Received: 28 February 2022 | Accepted: 25 April 2022

DOI: 10.1111/1759-7714.14460

ORIGINAL ARTICLE

WILEY

Conditional catheter-related thrombosis free probability and risk-adapted choices of catheter for lung cancer

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Funding information
Beijing Chaoyang District Science and Technology Plan, Grant/Award Number: CYSF2030; Beijing Hope Run Special Fund of Cancer Foundation of China, Grant/Award Number: LC2020A17; CAMS Innovation Fund for Medical Sciences (CIFMS), Grant/Award Number: 2021-12M-1-012

Abstract

Background: Current predictive tools assess catheter-related thrombosis (CRT) in patients with lung cancer in a static manner at a single time point of catheterization. The subsequent hazard changes over time are unknown. The conditional catheter-related thrombosis-free probability (CCFP) can provide dynamic information on continual CRT-free expectations. This study aimed to assess the CCFP and hazard rates based on risk categories and various venous access devices (VADs).

Methods: This retrospective study reviewed 939 patients with lung cancer with peripherally inserted central venous catheters (PICCs) or central venous catheters (CVCs) identified at the National Clinical Research Center for Cancer between January 1, 2015 and December 31, 2018. The incidence of CRT has also been reported. Patients were stratified into low- and high-risk groups according to multivariate Cox regression analyses. CCFP is defined as the CRT-free probability given that patients have no CRT for a definite time.

Results: A total of 507 patients with PICCs and 432 patients with CVCs were included in this study. The 3-month CCFP increased from 74.2% at catheter insertion to 93.6% at 3 months. The hazards of CRT in the first month were highest (16.4%) and slightly thereafter. The high-risk group initially had a higher (21.4%) but significantly decreased CRT hazard after 2 months (8.3%), whereas the low-risk group maintained a comparable lower risk hazard of less than 5% after 1 month. In the overall cohort, patients with CVCs had lower CRT probability than those with PICCs (HR, 1.76; 95% CI: 1.28–2.41; $p < 0.01$). Further analysis demonstrated that compared with PICCs, CVCs provided a CRT-free benefit in low-risk patients ($p = 0.02$) but not in high-risk patients ($p = 0.06$).

Conclusions: CCFP increased, and the hazards of CRT decreased over time in a risk-dependent manner in patients with lung cancer. These valuable dynamic data may help optimize risk-adjusted choices of VADs and risk-adjusted prophylactic anticoagulation strategies for patients.

KEYWORDS
catheter-related thrombosis, conditional, lung cancer, risk hazard, risk stratification

INTRODUCTION

Lung cancer is the most deadly cancer worldwide.[1] In China, the number of cases accounts for more than one-third of newly diagnosed lung cancers worldwide each year.[2] Central vascular

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access devices are essential for the treatment of patients with lung cancer. At present, peripherally inserted central venous catheters (PICCs) are commonly used because of their minimal trauma, reliability, safety, and long retention time.[3,4] The application of PICCs has been criticized because of the prohibitive risk of venous thromboembolism (VTE). VTE is known to have a detrimental effect on the quality of life and survival of patients with cancer.[5] The incidence of PICC-related VTE in patients with cancer ranges from 3.0% to 71.9% between the published series.[6,7] This may be related to the heterogeneity of studies, such as the types of cancers and diagnostic techniques. Multiple studies have compared PICCs with various other venous access devices (VADs) to select the most appropriate VADs in different clinical scenarios.[8,9] Several systematic reviews have indicated that PICCs are associated with a higher risk of VTE than central venous catheters (CVCs).[9] The optimal choice of VADs remains to be determined for patients with lung cancer.

It has been reported that more than 90% of catheter-related thrombosis (CRT) occur within 3 months after catheterization.[10] Because of disease heterogeneity, the identification of patients with cancer with VADs who are most likely to benefit from anticoagulant prophylaxis and effective treatment to reduce the risk of CRT are urgent problems. Several predictive tools have been developed to predict CRT risk in patients with cancer.[11–13] Yet, part of the risk covariates in these models were not fit for patients with lung cancer. However, current predictive tools assess CRT in a static manner at a single catheterization time point. The subsequent hazard changes over time in various risk groups of patients with lung cancer are unknown. The uncertainty of CRT risks for patients with lung cancer without CRT for several days since catheterization can potentially affect clinical decision-making.

Time-dependent statistics reflect real-time changes in the risk at a given time point. Conditional CRT-free probability (CCFP) and monthly hazard correspondingly convey the CRT-free probability and monthly event rate, given that patients have no CRT for a defined time. These dynamic methods have been used in various cancers to assist physicians in making optimal treatment decisions or establishing effective surveillance schedules but have never been established for CRT in patients with lung cancer.[14,15] Using the updated database from the National Clinical Research Center for Cancer in China, we identified lung cancer patients with PICCs or CVCs and assessed the conditional CRT-free state in the entire cohort and for various risk categories. These data could be used to better understand the CRT process, provide more accurate predictions of CRT, and provide evidence for risk-adjusted prophylactic anticoagulation strategies.

METHODS

Patients

The cohort consisted of patients with lung cancer treated at the National Cancer Center/National Clinical Research Center for Cancer/Cancer Hospital, Chinese Academy of Medical Sciences, and Peking Union Medical College between January 1, 2015 and 31 December 31, 2018. The inclusion criteria were as follows: (1) age ≥18 years and (2) pathological diagnosis of lung cancer. (3) Underwent PICC or CVC in our hospital and received systematic therapy, and (4) underwent vascular Doppler ultrasound examination during PICC or CVC placement. The exclusion criteria were as follows: (1) patients who were already receiving anticoagulant therapy at the time of PICCs or CVCs placement, (2) inability to obtain complete basic information of patients, and (3) pregnant or lactating patients; 939 patients with lung cancer were eligible based on the above criteria.

The modified Seldinger technique with ultrasound guidance was used for VADs placement. After catheterization, the direction of the catheter and position of the catheter tip were confirmed by chest radiography. Routine catheter care was provided by a professional team once or twice per week for all patients. VTE diagnosis was mainly based on vascular ultrasonography. Doppler ultrasound and color imaging (GE LOGIQTM E9; Philips) were used in this analysis. Each ultrasound report was evaluated by the same team. On ultrasound examination, the CRT showed a low-echo area in the lumen of the blood vessel, presenting as a mass. The lumen did not disappear after pressure application, and there was no blood flow signal.[16]

The study was approved by the National Cancer Center/Cancer Hospital, the Chinese Academy of Medical Sciences, and the Peking Union Medical College. The institutional review boards waived the need for informed consent because the patient data were deidentified in the data set.

Risk-dependent conditional CRT-free probability and monthly hazards over time

We determined whether the conditional CRT-free probability and monthly hazard varied among risk groups. According to previous studies, sex,[17] age,[18] smoking,[19] vascular endothelial growth factor inhibitor (VEGFI),[20,21] chest radiotherapy,[22] chemistry,[23] D-dimer,[24] catheter type,[25,26] stage,[27] catheter insertion site[28] and VTE history[11,21] were included in the multivariate analysis in this study. Accordingly, we stratified patients with lung cancer by catheterization into low- and high-risk groups.

Statistical analysis

With extensions of the concept of conditional survival, conditional CRT-free probability (CCFP) was defined as the probability of a CRT-free state for an additional number of days, given that the patient has already been without CRT for a certain number of days. For example, the 3-month CCFP at 1 month was the conditional probability of a CRT-free state for an additional 3 months (i.e., CRT-free state to 4 months after catheter insertion) given that the patient had no CRT for 1 month.

The CRT-free probability was estimated using the Kaplan–Meier method and compared using the log-rank test. Cox proportional hazards regression analyses used CRT-free probability as the dependent variable to identify potential independent clinical CRT risk factors. Statistical significance was set at $p < 0.05$ (2-sided) and was considered to be statistically significant. Monthly hazards were calculated as the monthly number of events divided by the total follow-up time accumulated by the at-risk patients in that month. Hazard rate curves were smoothed by applying an Epanechnikov kernel.[29] All statistical analyses were performed using SPSS (version 23.0; IBM Inc.) and R version 3.2.1 (R Foundation for Statistical Computing).

RESULTS

Cohort characteristics

In total, 939 patients were included in this study. 184 (19.6%) CRT were recorded in this study. The clinical characteristics of the cohort are shown in Table S1. The male to female ratio was 2.2:1; 227 patients (24.2%) were ≥65 years, 802 (85.4%) had stage III–IV disease, 25 (2.7%) had a VTE history, and 568 (60.5%) had a smoking history, 271 (28.9%) had D-dimer level ≥1.0 mg/l FEU, 373 (39.7%) received chest radiotherapy and 69 (7.4%) received VEGFI therapy. A total of 507 patients (54.0%) used PICC and 432 patients (46.0%) used CVC (Table 1).

Conditional CRT-free probability and monthly hazards overtime for the entire cohort

The 3-month CCFP at catheter insertion was 74.2% (95% CI: 70.3%–77.6%). The CRT-free probabilities for the CCFP increased with each additional month. The 3-month CCFP increased to 84.8% (95% CI: 80.1%–88.4%) for 1-month patients without CRT, 88.7% (95% CI: 81.2%–93.3%) for 2 months patients without CRT, 93.6% (95% CI: 84.9%–97.3%) for 3 months patients without CRT (Figure 1a, Table S1). The 3-month CCFP showed the greatest increase in the first month after catheter insertion (Figure 1b).

Smoothed hazard plots illustrated the dynamics of the monthly hazards of CRT (Figure 1c) and provided more detailed information on instantaneous risk than the Kaplan–Meier curves. The monthly hazard of CRT in the first month was the highest (16.4%), but the hazards decreased in the first 3 months. From month 4 onwards, the CRT hazards decreased to 3.3%.

Risk-dependent conditional CRT-free probability and monthly hazards over time

Multivariate analyses showed that chest radiotherapy, D-dimer ≥1.0 mg/l FEU, male sex, and VEGFI were identified as independent predictors for CRT (Figure 2). The patients were stratified into low- and high-risk groups based on these four independent risk factors. Patients in the low-risk group (defined as 0–1 risk factor) had better outcomes

TABLE 1 Clinical characteristics of the overall cohort of lung cancer patients with VADs

Characteristics	Number (%)
VEGFI	
Yes	69 (7.4)
No	870 (92.6)
Smoking	
Yes	568 (60.5)
No	371 (39.5)
Male	
Yes	644 (68.6)
No	295 (31.4)
Chest radiotherapy	
Yes	373 (39.7)
No	566 (60.3)
Insertion side	
Left	312 (33.2)
Right	627 (66.8)
D-dimer	
≥1.0 mg/l FEU	271 (28.9)
<1.0 mg/l FEU	668 (71.1)
Age	
≥65 years	227 (24.2)
<65 years	712 (75.8)
Stage	
I–II	137 (14.6)
III–IV	802 (85.4)
VTE history	
Yes	25 (2.7)
No	914 (97.3)
Chemistry	
Yes	707 (75.3)
No	232 (24.7)
VADs	
PICC	507 (54.0)
CVC	432 (46.0)
Catheter days	
0–30 days	283 (30.1)
31–60 days	342 (36.4)
61–90 days	127 (13.5)
91–436 days	187 (20.0)
CRT	
Yes	184 (19.6)
No	755 (80.4)

Abbreviations: CRT, catheter-related thrombosis; CVCs, central venous catheters; PICC, peripherally inserted central venous catheter; VADs, venous access devices; VEGFI, vascular endothelial growth factor inhibitor; VTE, venous thromboembolism.

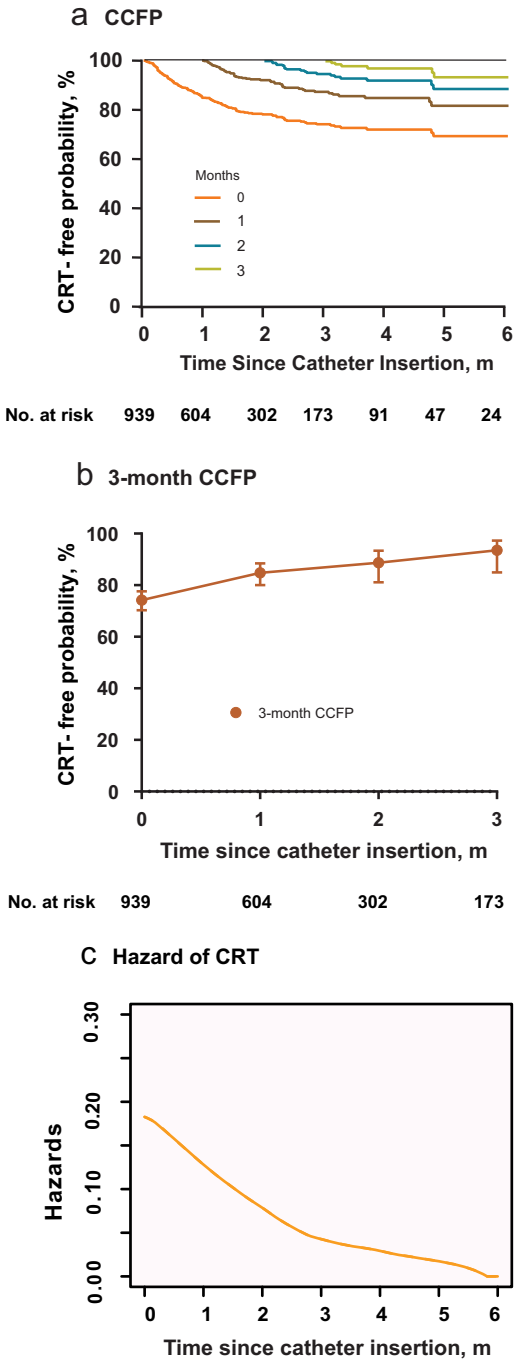

FIGURE 1 Conditional CRT-free probability and monthly hazard of CRT for lung cancers patients with VADs. (a) Conditional CRT-free probability curves as a function of the number of months without CRT since catheter insertion. (b) 3-month conditional CRT-free probability as a function of the number of months without CRT since catheter insertion. (c) Smoothed hazard plots for monthly rate of CRT after catheter insertion. CCFP, conditional CRT-free probability; CRT, catheter-related thrombosis; VADs, venous access devices.

than those in the high-risk group (defined as 2–4 risk factors) ($p < 0.01$, Figure 3a).

Each risk group achieved significantly different 3-month CCFP after catheter insertion, with rates of 81.8% (95% CI: 77.1%–85.6%) in the low-risk group and 64.0% (95% CI: 57.2%–70.0%) in the high-risk group ($p < 0.01$), suggesting excellent discrimination (Figure 3a). 3-month CCFP increased mainly in the high-risk group over time but remained excellent in the low-risk group (Figure 3b, Table S1). However, high-risk patients consistently maintained inferior CCFP compared with low-risk patients at any time point (Figure 3b, Table S1).

Patients in the low-risk group were constantly at a lower risk. Monthly CRT hazard was 12.1% for CRT in the first month. From month 2 onwards, the CRT hazards decreased to 4.2% (Figure 3c). Initially, high-risk patients had a higher risk. The monthly CRT hazards were 21.4% for CRT in the first month, which then decreased to 16.9% after 1 month. However, from month 3 onwards, the CRT hazards decreased to 8.3% (Figure 3c).

Risk-dependent CRT-free benefit according to various VADs

We then determined whether various VADs were associated with CRT. In the overall cohort, the CRT-free probability for patients with CVCs had better outcomes than those with PICCs (HR 1.76; 95% CI: 1.28–2.41; $p < 0.01$) (Figure 4a). After risk stratification, no difference was found in CRT-free probability between patients with PICCs and CVCs in the high-risk group (HR 1.50; 95% CI: 0.99–2.29; $p = 0.06$) (Figure 4c). However, the CRT-free probability for patients with CVCs was significantly better than those with PICCs in the low-risk group (HR 1.77; 95% CI: 1.09–2.89; $p = 0.02$) (Figure 4b).

In the low-risk group, CVCs were associated with an increase in CCFS compared to PICCs at 1 month ($p = 0.049$, Figure S1a) and 2 months ($p = 0.026$, Figure S1b), but this benefit was not significant at 3 months ($p = 0.752$, Figure 1c). However, in the high-risk group, no difference was found in the CCFP at 1 month ($p = 0.527$, Figure S1d), 2 months ($p = 0.214$, Figure S1e), and 3 months ($p = 0.690$, Figure S1f). These findings suggest a risk-dependent dynamic change in the CCFP according to the VADs.

DISCUSSION

The use of VADs has become a routine part of the management of patients with cancer, such as the administration of chemotherapy and parenteral nutrition.[9,23] With the development of VADs, multiple studies have focused on the complications of catheter-related thrombosis.[11–13,30,31] Thrombosis is recognized to have a detrimental effect on the quality of life and survival of patients with cancer.[5] However, the current predictive factors or tools assess CRT in a static manner at a single time point of catheterization. The subsequent hazard changes over time in various patient risk groups are not fully understood. In this cohort of patients with lung cancer with VADs, the CRT-free probability increased, whereas the hazards

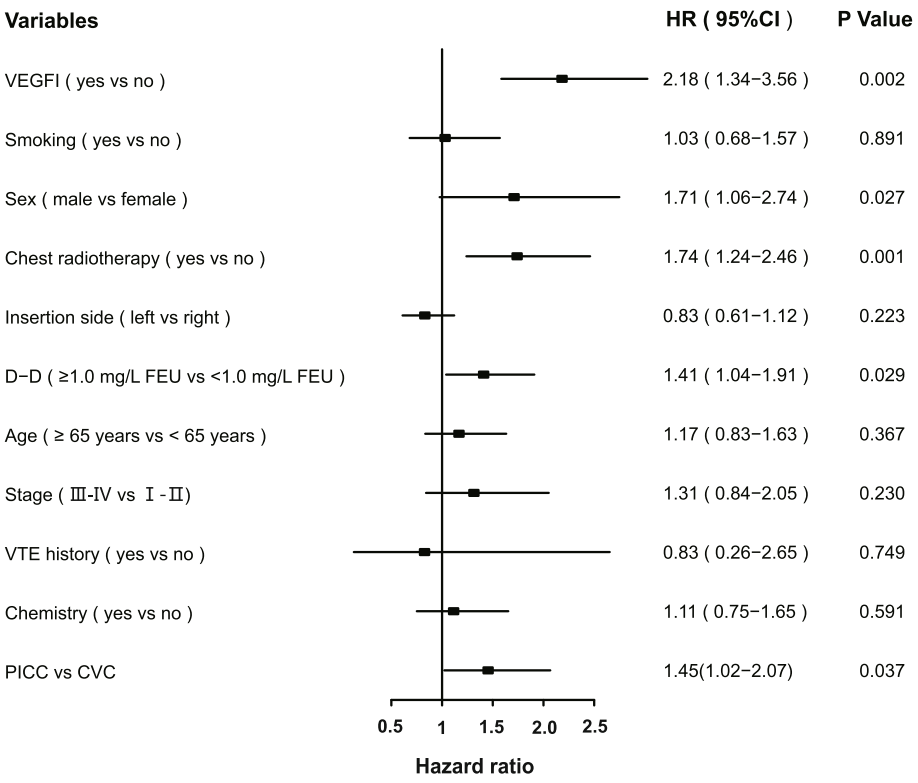

FIGURE 2 Forest plot showing independent predictors for CRT in lung cancer patients with VADs. Results suggest that chest radiotherapy, high level of D-dimer, male, PICC and VEGFI were identified as independent predictors for CRT in lung cancer patients. CRT, catheter-related thrombosis; CVC, central venous catheter; D-D, D-dimer; PICC, peripherally inserted central venous catheter; VADs, venous access devices; VEGFI, vascular endothelial growth factor inhibitor; VTE, venous thromboembolism.

of CRT decreased with time. Further analysis demonstrated that low- and high-risk patients had an initially higher but significantly decreased risk of CRT over time, whereas low-risk patients had a consistently lower risk of CRT than high-risk patients at any time point. Compared with PICCs, CVCs provided a CRT-free benefit in low-risk patients but not in high-risk patients. Within each risk group, time-dependent CRT-free probabilities and hazards after catheter insertion showed similar risk-dependent patterns across different VADs. These findings add to the accuracy of continuous estimates of CRT after catheter insertion and provide a rationale for risk-adapted choices of VADs and risk-adjusted prophylactic anticoagulation strategies in this population.

CRT has been recognized to affect the long-term curative effect of cancer treatment and even endanger a patient's life. In this study, we introduced a conditional approach to reflect time-dependent changes in the probability for patients with lung cancer with VADs. The conditional CRT-free probability increased greatly in the first month and slightly thereafter. This result was similar to the previous studies, which suggested that 1 month after catheter insertion was the time of high incidence of CRT.[10] The low hazards of CRT after 3 months suggest that late CRT rarely occur after catheter insertion. These results are consistent with the study of Lin et al., which suggested that more than 90% of CRT occurred within 3 months after catheter insertion.[10] From a dynamic standpoint, this finding suggests that a longer period of CRT-free probability was associated with an increased probability of a further CRT-free state. The absence of CRT over a 3-month landmark was associated with an excellent long-term CRT-free state after catheter insertion for patients with lung cancer in this cohort.

There have been previous studies on risk prediction models for CRT.[10,31,32] However, some of the risk covariates in these models were unsuitable for lung cancer patients. In addition, these analyses were based on proportional hazard models and implicitly assumed a constant risk of covariates. Data on how individual states evolve over time after catheter insertion are lacking. In this study, multivariate analyses suggested that D-dimer ≥1.0 mg/l FEU, VEGFI, chest radiotherapy, and male sex were identified as independent predictors for CRT in patients with lung cancer with VADs.[17,20–22,24] This result is similar to that of Hao et al. suggesting that D-dimer level could be used as a predictor for CRT.[33] The study of Kiuru et al. showed that the role of VEGFI might include direct endothelial cell injury, induced platelet aggregation, and activation of FcγRIIa platelet receptors.[34] However, platelet aggregation led to a blood hypercoagulable state and thrombosis in susceptible patients, and its effect depends on FcγRIIa platelet receptors.[35] In the study by Verso et al., the association between chest radiotherapy and CRT in patients with cancer was also observed.[22] This association is probably due to endothelial activation induced by radiotherapy, which acts synergistically with the endothelial damage associated with the catheter dwell in determining the local activation of the coagulation cascade. Based on these four independent risk factors, patients with lung cancer were stratified into low- and high-risk groups. The conditional CRT-free probability improved clearly in the high-risk group patients over time. In contrast, conditional CRT-free probability remained excellent (>80%) in low-risk group patients.

Patients in the high-risk group were more likely to undergo early CRT, especially in the first 2 months.

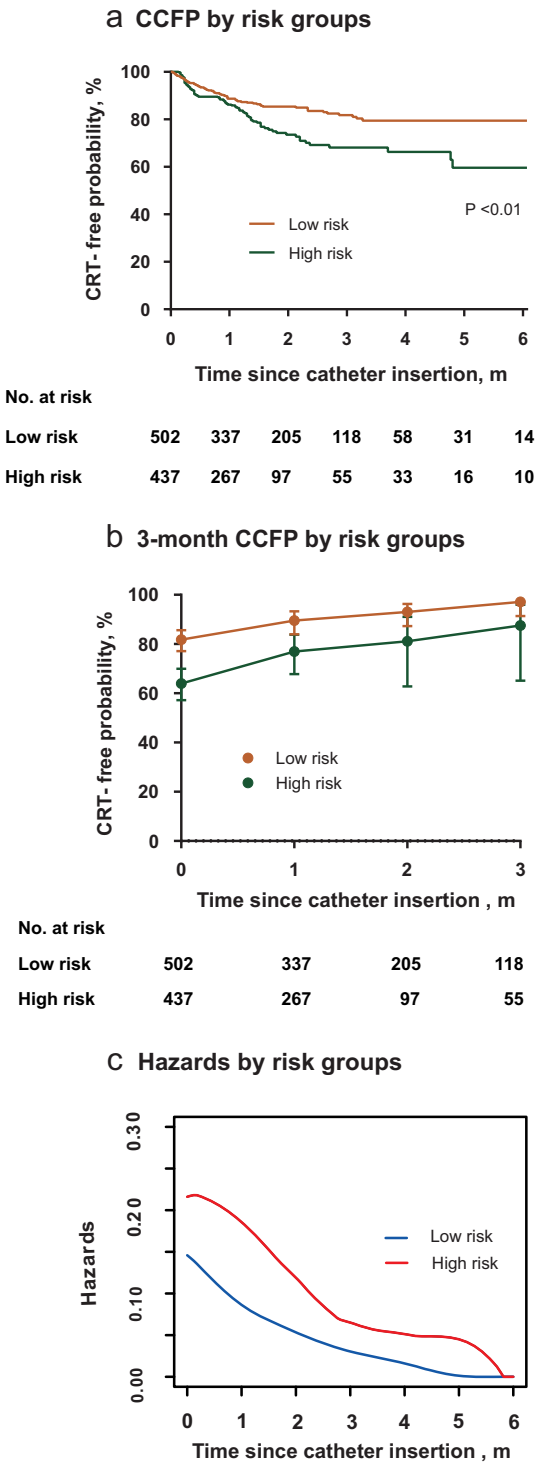

FIGURE 3 Kaplan–Meier curves, conditional CRT-free probability curves and hazards stratified by risk groups. (a) Kaplan–Meier curves of CRT-free probability at catheter insertion in low- and high-risk groups. (b) 3-month conditional CRT-free probability over time in low- and high-risk groups. (c) Smoothed hazard plots for monthly rate of CRT in low- and high-risk groups. CCFP, conditional CRT-free probability; CRT, catheter-related thrombosis.

However, from month 3 onwards, the monthly hazards decreased over time, resulting in comparably low hazards (<10%) in the high-risk group patients. Conversely, patients

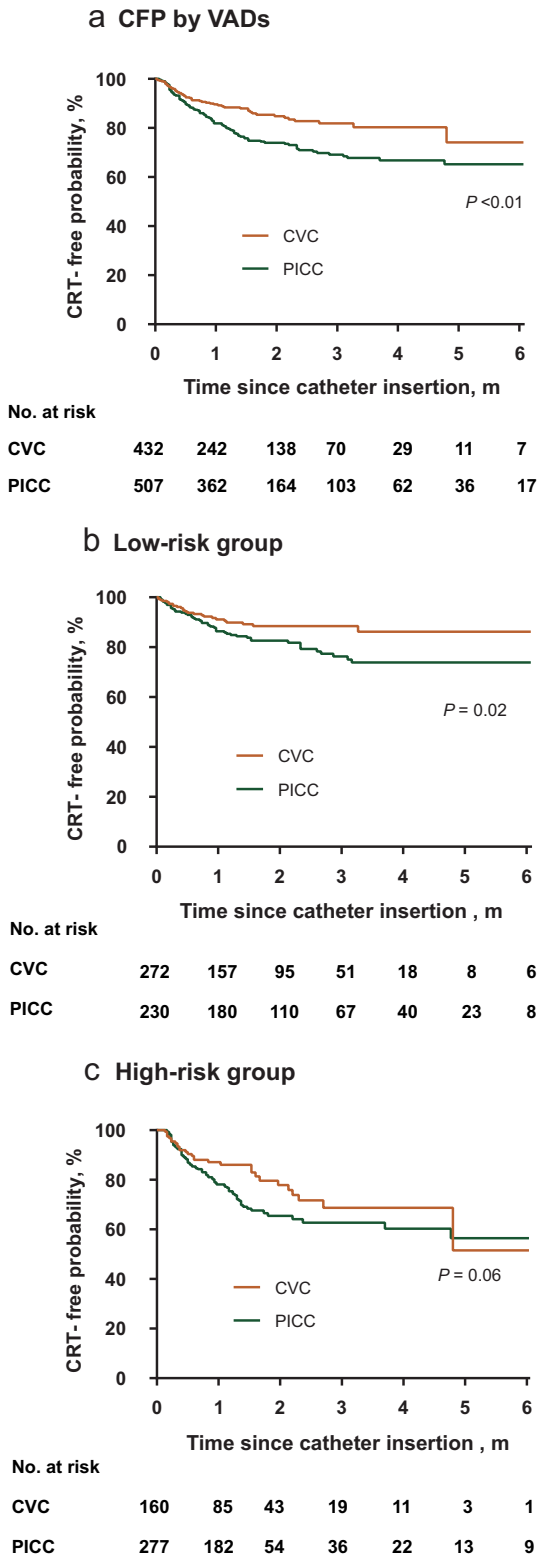

FIGURE 4 Kaplan–Meier curves of CRT-free probability by PICCs and CVCs in each risk group. (a) Kaplan–Meier curves of CRT-free probability for patients with PICCs and CVCs. (b) Kaplan–Meier curves of CRT-free probability for patients with PICCs and CVCs in low-risk groups. (c) Kaplan–Meier curves of CRT-free probability for patients with PICCs and CVCs in high-risk groups. CFP, CRT-free probability; CRT, catheter-related thrombosis; CVCs, central venous catheters; PICC, peripherally inserted central venous catheters; VADs, venous access devices.

in the low-risk group had a comparably lower risk of CRT. From month 2 onwards, the CRT hazards decreased to less than 5% in low-risk group patients. Consequently, all patients attained an equivalent favorable CRT-free probability (>85%) after 3 months, regardless of their initial risk category. Accordingly, we introduced a new term for a comparatively lower risk to low-risk patients (with 0–1 risk factor) and initially higher risk to high-risk patients (with 2–4 risk factors) who had more hazards at catheter insertion but reduced hazards during follow-up.

In the overall cohort, patients with CVCs had a lower CRT probability than those with PICCs. These results are consistent with those of previous studies.[36,37] Further analysis demonstrated that there was no difference in the CRT-free probability between patients with PICCs and CVCs in the high-risk group. In contrast, the CRT-free probability for patients with CVCs was significantly higher than that for patients with PICCs in the low-risk group. However, in the low-risk group, CVCs were associated with an increase in CRT-free probability compared with PICCs at 1 and 2 months, but this benefit was not significant at 3 months. These results indicated that in the high-risk group, the types of VADs were not the main factors affecting the occurrence of CRT, whereas, in the low-risk group, the relationship between patients with PICCs and the occurrence of early CRT was clear but not obvious over 3 months.

This study had several implications for clinical practice. These results suggest that the first 3 months after catheter insertion is a critical period, especially in the first month, warranting routine ultrasound examination. Regardless of the VADs type, initially, higher-risk patients may require more intensive surveillance during the first 3 months and an appropriately reduced follow-up frequency after 3 months. However, low-risk patients require more intensive surveillance during the first month, especially those with PICCs, followed by less frequent follow-up. However, the prevention of CRT should be initiated. Previous studies support the use of low-molecular-weight heparin and daily handgrip exercise with an elastic ball for patients at high risk of CRT.[38,39] These methods may be used in clinical practice to facilitate blood circulation after catheter insertion.

This study had several limitations. First, the population in our study was probably heterogeneous, with low rates of patients being treated with VEGFI. Second, this was a single-center retrospective study with inherent limitations, such as potential confounding factors or validation. Our study might not reflect the full spectrum of patients with lung cancer. Thus, a multicenter large-scale collaborative study is required for further verification. Third, we only assessed CCFP and hazard rates in patients with lung cancer. Other cancers were analyzed in a further study.

In conclusion, these findings suggest that risk-dependent changes in CRT-free probability over time in patients with lung cancer with VADs provide accurate information on continual CRT-free expectations. These valuable dynamic data may better optimize the risk-adjusted choices of VADs and risk-adjusted prophylactic anticoagulation strategies for patients with lung cancer.

ACKNOWLEDGMENT

This study was supported by CAMS Innovation Fund for Medical Sciences (CIFMS) (grant no. 2021-12M-1-012), Beijing Hope Run Special Fund of Cancer Foundation of China (LC2020A17) and Beijing Chaoyang District Science and Technology Plan (CYSF2030).

CONFLICT OF INTEREST

None of the authors report any conflict of interest.

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REFERENCES

1. Gao S, Li N, Wang S, Zhang F, Wei W, Li N, et al. Lung cancer in People's Republic of China. J Thorac Oncol. 2020;15:1567–76.
2. Hong QY, Wu GM, Qian GS, Hu CP, Zhou JY, Chen LA, et al. Prevention and management of lung cancer in China. Cancer. 2015;121-(Suppl 17):3080–8.
3. Campagna S, Gonella S, Berchialla P, Morano G, Rigo C, Zerla PA, et al. Can peripherally inserted central catheters be safely placed in patients with cancer receiving chemotherapy? A retrospective study of almost 400,000 catheter-days. Oncologist. 2019;24:e953–9.
4. Scrivens N, Sabri E, Bredeson C, McDiarmid S. Comparison of complication rates and incidences associated with different peripherally inserted central catheters (PICC) in patients with hematological malignancies: a retrospective cohort study. Leuk Lymphoma. 2020;61:156–64.
5. Robinson A, Souied O, Bota AB, Levasseur N, Stober C, Hilton J, et al. Optimal vascular access strategies for patients receiving chemotherapy for early-stage breast cancer: a systematic review. Breast Cancer Res Treat. 2018;171:607–20.
6. Khorana AA, Francis CW, Culakova E, Kuderer NM, Lyman GH. Thromboembolism is a leading cause of death in cancer patients receiving outpatient chemotherapy. J Thromb Haemost. 2007;5:632–4.
7. Evans RS, Sharp JH, Linford LH, Lloyd JF, Tripp JS, Jones JP, et al. Risk of symptomatic DVT associated with peripherally inserted central catheters. Chest. 2010;138:803–10.
8. Schmidli J, Widmer MK, Basile C, de Donato G, Gallieni M, Gibbons CP, et al. Editor's choice—vascular access: 2018 clinical practice Guidelines of the European Society for Vascular Surgery (ESVS). Eur J Vasc Endovasc Surg. 2018;55:757–818.
9. Chopra V, Anand S, Hickner A, Buist M, Rogers MA, Saint S, et al. Risk of venous thromboembolism associated with peripherally inserted central catheters: a systematic review and meta-analysis. Lancet. 2013;382:311–25.
10. Lin BX, Xu CS. Risk factors of PICC-related venous thrombosis in breast cancer patients undergoing chemotherapy. Int J Gen Med. 2021;14:1337–41.
11. Ko JJ, Bernard B, Tran B, Li H, Asif T, Stukalin I, et al. Conditional survival of patients with metastatic testicular germ cell tumors treated with first-line curative therapy. J Clin Oncol. 2016;34:714–20.
12. Harshman LC, Xie W, Bjarnason GA, Knox JJ, MacKenzie M, Wood L, et al. Conditional survival of patients with metastatic renal-cell carcinoma treated with VEGF-targeted therapy: a population-based study. Lancet Oncol. 2012;13:927–35.
13. Liu X, Wu T, Zhu SY, Shi M, Su H, Wang Y, et al. Risk-dependent conditional survival and failure Hazard after radiotherapy for early-stage Extranodal natural killer/T-cell lymphoma. JAMA Netw Open. 2019;2:e190194.
14. Chopra V, Kaatz S, Conlon A, Paje D, Grant PJ, Rogers MAM, et al. The Michigan risk score to predict peripherally inserted central catheter-associated thrombosis. Thromb Haemost. 2017;15:1951–62.

15. Mulder FI, Candeloro M, Kamphuisen PW, Di Nisio M, Bossuyt PM, Guman N, et al. The Khorana score for prediction of venous thromboembolism in cancer patients: a systematic review and meta-analysis. Haematologica. 2019;104:1277–87.
16. Gaitini D. Current approaches and controversial issues in the diagnosis of deep vein thrombosis via duplex Doppler ultrasound. J Clin Ultrasound. 2006;34:289–97.
17. Gizzi M, Oberic L, Massard C, Poterie A, Le Teuff G, Loriot Y, et al. Predicting and preventing thromboembolic events in patients receiving cisplatin-based chemotherapy for germ cell tumours. Eur J Cancer. 2016;69:151–7.
18. Heit JA, Ashrani A, Crusan DJ, McBane RD, Petterson TM, Bailey KR. Reasons for the persistent incidence of venous thromboembolism. Thromb Haemost. 2017;117:390–400.
19. Chen P, Wan GM, Zhu BQ. Incidence and risk factors of symptomatic thrombosis related to peripherally inserted central catheter in patients with lung cancer. J Adv Nurs. 2021;77:1284–92.
20. Vedantham S, Goldhaber SZ, Julian JA, Kahn SR, Jaff MR, Cohen DJ. Pharmacomechanical catheter-directed thrombolysis for deep-vein thrombosis. N Engl J Med. 2017;377:2240–52.
21. Hou J, Zhang J, Ma M, Gong Z, Xu B, Shi Z. Thrombotic risk factors in patients with superior vena cava syndrome undergoing chemotherapy via femoral inserted central catheter. Thromb Res. 2019;184: 38–43.
22. Verso M, Agnelli G, Kamphuisen PW, Ageno W, Bazzan M, Lazzaro A. Risk factors for upper limb deep vein thrombosis associated with the use of central vein catheter in cancer patients. Intern Emerg Med. 2008;3:117–22.
23. Jones D, Wismayer K, Bozas G, Palmer J, Elliott M, Maraveyas A. The risk of venous thromboembolism associated with peripherally inserted central catheters in ambulant cancer patients. Thromb J. 2017;15:25.
24. Al-Asadi O, Almusarhed M, Eldeeb H. Predictive risk factors of venous thromboembolism (VTE) associated with peripherally inserted central catheters (PICC) in ambulant solid cancer patients: retrospective single Centre cohort study. Thrombosis Journal. 2019;17:2.
25. Chopra V, Fallouh N, McGuirk H, Salata B, Healy C, Kabaeva Z, et al. Patterns, risk factors and treatment associated with PICC-DVT in hospitalized adults: a nested case-control study. Thromb Res. 2015; 135:829–34.
26. Günther SC, Schwebel C, Hamidfar-Roy R, Bonadona A, Lugosi M, Ara-Somohano C, et al. Complications of intravascular catheters in ICU: definitions, incidence and severity. A randomized controlled trial comparing usual transparent dressings versus new-generation dressings (the ADVANCED study). Intensive Care Med. 2016;42:1753–65.
27. Kang J, Chen W, Sun W, Ge R, Li H, Ma E, et al. Peripherally inserted central catheter-related complications in cancer patients: a prospective study of over 50,000 catheter days. J Vasc Access. 2017;18:153–7.
28. Debourdeau P, Farge D, Beckers M, Baglin C, Bauersachs RM, Brenner B, et al. International clinical practice guidelines for the treatment and prophylaxis of thrombosis associated with central venous catheters in patients with cancer. J Thromb Haemost. 2013;11:71–80.
29. Epanechnikov V. Nonparametric estimation of a multivariate probability density. Theory Probab Appl. 1969;14:153–8.
30. Chen H, Tao L, Zhang X, Jing W, Su X, Chen H, et al. The effect of systemic and local risk factors on triggering peripherally inserted central catheter-related thrombosis in cancer patients: a prospective cohort study based on ultrasound examination and structural equation modeling. Int J Nurs Stud. 2021;121:104003.
31. Debourdeau P, Lamblin A, Debourdeau T, Marcy PY, Vazquez L. Venous thromboembolism associated with central venous catheters in patients with cancer: from pathophysiology to thromboprophylaxis, areas for future studies. J Thromb Haemost. 2021;19:2659–73.
32. Liu B, Xie J, Sun X, Wang Y, Yuan Z, Liu X. Development and validation of a new clinical prediction model of catheter-related thrombosis based on vascular ultrasound diagnosis in cancer patients. Front Cardiovasc Med. 2020;7:571227.
33. Hao N, Xie X, Zhou Z, Li J, Kang L, Wu H, et al. Nomogram predicted risk of peripherally inserted central catheter related thrombosis. Sci Rep. 2017;7:6344.
34. Kiuru M, Schwartz M, Magro C. Cutaneous thrombogenic vasculopathy associated with bevacizumab therapy. Dermatol Online J. 2014;20: 13030.
35. Rollin J, Pouplard C, Gruel Y. Risk factors for heparin-induced thrombocytopenia: focus on Fcγ receptors. Thromb Haemost. 2016;116: 799–805.
36. Nolan ME, Yadav H, Cawcutt KA, Cartin-Ceba R. Complication rates among peripherally inserted central venous catheters and centrally inserted central catheters in the medical intensive care unit. J Crit Care. 2016;31:238–42.
37. Fracchiolla NS, Todisco E, Bilancia A, Gandolfi S, Orofino N, Guidotti F, et al. Clinical management of peripherally inserted central catheters compared to conventional central venous catheters in patients with hematological malignancies: a large multicenter study of the REL GROUP (rete Ematologica Lombarda-Lombardy hematologic network, Italy). Am J Hematol. 2017;92:E656–9.
38. Lv S, Liu Y, Wei G, Shi X, Chen S, Zhang X. The anticoagulants rivaroxaban and low molecular weight heparin prevent PICC-related upper extremity venous thrombosis in cancer patients. Medicine. 2019;98:e17894.
39. Liu K, Zhou Y, Xie W, Gu Z, Jin Y, Ye X, et al. Handgrip exercise reduces peripherally-inserted central catheter-related venous thrombosis in patients with solid cancers: a randomized controlled trial. Int J Nurs Stud. 2018;86:99–106.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Wang Y, Cui C, Liu X, Deng L, Yang K, Li B, et al. Conditional catheter-related thrombosis free probability and risk-adapted choices of catheter for lung cancer. Thorac Cancer. 2022;13(12):1814–21. https://doi.org/10.1111/1759-7714.14460