INTRODUCTION

Major portal vein tumor thrombosis (mPVT) refers to tumor thrombus invasion in the first branch or the main portal vein, or the opposite side portal branch [1]. Patients with hepatocellular carcinoma (HCC) complicated by mPVT...
generally have unfavorable prognoses due to severe intrahepatic and/or extrahepatic metastases, portal hypertension, jaundice, and ascites. Research on the medical history of HCC patients with mPVTT indicated that the median survival of untreated patients was 2.7–4 months [2,3]. Meanwhile, the incidence of mPVTT was considerably higher than expectation. According to a nationwide follow-up survey conducted in Japan, 7.4% patients were diagnosed as having mPVTT when first diagnosed with HCC and more than half of them (3.8%) then underwent liver resection [4]. Liver resection is a promising therapeutic strategy for large cohorts and for patients with advanced conditions. Another nationwide multicentral study from Japan also showed survival benefits from liver resection in portal vein invasion associated HCC [5]. However, the postoperative outcomes of the HCC patients complicated by mPVTT were unsatisfactory and debatable in view of the postsurgical median survival ranging from 6 months to 20 months [6-8].

With the evolution of surgical techniques and perioperative management, liver resection has become a reliable and safe treatment option with an acceptable mortality of less than 2% [9,10]. However, tumor recurrence is the most critical factor that shortens the long-term survivals of HCC patients with mPVTT. Notably, portal vein tumor thrombosis (PVTT) itself is the most important independent risk factor for early postoperative recurrence of HCC [11]. Currently, there are few clinicopathological prognostic factors for predicting the tumor recurrence of HCC patients complicated by mPVTT. Positron emission tomography with fluorine-18-fluorodeoxyglucose (18F-FDG PET) has been widely used in detecting the glucose metabolic activity of tumors, thus it could be used as an indicator for tumor aggressiveness. Torizuka et al. [12] reported that 18F-FDG uptake in high-grade HCC was significantly higher than that in low-grade HCCs. Recently, several clinical studies showed that preoperative 18F-FDG PET measurement could predict tumor differentiation and postoperative outcomes of HCC patients [13-15].

So far, few studies have focused on the application of 18F-FDG PET in predicting recurrence-free survival (RFS) and overall survival (OS) of HCC patients with mPVTT based on the maximum standard uptake value (SUVmax). Thus, in this retrospective study, we calculated the optimal cutoff value of SUVmax by drawing receiver operating characteristic (ROC) curves in order to predict the prognoses of HCC patients with mPVTT after liver resection.

**METHODS**

**Patients**

A total of 501 HCC patients underwent surgery in our hospital during November 2008 and December 2014, among which 32 HCC patients (6.4%) had mPVTT complications of Vp3 or Vp4 stage according to the classification method described in the study by Ikai et al. [1].

Vp3 refers to the formation of tumor thrombi in the first-order branches of the portal vein. Vp4 refers to the formation of tumor thrombi in the main trunk of the portal vein or a portal vein branch contralateral to the primarily involved lobe (or both). Six cases were excluded due to the following reasons: 2 cases receiving living donor liver transplantation. 2 cases undergoing re-resection after recurrence of tumor with mPVTT, 1 case with both HCC and inferior vena cava thrombosis, and 1 case with residual PVTT. Ultimately, 26 HCC patients including 23 males and 3 females with a median age of 50 years (range, 31 to 72 years) were enrolled in this study. Serological testing showed positive expression of serum hepatitis B surface antigen in 23 cases and positive expression of anti-hepatitis C viral antibody in 1 case. The detailed clinicopathological

| Variable | Value |
|----------|-------|
| Age (yr) | 50 (31–72) |
| Male sex | 23 (88.5) |
| Platelet count (×1,000/mm³) | 178 (64–315) |
| Serum total bilirubin (mg/dL) | 0.9 (0.4–2.4) |
| Serum AST (U/L) | 52.5 (21.0–243.0) |
| Serum ALT (U/L) | 38.0 (17.0–340.0) |
| Serum albumin (g/dL) | 4.3 (3.2–4.8) |
| PT-INR | 1.1 (0.88–1.5) |
| Serum α-FP (ng/mL) | 483.3 (2.6–60,500.0) |
| Serum α-FP (>400 ng/mL) | 13 (50) |
| ICG R15 (%) | 14.5 (4.2–36.4) |
| Child-Pugh stage A | 15 (57.7) |
| Child-Pugh stage B | 25 (96.2) |
| PET-SUVmax | 6.2 (2.6–15.1) |
| Preoperative TACE | 4 (15.4) |
| Tumor size (cm) | 9.3 (1.4–20.0) |
| Tumor number | 1 (1–6) |
| Multiple tumor number | 6 (23.1) |
| Liver cirrhosis (fibrosis stage 4) | 17/26 (65.4) |
| Bile duct involvement | 7/24 (29.2) |
| Hepatic vein involvement | 3/23 (13.0) |
| Resection margin positive | 11 (42.3) |
| Microvascular invasion | 25/25 (100) |
| Ig/Î²g | 20 (76.9)/6 (23.1) |
| Intrahepatic Metastasis | 20/24 (80.3) |
| 90-Day mortality (OP mortality) | 0 (0) |
| Disease-free survival (mo) | 3 (1–88) |
| Overall survival (mo) | 16 (4–88) |

**Values are presented as median (range) or number (%).**

PT-INR, prothrombin time-international normalized ratio; ICG R15, indocyanine green retention rate at 15 min; PET-SUVmax, positron emission tomography-the maximum standard uptake value; TACE, transcatheter arterial chemoembolization; OP, operation.
characteristics of the 26 patients were listed in Table 1. All the data retrospectively analyzed in the study were retrieved from the database of our hospital that prospectively stored clinical data. The protocol of this study was approved by the medical ethics committee of our hospital (AJIRB-MED-MDB-19-448).

Operating procedure and portal vein thrombectomy

Patients received specific operations according to the sites and the sizes of PVTT. Five cases received right trisectionectomy. Fifteen cases received right or extended right hemihepatectomy and 6 cases underwent left hemihepatectomy. The tumor embolisms in the first branch of the left portal vein (Vp3) were en bloc removed with the tumor. The tumor embolisms in the first branch of the right portal vein and/or the main portal vein were removed by open resections under the occlusion of the main glissonean pedicle and the first branch of the contralateral glissonean pedicle. The occlusion was achieved by using extra fascial access but not dissecting the glissonean pedicle. The detailed procedures of the thrombectomies were shown in Fig. 1. Portal vein dissection was performed after the parenchyma had been divided. The hepatic artery and the bile duct were ligated and divided separately. Then, the anterior wall of the portal vein where tumor embolisms invaded was transversely incised. The PVTT was peeling off from the portal vein lumen. Any residual tumor thrombus, if existing, in the caudate branch could be removed by meticulously suction. After removing the gross PVTT, the lumen was flushed with heparinized saline and back-bleeding to remove potentially cancerous residual tissue. The posterior wall of the portal vein was dissected using scalpels and the stump was closed with 6/0 prolene continuous sutures. To prevent portal vein stenosis, a distance of 3–5 mm was reserved from the incision site to the bifurcation of the right and left portal veins.

Follow-up strategy, recurrence, and treatment pattern

The median duration of follow-up was 12 months (range, 4 to 88 months). All the patients in our hospital were followed up in strict accordance with the standard protocol. In detail, these patients underwent enhanced CT scan of the upper abdomen at day 7 postoperatively. After discharge from the hospital, all patients were followed up monthly by detecting tumor markers (i.e., α-FP) and analyzing laboratory data (i.e., CBC, AST, ALT, albumin, total bilirubin) during the first 6 months after surgery. Thereafter, the patients were followed up every 2–3 months by measuring the tumor markers, evaluating liver function and performing radiological examinations (i.e., chest X-ray). An enhanced CT scan was performed every 6 months. In addition, more specialized, accurate examinations such as magnetic

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Fig. 1. The surgical procedures for thrombectomy. (A) Schema showing a right liver hepatocellular carcinoma (HCC) and HCC-derived portal vein tumor thrombus (PVTT) extending to the main portal vein. (B) Exposure the hilar structure after the liver parenchyma divided. (C) Extra fascial access to tape the main and the left glissonean pedicle. (D) The hepatic artery and the bile duct were ligated and divided separately. (E) While clamping the main and left portal glissonean pedicle, the anterior wall of the portal vein was transversely incised. The PVTT was peeling off from the portal vein lumen. (F) The lumen was flushed with heparinized saline and main portal bleeding to remove potentially cancerous residual tissue. (G) Left portal back-bleeding to remove potentially cancerous residual tissue. (H) The posterior wall of the portal vein was dissected by scalpel and the stump was closed with 6/0 prolene by continuous suture.
resonance imaging or PET/CT would be performed once there existed a high risk of recurrence.

During the follow-up period, tumor recurrences were observed in 21 cases. Among these cases, there were 11 cases of multiple intrahepatic recurrences, 5 cases of multiple intrahepatic recurrences combined with PVTT recurrence, 2 cases of multiple intrahepatic recurrence with lung metastasis, 2 cases of single intrahepatic recurrence, and 1 case of multiple lung metastasis. Thus, 4 different therapeutic strategies were developed for treating tumor recurrences according to hepatic function and recurrence patterns of the patients. Twelve patients received transcatheter arterial chemoembolization (TACE) treatment. Four patients received treatment with multikinase inhibitor of sorafenib; Two patients received palliative radiotherapeutic treatment and 3 patients received conservative management.

18F-FDG PET/CT acquisition, analysis, and the determination of the optimal cutoff value of SUVmax

Patients were fasted for at least 6 hours before the examination. The blood glucose levels of these patients were normal (range, 74 to 106 mg/dL) before 18F-FDG administration. Then, these patients were injected with 370 MBq of 18F-FDG and rested for 1 hour before scanning. Emission PET data were acquired from the vertex to the upper thigh using a Discovery ST scanner (GE Healthcare, Milwaukee, WI, USA). Noncontrast CT scans were also performed for reconstruction (tube rotation time 1 s/rev, 120 kV, 60 mA, 7.5 mm/rotation, ordered subset expectation maximization, 2 iterations, 30 subsets).

The characteristics of liver tumors including 18F-FDG uptake and extrahepatic metastasis were analyzed. Volumes-of-interest were placed on the tumor and the background (contralateral lobe of liver). The amounts of 18F-FDG uptake were expressed by standardized uptake values (SUV, g/mL), which were calculated based on the radioactivities in volume-of-interest, injection dosages, and patient’s body weight. Maximum SUV (SUVmax, the hottest single voxel) was used for analysis in the present study.

The ROC curve has demonstrated in this cohort study a value of 4.65 as the best cutoff value of SUVmax for tumor recurrence after hepatectomy. The area under the curve was 0.948. The P-value was 0.002 (Fig. 2).

Statistical analysis

All data were processed and analyzed using IBM SPSS Statistics ver. 19.0 (IBM Co., Armonk, NY, USA). The continuous variables were expressed as median (range) deviation and compared by the Student t-test. The categorical data were presented as frequency and were analyzed using the Fisher chi-square test. The multivariate analysis was performed with Cox regression for significant variables on the univariate analysis.

OS and RFS were analyzed using the Kaplan-Meier method and compared by the log-rank test. Confidence intervals were constructed at 95%, and P-values < 0.05 were considered statistically significant.

RESULTS

The characteristics of HCC patients complicated by mPVTT

As the last follow-up time was March 2017, the median duration of follow-up in the present study was 12 months (range, 4 to 88 months). Hepatitis B was the most common etiological factor. These patients were relatively young with a median age of 50 years, as well as having relatively normal liver function. According to the Child-Pugh classification, 25 patients belonged to grade A and one patient belonged to grade B. Most of the patients possess aggressive tumor characteristics which presented by microvascular invasion, intrahepatic metastasis, and infiltrative growth type. The postoperative pathological examinations indicated that the median tumor size was 9.3 cm (range, 1.4 to 20 cm), and the median number of tumors was 1 (range, 1 to 6). Four patients had a history of treatment with TACE. Three patients had complications by hepatic vein involvement, and 7 patients had complications by bile duct involvement. The median SUVmax was 6.2, ranging from 2.6 to 15.1. Hospital mortality was defined as any death within 90 days after surgery. Notably, there were no hospital mortalities in this study. The clinicopathological characteristics of these patients were shown in Table 1.
Survival outcomes and characteristics of patients with long-term survivals

The Kaplan-Meier plot of OS for these patients showed that 1-, 3-, and 5-year OS were 55.6%, 31.7%, and 31.7%, respectively (Fig. 3). The median OS was 16 months. Six patients experienced long-term survival of more than 3 years. The characteristics of these long-term survival patients were shown in Table 2, among which relatively low SUV\(_{\text{max}}\) (range, 2.1 to 4.4) was the most common characteristic. Among the 6 cases, there were 2 cases of recurred intrahepatic tumor within 1 year; among which, 1 had single intrahepatic recurrence and the other had 5 intrahepatic recurrences. However, both of them survived for a long period after TACE treatment.

The survival analysis of low and high SUV\(_{\text{max}}\) groups

The patients were divided into 2 groups based on the optimal cutoff value of SUV\(_{\text{max}}\) (4.65), including low SUV\(_{\text{max}}\) group (SUV\(_{\text{max}}\) values < 4.65) and high SUV\(_{\text{max}}\) group (SUV\(_{\text{max}}\) values ≥ 4.65). The RFS time of high SUV\(_{\text{max}}\) group was significantly shorter than that of the low SUV\(_{\text{max}}\) group (the log-rank test: 12.756, \(P = 0.000\)) (Fig. 4A). The 1-, 3-, and 5-year of RFS in high SUV\(_{\text{max}}\) group was 0%, 0%, and 0%, respectively. However, the 1-, 3-, and 5-year of RFS in the low SUV\(_{\text{max}}\) group reached up to 60%, 60%, and 60%, respectively. OS time of high SUV\(_{\text{max}}\) group was significantly shorter than that of the low SUV\(_{\text{max}}\) group (the log-rank test: 7.586, \(P = 0.006\)) (Fig. 4B). In terms of OS, the 1-, 3-, and 5-year survivals of high SUV\(_{\text{max}}\) group were 46.0%, 0%, and 0%, respectively, while the 1-, 3-, and 5-year survivals of low SUV\(_{\text{max}}\) group were 75.0%, 75.0%, and 37.5%, respectively. Tumor recurrence was observed in 3 patients from low SUV\(_{\text{max}}\) group. Two of these cases were shown in Table 2, and they survived for 46 months and 51 months, respectively. One patient experienced multiple liver tumors recurrence and died 8 months after TACE treatment. Two patients in the low SUV\(_{\text{max}}\) group died during the follow-up period. Another patient died of hepatic failure after the HBV recurrence. However, all the patients in the high SUV\(_{\text{max}}\) group had tumor recurrences within 10 months, and 14 of 18 patients finally died of tumor progression during the follow-up period. The remaining 4 patients were lost to follow-up.

Analysis of risk factors for mPVTT patients

The comparisons of the clinicopathological characteristics between high and low SUV\(_{\text{max}}\) groups were shown in Table 3. There were no significant differences in liver function and tumor factors represented by Child-Pugh class grades, indocyanine green retention rate at 15 minutes and tumor sizes, tumor growth types, microvessel invasion, intrahepatic metastasis, and Edmondson-Steiner grades. In addition, results showed no significant difference in postoperative PVTT recurrence, despite there being no PVTT recurrence in low SUV\(_{\text{max}}\) group, though there were 5 cases with PVTT recurrence.

| No. | ICG R15 (%) | T-S (cm) | T-N (n) | AFP (ng/mL) | Gr. type | Resection Margin | VP type | OS (mo) | PET-CT SUV\(_{\text{max}}\) | DFS (mo) | Recurrence site | Status |
|-----|-------------|----------|---------|-------------|----------|-----------------|---------|---------|---------------------|---------|----------------|--------|
| 1   | 18.8        | 1.4      | 1       | 15.4        | Eg       | Negative        | 4       | 88      | 2.6                 | 88      | NA             | Alive  |
| 2   | 14.4        | 11.0     | 1       | 35797.0     | lg       | Negative        | 3       | 51      | 2.1                 | 10      | Liver-multi     | Dead   |
| 3   | 25.2        | 4.0      | 1       | 378.9       | lg       | Positive        | 4       | 39      | 4.4                 | 39      | NA             | Alive  |
| 4   | 11.0        | 12.0     | 1       | 15.5        | lg       | Positive        | 3       | 49      | 2.2                 | 49.0    | NA             | Alive  |
| 5   | 14.5        | 10.1     | 1       | 7410        | lg       | Negative        | 4       | 46      | 3.3                 | 4       | Liver-single    | Alive  |
| 6   | 8.3         | 5.5      | 2       | 2769        | lg       | Negative        | 3       | 38      | 3.8                 | 38      | NA             | Alive  |

ICG R15, indocyanine green retention rate at 15 min; T-S, tumor size; T-N, tumor number; Gr. type, growth type; VP type, portal vein thrombosis type; OS, overall survival; PET-SUV\(_{\text{max}}\), positron emission tomography-the maximum standard uptake value; DFS, disease-free survival; Eg, expanding type; lg, infiltrate growth type.
Table 3. Comparison of clinical-pathologic characteristic between patients with high and low SUV$_{max}$

| Factor                        | High SUV$_{max}$ group (n = 18) | Low SUV$_{max}$ value group (n = 8) | P-value |
|-------------------------------|---------------------------------|-------------------------------------|---------|
| Age (yr)                      | 51 (31–60)                      | 50 (43–72)                          | 0.461   |
| Serum $\alpha$-FP (≥400 ng/mL)| 9                               | 4                                   | >0.999  |
| ICG R15 (%)                   | 14.4 (4.2–31.3)                 | 14.5 (5.8–25.2)                     | 0.558   |
| MELD score                    | 8 (6–14)                        | 7 (6–11)                            | 0.979   |
| Serum albumin (g/L)           | 4.1 (3.2–4.8)                   | 4.4 (4.0–4.8)                       | 0.209   |
| Serum T.Bilirubin (mg/dL)     | 0.9 (0.4–2.4)                   | 0.8 (0.4–2.0)                       | 0.786   |
| PT-INR                        | 12.3 (10.5–16.6)                | 11.1 (9.7–12.8)                     | 0.229   |
| Tumor size (cm)               | 8.2 (3–20)                      | 10 (1.4–12)                         | 0.332   |
| Tumor size (≥6.5 cm)          | 12                              | 5                                   | >0.999  |
| Growth type (infiltrate type) | 14                              | 6                                   | >0.999  |
| Microvascular invasion        | 18/18                           | 7/7                                 | >0.999  |
| Multiple tumors               | 3                               | 3                                   | 0.330   |
| Liver cirrhosis               | 12                              | 5                                   | >0.999  |
| Resection margin positive     | 9/17                            | 2                                   | 0.234   |
| Vp4                           | 13                              | 5                                   | 0.667   |
| Introhepatic metastasis       | 14/17                           | 6/7                                 | >0.999  |
| ES grade (grade 3 or 4)       | 15/16                           | 6/7                                 | 0.526   |
| ES grade (grade 4)            | 13/16                           | 4/7                                 | 0.318   |
| Preop TACE                    | 4                               | 0                                   | 0.277   |
| Postop PVTT recurrence        | 5                               | 0                                   | 0.281   |
| PET-SUV$_{max}$               | 7.65 (4.9–15.1)                 | 3.25 (2.6–4.4)                      | 0.007   |

Values are presented as median (range) or number.

PET-SUV$_{max}$, positron emission tomography-the maximum standard uptake value; MELD, model for end-stage liver disease; T.Bilirubin, total bilirubin; ICG R15, indocyanine green retention rate at 15 min; Vp4, presence of a tumor thrombus in the main trunk of the portal vein or a portal vein branch contra lateral to the primarily involved lobe (or both); ES grade, Edmondson-Steiner grade; TACE, transcatheter arterial chemoembolization; PVTT, portal vein tumor thrombosis; Preop, preoperative; Postop, postoperative.
Annals of Surgical Treatment and Research 2020.99(1):8-17

in high SUV\textsubscript{max} group. However, SUV\textsubscript{max} values were significantly different between the 2 groups. The Cox regression analysis showed that SUV\textsubscript{max} was the only risk factor for RFS and OS (Tables 4, 5).

**DISCUSSION**

Surgical resection has been identified as an effective treatment for HCC complicated by mPVTT. However, the outcomes of the HCC patients complicated by mPVTT were unsatisfactory in terms of the limited survival ranging from 6 months to 20 months [6-8]. The poor prognosis could be potentially caused by 2 reasons. On the one hand, HCC patients complicated by mPVTT generally received large-scale anatomical hepatectomy in order to reserve safe surgical margins and prevent intrahepatic metastasis. As a result,
demonstrated that the degree of 18F-FDG uptake was a poor risk factor for early postoperative recurrence of HCC, which was in analog to the finding in this work that the patients with recurrence (21 of 26) recurred within 10 months after surgery. Besides, most of the cases (18 of 21) had multiple intrahepatic recurrences. Four distinct therapeutic strategies were carried out to treat the tumor recurrence based on degrees of liver function and patterns of recurrence. Twelve patients received TACE. Four patients received multikinase inhibitor of sorafenib; Two patients underwent palliative radiotherapy treatment and 3 patients received conservative management.

PVTT itself was the most important independent risk factor for early postoperative recurrence of HCC [11]. Further, intrahepatic tumor recurrence was the most important risk factor for patient OS [7,16-18]. Thus, it was of great importance to predict the tumor recurrence for HCC patients with mPVTT. 18F-FDG PET had several limitations in diagnosing primary HCC due to the variations of 18F-FDG uptakes caused by heterogeneous glucose metabolism in HCC [19]. Subsequent studies further demonstrated that the phenomenon was associated with HCC progression or aggressiveness [14,15,20]. Low 18F-FDG uptake was observed in well-differentiated HCC, whereas high SUV was observed in moderately- and poorly differentiated HCCs. Moreover, several studies have demonstrated that the degree of 18F-FDG uptake was a significant independent and significant prognostic factor for RFS and OS of HCC patients after surgery [13,14]. Recently, preoperative positive 18F-FDG PET/CT appears to be associated with better OS in HCC patients [21]. In this study, all the patients suffering both HCC and mPVTT were scanned by 18F-FDG PET/CT preoperatively. The optimal cutoff value of SUV_{max} for tumor recurrence after hepatectomy was determined by ROC curve. Then, high SUV_{max} patients and low SUV_{max} patients were divided into 2 groups according to optimal cutoff value of 4.65. The SUV_{max} value was the sole risk factor that differed significantly between high and low SUV_{max} groups. The RFS and OS of the high SUV_{max} group were significantly shorter than that of the low SUV_{max} group. The recurrence period of high SUV_{max} group was relatively short in that they commonly recurred within 10 months (range, 1 to 10 months) after surgery.

Besides, these patients showed aggressive recurrence patterns, characterized by multiple intrahepatic recurrences, main portal vein tumor thrombus recurrence, and multiple lung recurrences. Only 3 of 8 patients in low SUV_{max} group experienced tumor recurrence during the follow-up period. Also, the recurrent liver tumors were in accordance with Milan criteria and could be effectively controlled by TACE treatment. Notably, there were 3 deaths during the follow-up period, among which 1 case died of hepatitis B virus recurrence and subsequent liver failure at 4 months after operation, and 2 cases died of tumor recurrence and subsequent liver failure in 8 and 51 months, respectively.

There were 6 patients in low SUV_{max} group surviving more than 3 years postoperatively. The characteristics of these patients were shown in Table 2. Intriguingly, the α-FP levels of 2 patients who had liver tumor recurrence were relatively high. Herein, it could be concluded that patients with high α-FP levels deserved serious attention during the follow-up duration due to the possibility of tumor recurrence even though α-FP values were not optimal sensitivity markers for predicting tumor recurrence. Furthermore, adjuvant therapies such as adjuvant TACE, chemotherapy, and multikinase inhibitor could be applied in such cases. The application of total resection with portal vein reconstruction or thrombectomy as the radical resection for HCC complicated by mPVTT remains controversial. Debates on en bloc resection with portal vein reconstruction and thrombectomy have emerged. Theoretically, en bloc resection of the portal vein is a superior surgical strategy owing to no tumor thrombus exposure. Besides, thrombectomy was considered as a potentially noncurative resection because of possible dissemination of tumor cells in operative sites during decollement of the portal vein thrombus in spite of subtle manipulation. However, several previous studies showed that there were no significant differences in the hospital mortalities and morbidities between en bloc resection combined with portal vein reconstruction and thrombectomy for the HCC complicated by mPVTT [22,23]. In the present study, thrombectomy was performed on HCC patients complicated by PVTT extending to or beyond the main portal vein, and multivariate analysis based on Cox proportional hazards
model (Table 4). The univariate analysis showed that both the $SUV_{max}$ value obtained from PET/CT and the tumor diameters larger than 6.5 cm were the risk factors for OS. However, according to the multivariate analysis based on Cox proportional hazards model, only the $SUV_{max}$ obtained from PET/CT was determined as a risk factor for RFS (Table 5). The main reason could be that most of all the HCC cases complicated by mPVTT showed aggressive clinical and pathological characteristics, such as microvascular invasion, intrahepatic metastasis, and infiltrative growth type (Table 1). A prior study revealed that the values of $SUV_{max}$ were closely correlated with the expression of glucose transporter 1 (GLUT1), which was a key rate-limiting factor in the transport and metabolism of glucose in cancer cells [24]. Besides, the expression of GLUT1 was associated with poor differentiation and vascular invasion. Thus, our findings in this study suggested that the role of PET/CT $SUV_{max}$ in tumor prognosis was not only limited to reflect tumor differentiation. Kitamura et al. [25] demonstrated that the proliferative activities of tumors that could predict the prognosis of HCC patients had close correlations with the glucose metabolism. However, the mechanisms of $SUV_{max}$ to predict HCC complicated by mPVTT remained unclear and should be elucidated in future studies.

However, there were several limitations in this study: Firstly, this study was only performed based on a single center in a retrospective manner. Secondly, the number of recruited patients was relatively limited, which could increase the selection bias in this study. Thirdly, only one surgical procedure was performed in this work. Thus, in future studies, more practical surgical procedures such as en bloc portal vein resection and reconstruction should be included as a control group for determining the best surgical method.

In conclusion, the $SUV_{max}$ value obtained from $^{18}$F-FDG-PET/CT scan was considered as a reliable risk factor for RFS and OS of HCC patients complicated by mPVTT. Low $SUV_{max}$ could serve as an indicator for selecting suitable candidates with low risk of recurrence for surgical resections and to achieve long-term survivals. More precisely, thrombectomy, which did not increase the risk of tumor recurrence, was appropriate for HCC combined with mPVTT patients with low $SUV_{max}$ values. However, it remained unclear whether surgical resections were suitable for patients with high $SUV_{max}$ values. Thus, more in-depth clinical studies are needed to solve this question. Also, larger cohorts and multicentral studies are needed for further investigation as to whether en bloc resection combined with portal vein reconstruction could prevent local tumor thrombus recurrence. Moreover, whether the mechanisms underlying HCC prediction by $SUV_{max}$ were associated with tumor differentiation or proliferation is urgently needing to be addressed.

ACKNOWLEDGEMENTS

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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