the MHT and MAD in predicting early (1 month) adverse aorta-related events, defined as that maximizing the sum of sensitivity and specificity. Multivariate logistic regression analysis was used to identify predictors for 1-month adverse aorta-related events. Baseline CT-based model was constructed by using baseline CT-related variables as predictors. Combined model was constructed by using baseline and follow-up CT-related variables. All *p* values were two-sided with a p value < 0.05 considered statistically significant.

Results

Patient characteristics

A total of 275 patients with acute type B aortic IMH received initial medical treatment and follow-up CT. Original CT images were not available for analysis in 15 patients and 22 were lost to follow-up. Consequently, 238 patients were retrospectively enrolled in this study. All enrolled patients received repeated CT examinations; follow-up scans were performed at a median of 13.5 (7.0–46.8) days after the initial CT. Of these patients, 176 (73.9%) were men and 62 (26.1%) were women, with a mean age of 58.1 ± 9.8 years. Mean age of the 176 male patients was lower than that of the 62 female patients (57.4 ± 10.0 vs 60.1 ± 9.1 years, $p = 0.056$). Most patients (89.1%) of the cohort had history of hypertension.

As for CT characteristics, the mean MHT and MAD at baseline were 9.9 ± 2.4 and 40.2 ± 5.5 mm, respectively. Presence of ULP and IBP was detected in 91 (38.2%) and 49 (20.6%) patients at baseline CT imaging, respectively. Median changes of MHT and MAD detected by follow-up CT imaging were − 1.5 (− 4.3 to 0.2) and − 0.1 (− 1.2 to 1.0) mm, respectively. Newly developed ULP and IBP were detected in 16 (6.7%) and 75 (31.5%) patients by follow-up CT imaging, respectively. Clinical and CT characteristics of the full cohort as well as comparisons between patients with and without adverse aorta-related events are shown in Table 1. A representative case of type B IMH evolution detected by repeated CT is shown in Fig. 1.

The Cox regression model for predicting adverse aorta-related events

During a median follow-up time of 543.0 (7.8–1631.8) days, 83 patients (34.9%) experienced adverse aorta-related events, including 76 patients who received aortic invasive treatment and 7 patients who suffered aortic disease–related death. Among the patients who suffered aortic disease–related death,

Table 1 Clinical and CT characteristics

Parameter	Full cohort ($n = 238$)	Adverse aorta-related events		p value
		Yes ($n = 83$)	No ($n = 155$)	
Age (year)	58.1 ± 9.8	59.4 ± 9.4	57.4 ± 10.0	0.130
Male, *n* (%)	176 (73.9)	61 (73.5)	115 (74.2)	0.907
BMI (kg/m^2)	25.6 ± 3.5	25.2 ± 3.5	25.8 ± 3.4	0.196
Hypertension, *n* (%)	212 (89.1)	75 (90.4)	137 (88.4)	0.642
Dyslipidemia, *n* (%)	98 (41.2)	39 (47.0)	59 (38.1)	0.183
Diabetes, *n* (%)	16 (6.7)	2 (2.4)	14 (9.0)	0.059
Smoking, *n* (%)	143 (60.1)	53 (63.9)	90 (58.1)	0.385
Baseline CT findings				
MHT (mm)	9.9 ± 2.4	10.3 ± 2.6	9.6 ± 2.2	0.034
MAD (mm)	40.2 ± 5.5	41.6 ± 6.9	39.4 ± 4.4	0.008
Segment numbers involved	2 (2–2)	2 (2–2)	2 (2–2)	0.087
Presence of ULP, *n* (%)	91 (38.2)	48 (57.8)	43 (27.7)	< 0.001
Presence of IBP, *n* (%)	49 (20.6)	17 (20.5)	32 (20.6)	0.976
Aortic aneurysm, *n* (%)	16 (6.7)	7 (8.4)	9 (5.8)	0.440
Pericardial effusion, *n* (%)	6 (2.5)	2 (2.4)	4 (2.6)	1.000
Pleural effusion, *n* (%)	47 (19.7)	20 (24.1)	27 (17.4)	0.218
Follow-up CT findings				
Changes of MHT (mm)	− 1.5 (− 4.3 to 0.2)	0.6 (0.0 to 2.0)	− 2.5 (− 5.4 to − 0.8)	< 0.001
Changes of MAD (mm)	− 0.1 (− 1.2 to 1.0)	1.1 (− 0.2 to 1.9)	− 0.6 (− 1.7 to 0.3)	< 0.001
Newly developed ULP, *n* (%)	16 (6.7)	13 (15.7)	3 (1.9)	< 0.001
Newly developed IBP, *n* (%)	75 (31.5)	34 (41.0)	41 (26.5)	0.022
Newly developed aneurysm, *n* (%)	6 (2.5)	3 (3.6)	3 (1.9)	0.423
Newly developed dissection, *n* (%)	6 (2.5)	4 (4.8)	2 (1.3)	0.187
Newly developed pericardial effusion, *n* (%)	1 (0.4)	1 (1.2)	0 (0.0)	0.349
Newly developed pleural effusion, *n* (%)	28 (11.8)	18 (21.7)	10 (6.5)	0.001

Mean ± SD or median (interquartile range) is reported

BMI, body mass index; *MHT*, maximal hematoma thickness; *MAD*, maximal aortic diameter; *ULP*, ulcer-like projection; *IBP*, intramural blood pool

one experienced significant thickening of hematoma with a marked increase of associated pleural effusion by follow-up CT, one presented with greater diameter and depth of ULP detected by follow-up CT images, and invasive treatment was refused. Three developed classic type A aortic dissection during follow-up and declined to received surgery; another two developed aneurysms without surgery or endovascular aortic repair.

The Cox regression model for predicting adverse aorta-related events is shown in Table 2. Multivariate analysis showed that baseline MAD (HR = 1.05, $p = 0.008$), presence of ULP (HR = 2.47, $p < 0.001$), changes of MHT (HR = 1.22, $p < 0.001$), newly developed ULP (HR = 4.44, $p < 0.001$), and newly developed pleural effusion (HR = 2.46, $p = 0.002$) were independently associated with adverse aorta-related events. Figure 2 depicts Kaplan-Meier curves of adverse aorta-related events according to ULP, newly developed ULP, newly developed pleural effusion, and resorption of pleural effusion. Significantly lower event-free survival rates were observed in patients with ULP, with newly developed ULP, with newly developed pleural effusion, and without resorption of pleural effusion.

Logistic regression analysis for predicting early adverse aorta-related events

In this cohort, most of the adverse aorta-related events (83.1%) occurred within 1 month after follow-up CT imaging ($n = 69$). ROC analysis was used to define the optimal cutoff values of the MHT and MAD in predicting early (1 month) adverse aorta-related events. ROC-derived optimal cutoff points for MHT and MAD were 11.8 mm (31.9% sensitivity and 84.0% specificity) and 38.2 mm (75.4% sensitivity and 39.6% specificity), respectively. Areas under the curve of MHT and MAD were 0.580 (95% CI 0.497–0.662, $p =$

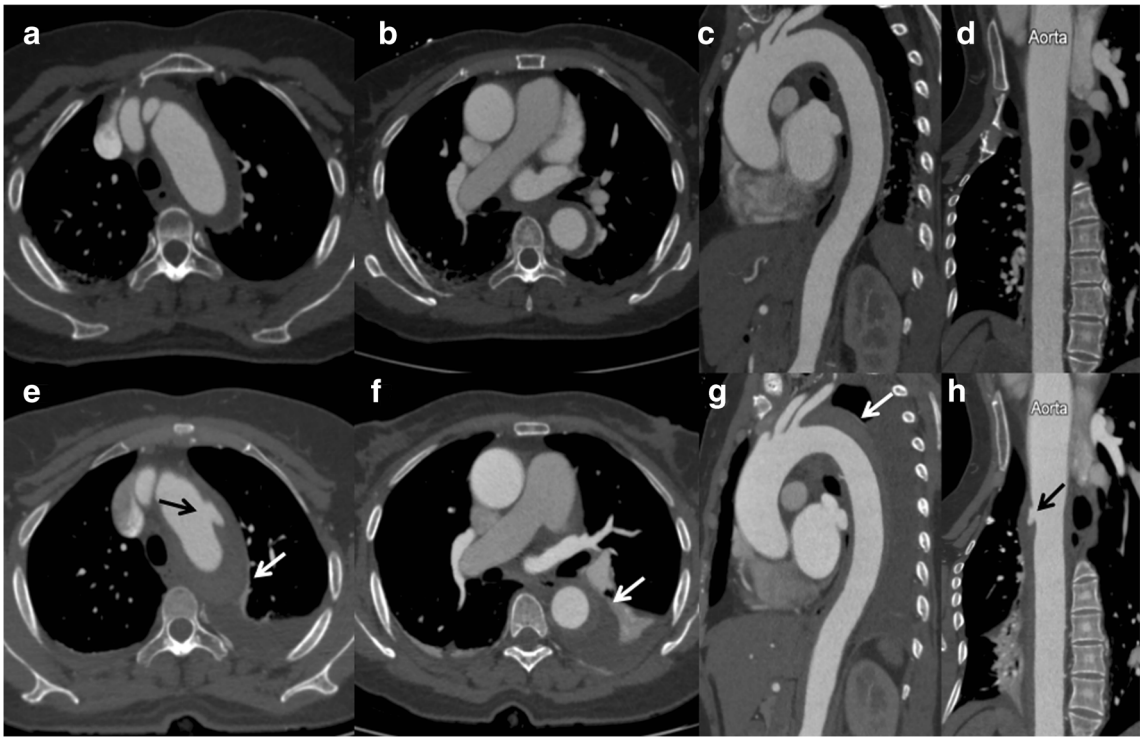

Fig. 1 Progression of a representative case of type B IMH detected by serial CT. A 56-year-old woman with type B IMH underwent serial CT scans. Intramural hematoma at baseline was identified on the cross-sectional (**a**, **b**), multiplanar reformation (**c**), and curved planar reformation (**d**) images; initial medical therapy under careful surveillance was given. One week later, the follow-up CT images (**e**–**h**) showed significant progression of the IMH. Hematoma thickness was significantly increased with associated pleural effusion (white arrows), and a new developed ulcer-like projection was observed on the follow-up CT images (black arrows). Thoracic endovascular aortic repair was performed for this patient

0.054) and 0.575 (95% CI 0.497–0.653, $p = 0.069$), respectively.

Baseline and follow-up CT findings as predictors for early adverse aorta-related events were assessed using multivariate logistic regression analysis, as shown in Table 3. Baseline CT-based predictive model was constructed by using baseline CT-related variables as predictors. After adjustment for other variables in this model, baseline MHT ≥ 11.8 mm (OR = 2.27, $p = 0.020$), MAD ≥ 38.2 mm (OR = 2.01, $p = 0.040$), and presence of ULP (OR = 3.72, $p < 0.001$) were independent predictors of 1-month aortic events. Combined model was constructed by using baseline and follow-up CT-related variables as predictors; in this model, baseline MHT ≥ 11.8 mm (OR = 4.39, $p = 0.001$), presence of ULP (OR = 3.98, $p < 0.001$), changes of MHT (OR = 1.46, $p < 0.001$), newly developed ULP (OR = 9.27, $p = 0.002$), and newly developed pleural effusion (OR = 3.45, $p = 0.015$) were independent predictors. *C* statistics of the two predictive models were 0.71 and 0.87, respectively.

In addition, we investigated association between adverse aorta-related events and resorption of IBP, pericardial effusion, and pleural effusion, as shown in Table 4. There were 47 patients with pleural effusion at baseline; resorption of pleural effusion was observed in 27 patients by follow-up CT imaging and resorption of pleural effusion was shown to be associated with adverse aorta-related events (HR = 0.36, $p = 0.027$) and 1-month aortic events (OR = 0.23, $p = 0.026$) in univariate analysis.

Discussion

Prior studies provided limited data about evolution of IMH and some clinical and imaging predictors of IMH complications are still controversial. This study focused on not only baseline imaging predictors but also changes of them. We demonstrated that morphological changes detected by follow-up CT imaging provide strong and incremental prognostic information for initially medically treated type B IMH. Follow-up CT is highly recommended for type B intramural hematoma in patients who did not receive urgent invasive therapy, which is helpful for risk estimates and decisions-making.

In this cohort, male patients constitute a high proportion, and mean age of the male patients was lower than that of female patients, suggesting higher incidence and younger onset age in men than in women, consistently with previous series [18]. Most patients in our cohort had a history of

Table 2 Cox regression model for predicting adverse aorta-related events

Parameters ($n = 238$)	Adverse aorta-related events			
	Univariate analysis		Multivariate analysis	
	HR (95% CI)	p value	HR (95% CI)	p value
Age (year)	1.02 (1.00–1.04)	0.086		
Male	0.92 (0.56–1.49)	0.726		
BMI (kg/m^2)	0.96 (0.90–1.02)	0.176		
Hypertension	1.25 (0.60–2.59)	0.553		
Dyslipidemia	1.34 (0.87–2.07)	0.179		
Diabetes	0.31 (0.08–1.25)	0.099		
Smoking	1.14 (0.73–1.78)	0.573		
MHT (mm)	1.10 (1.00–1.20)	0.041		
MAD (mm)	1.05 (1.02–1.08)	0.003	1.05 (1.01–1.08)	0.008
Segment numbers involved	1.54 (0.99–2.40)	0.053		
Presence of ULP	2.76 (1.79–4.28)	< 0.001	2.47 (1.55–3.92)	< 0.001
Presence of IBP	0.99 (0.58–1.69)	0.975		
Aortic aneurysm	1.39 (0.64–3.01)	0.407		
Pericardial effusion	0.95 (0.23–3.86)	0.940		
Pleural effusion	1.41 (0.85–2.33)	0.185		
Changes of MHT (mm)	1.25 (1.18–1.31)	< 0.001	1.22 (1.15–1.29)	< 0.001
Changes of MAD (mm)	1.15 (1.10–1.21)	< 0.001		
Newly developed ULP	3.84 (2.12–6.96)	< 0.001	4.44 (2.38–8.27)	< 0.001
Newly developed IBP	1.72 (1.11–2.67)	0.015		
Newly developed aneurysm	1.12 (0.35–3.56)	0.843		
Newly developed dissection	2.17 (0.79–5.93)	0.131		
Newly developed pericardial effusion	7.56 (1.03–55.45)	0.047		
Newly developed pleural effusion	2.74 (1.62–4.64)	< 0.001	2.46 (1.41–4.31)	0.002

HR, hazard ratio; *CI*, confidence interval; other abbreviations as in Table 1

hypertension, indicating that it might be an important risk factor for onset of IMH. IMH was initially described as aortic dissection without an intimal tear [19, 20]; however, intimal defects were detected in 70% with CT and 70–80% of the surgically treated IMH in previous reports [8, 20, 21], and some tiny intimal defects might not be well identified by CT. ULP, also described as localized intimal defect, was detected in 38.2% patients by CT at baseline in our initially medically treated type B IMH cohort. This raised a question to the traditional theory with vasa vasorum bleeding; conventional definition of IMH might be changed [20]. IMH might be the result of thrombosed false lumen aortic dissection with detectable or undetectable intimal tear [20].

Both presence of ULP at baseline and newly developed ULP at follow-up were independently associated with adverse aorta-related events, suggesting its robust prognostic significance in IMH development. Risk of adverse aortic events in patients with ULP was 2.76 times that of patients without ULP, and the risk in patients with newly developed ULP was 3.84 times as high as patients without. ULP represents new disruption of the aortic intima and is directly related to the pathogenesis of IMH; patients with ULP should be followed up closely and treated more aggressively. Unlike ULP, IBP has been described as focal contrast enhancement within the IMH and it may resolve over time or appear during follow-up [7, 18, 22, 23]. According to previous studies, IBP has no established association with adverse events and bears a relatively benign clinical course. Presence of new IBP at follow-up CT was identified as a predictor of incomplete resorption of IMH [18]. In the present study, we found the presence of IBP at baseline unrelated to adverse aorta-related events. However, newly developed IBP at follow-up was associated with adverse aorta-related events in univariate analysis, although it was not an independent predictor in multivariate analysis. Prognostic significance of newly developed IBP for type B IMH still needs to be further confirmed in larger prospective cohort study.

Controversy exists concerning initial hematoma thickness as an independent predictor of adverse aortic events. In some study series, thickness > 11 to 16 mm identified patients at

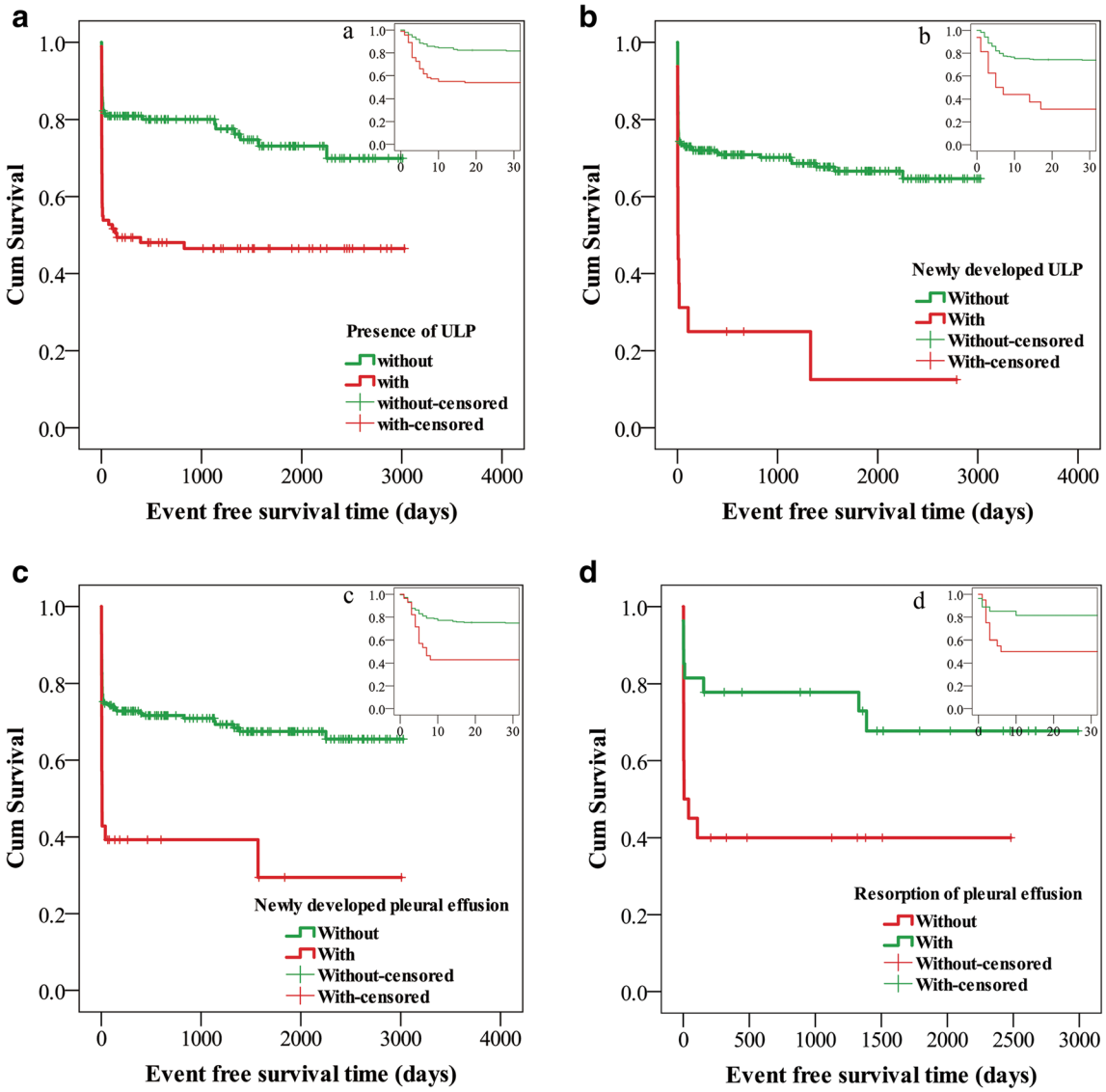

Fig. 2 Kaplan-Meier curves of adverse aorta-related events. Significantly lower event-free survival rates were observed in patients with ULP (**a**), with newly developed ULP (**b**), with newly developed pleural effusion (**c**), and without resorption of pleural effusion (**d**) (all $p < 0.05$, log-rank test). Kaplan-Meier curves of early adverse aorta-related events (within 1 month) are shown in the upper right corner of the figures (**a**–**d**)

increased risk of aortic complications [7]. Others did not show this correlation [14, 24]. MAD is considered as an independent predictor of adverse aortic events like progression to dissection, need for surgery, rupture, and mortality [9, 22, 25], and normal aortic diameter in acute phase is described as the best predictor of IMH regression without complications [10]. In the present study, both baseline MHT and changes of MHT at follow-up were associated with adverse aorta-related events. Baseline MHT ≥ 11.8 mm and increased MHT at follow-up were robust predictors for adverse aorta-related events. In addition, both MAD at baseline and changes of MAD at follow-up were associated with adverse aortic events, and initial MAD ≥ 38.2 mm could well predict early aortic events. These findings indicate a significant prognostic role of both MHT and MAD for risk stratification of type B IMH.

The prognostic significance of pleural effusion has not been established by previous studies [7]. Baseline pleural effusion was not correlated with adverse aortic events in our study; however, newly developed pleural effusion detected by follow-up CT was independently associated with adverse aorta-related events. Besides, in patients with pleural effusion at baseline, resorption of pleural effusion was a protective factor of adverse aortic events. This suggests that changes of pleural effusion detected by follow-up CT provide important prognostic information for type B IMH.

Most of the adverse aorta-related events occurred within 1 month after follow-up CT imaging in our cohort. Construction of predictive models for early adverse aortic events could help risk stratification and management decisions. The proposed baseline CT-based model suggests that

Table 3 Univariate predictor analysis and predictive models for 1-month aortic events

Parameters ($n = 238$)	One-month aortic events		Predictive models			
	Univariate analysis		Baseline CT-based model		Combined model	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Age (year)	1.02 (0.99–1.05)	0.225				
Male	0.73 (0.39–1.36)	0.326				
BMI (kg/m^2)	0.96 (0.88–1.04)	0.293				
Hypertension	1.82 (0.66–5.03)	0.251				
Dyslipidemia	1.35 (0.77–2.38)	0.298				
Diabetes	0.15 (0.02–1.17)	0.070				
Smoking	1.05 (0.59–1.86)	0.874				
MHT ≥ 11.8 mm	2.46 (1.28–4.73)	0.007	2.27 (1.14–4.53)	0.020	4.39 (1.78–10.80)	0.001
MAD ≥ 38.2 mm	2.01 (1.07–3.77)	0.030	2.01 (1.03–3.90)	0.040		
Segment numbers involved	1.94 (1.07–3.49)	0.028				
Presence of ULP	3.81 (2.12–6.85)	< 0.001	3.72 (2.04–6.79)	< 0.001	3.98 (1.87–8.46)	< 0.001
Presence of IBP	1.24 (0.63–2.45)	0.527				
Aortic aneurysm	1.12 (0.38–3.36)	0.837				
Pericardial effusion	1.23 (0.22–6.88)	0.813				
Pleural effusion	1.19 (0.60–2.37)	0.622				
Changes of MHT, (mm)	1.49 (1.30–1.70)	< 0.001			1.46 (1.27–1.67)	< 0.001
Changes of MAD, (mm)	1.44 (1.23–1.69)	< 0.001				
Newly developed ULP	6.22 (2.07–18.66)	0.001			9.27 (2.25–38.18)	0.002
Newly developed IBP	1.94 (1.08–3.48)	0.027				
Newly developed dissection	1.23 (0.22–6.88)	0.813				
Newly developed pleural effusion	3.95 (1.76–8.88)	0.001			3.45 (1.27–9.39)	0.015
C statistic			0.71 (0.64–0.79)	< 0.001	0.87 (0.82–0.93)	< 0.001

OR, odds ratio; other abbreviations as in Tables 1 and 2

patients with MHT ≥ 11.8 mm, MAD ≥ 38.2 mm, and presence of ULP have high risk of adverse aortic events. However, the predictive performance of this model is relatively low. The combined model indicates that patients with MHT ≥ 11.8 mm, presence of ULP, increased MHT, newly developed ULP, and newly developed pleural effusion are more likely to suffer from adverse aortic events; this model has a superior predictive performance.

In addition, magnetic resonance imaging (MRI) could also be used as follow-up imaging. MR angiography (MRA) with gadolinium-based contrast allows delineation of vascular anatomy and improved detection of subtle lesions such as ULPs and IBPs [26]. MHT and MAD can also be well measured. Non-contrast MRI using bright-blood or dark-blood pulse sequences could also be considered; however, whether

Table 4 Association between adverse aorta-related events and resorption of IBP, pericardial effusion, and pleural effusion

Baseline	Follow-up	Univariate analysis	
		Adverse aorta-related events HR (95% CI)	One-month aortic events OR (95% CI)
Patients with IBP at baseline ($n = 49$)	Resorption of IBP ($n = 16$)	1.81 (0.70–4.71), $p = 0.221$	2.07 (0.59–7.24), $p = 0.253$
Patients with pericardial effusion at baseline ($n = 6$)	Resorption of pericardial effusion ($n = 3$)	0.82 (0.05–13.24), $p = 0.887$	1.00 (0.03–29.81), $p = 1.000$
Patients with pleural effusion at baseline ($n = 47$)	Resorption of pleural effusion ($n = 27$)	0.36 (0.14–0.89), $p = 0.027$	0.23 (0.06–0.84), $p = 0.026$

Abbreviations as in Tables 1, 2, and 3

subtle lesions like ULPs and IBPs can be well detected as in MRA or CT needs further investigation.

Study limitations

Selection bias is possible due to the retrospective design. We only enrolled initially medically treated type B IMH patients with repeated CT imaging. Patients who underwent urgent endovascular therapy after initial CT and patients without follow-up CT were not included. We focused on not only the baseline imaging characteristics but also the changes. The potential selection bias might somewhat affect the accuracy of the proposed predictive models that need validation. In addition, patients with suspected acute aortic syndrome (AAS) were given directly contrast-enhanced acquisition in our hospital. This approach reflects our routine clinical practice, where we avoid non-contrast acquisition partly because of reduction of radiation dose. However, AAS could also be well diagnosed by contrast CT. All enrolled patients were diagnosed as type B intramural hematoma by their initial contrast-enhanced acquisition and were reconfirmed by subsequent medical testing, to limit misdiagnosis in the present study. Finally, we just used simple CT characteristics as predictors, additional information like location, diameter, and depth of ULP was not analyzed, as we aimed to develop simple and practical predictive models.

In conclusion, our study suggests that follow-up CT has a significant incremental prognostic value in the case of initially medically treated type B IMH and should be recommended in the surveillance strategy. Patients with increased MHT, newly developed ULP, and newly developed pleural effusion are more likely to suffer from adverse aortic events.

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Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Bin Lu.

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Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- diagnostic or prognostic study
- performed at one institution

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