Prognostic Significance of $^{18}$F-FDG PET/CT Imaging in Survival Outcomes in Patients with Renal Cell Carcinoma

Renal Hücreli Karsinom Hastalarının Sağkalım Sonuçlarında $^{18}$F-FDG PET/BT Görüntülemenin Prognostik Önemi

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Abstract

Objectives: Renal cell carcinoma (RCC) comprises 85%-90% of primary renal malignant tumors originating from the renal tubular epithelium and has different genetic characteristics. This study aimed to investigate the potential predictive role of $^{18}$F-fluorodeoxyglucose (FDG) positron emission tomography/computed tomography (PET/CT) and metabolic parameters in overall survival (OS) analysis in patients with RCC.

Methods: $^{18}$F-FDG PET/CT images of 100 patients performed for initial staging before surgical or oncological treatments were analyzed retrospectively. Maximum standard uptake value ($\text{SUV}_{\text{max}}$-T) of the primary tumor was calculated and its relationship to patient survival was analyzed. The median follow-up time was 5.61 years (0.01-8.7 years).

Results: $\text{SUV}_{\text{max}}$-T levels in the patients ranged from 2.1 to 48.9 (median 5.9, mean 9.0±7.9). $\text{SUV}_{\text{max}}$-T was significantly higher in RCC-related death more positive than in the negative cases ($p<0.001$). However, there was not any statistical significance for gender and pathological subtypes on the survival outcomes of patients ($p=0.264$ and $p=0.784$). The patients’ 1-year, 3-year, and 5-year OS rates were 71%, 61%, and 57%, respectively. The highest action of $\text{SUV}_{\text{max}}$-T for estimating OS was a cut-off level of 5.4, which maintained sensitivity and specificity of 81% and 75%, respectively. However, cancer staging remained independent significance for OS ($p<0.001$).

Conclusion: $\text{SUV}_{\text{max}}$ of primary tumor and cancer stage were demonstrated as significant prognostic factors for OS in patients with RCC. Evaluation of $^{18}$F-FDG accumulation with PET/CT may help plan treatment strategies and predict survival outcomes of these patients at diagnosis.

Keywords: Fluorine-18-fluorodeoxyglucose, positron emission tomography, prognosis, renal cell carcinoma, survival

Öz

Amaç: Renal hücreli karsinom (RHK), renal tübüler epitelden kaynaklanan primer renal malign tümörlerin %85-90’ını oluşturur ve farklı genetik özellikler içerir. Bu çalışmanın amacı RHK tanılı hastalarda genel sağkalım analizinde $^{18}$F-florodeoksiglukoz (FDG) pozitron emisyon tomografisi/bilgisayarlı tomografi (PET/CT) ve metabolik verilerin potansiyel öngörücü rolünü araştırmaktır.

Yöntem: Hastalar (n=100) genelde cerrahi veya onkolojik tedaviler uygulanmadan önce, evreleme $^{18}$F-FDG PET/BT görüntülemeleri incelendi. Primer tümörün maksimum standartlaştırılmış alım değeri ($\text{SUV}_{\text{max}}$-T) hesaplandı ve hasta sağkalımı ile ilişkisi analiz edildi. Medyan takip süresi 5.61 yıl idi (0.01-8.7 yıl).

Bulgular: Tüm hastalarda $\text{SUV}_{\text{max}}$-T ölçümleri, 2.1 ile 48.9 arasında idi (median 5.9, ortalama 9.0±7.9). $\text{SUV}_{\text{max}}$-T, RHK ile ilişkili eksitus pozitif olgularda negatif olgulardan anlamılı olarak daha yüksek idi ($p<0.001$), ancak hastaların sağkalım sonuçlarında cinsiyet ve patolojik alt tipler için...
Introduction
Kidney cancers have histological subtypes with different characteristics, account for approximately 3% of adult cancers, and are in the third rank among urogenital cancers (1). Renal cell carcinoma (RCC) comprises 85%-90% of primary renal malignant tumors originating from the renal tubular epithelium and has different genetic characteristics (2). RCCs, highly angio-invasive tumors, tend to metastasize to the lungs, bones, liver, and brain by hematogenous and lymphatic spread. Survival in RCC is poor, especially in the clear cell subtype, which is prone to diagnosis at an advanced stage, and 20%-30% of patients are also in the metastatic stage during this period (3,4). Therefore, the management of these patients is very challenging. The 5-year survival rate is less than 20%, even if the metastatic tumor is removed, the survival is between 25 and 50% (5). However, the incidence of renal tumors, which are often incidentally diagnosed as smaller and low-grade tumors, is increasing because of the widespread use of non-invasive imaging tools. The histological subtype, grade, size, extracapsular spread, and lymphovascular invasion status can be considered among the main factors affecting the prognosis of renal tumors (6).

Positron emission tomography integrated with computed tomography (PET/CT) imaging has become a key modality for imaging patients with cancer and is frequently used in renal cancers, particularly to detect recurrence and evaluate treatment response. Cancer staging with 18F-fluorodeoxyglucose (FDG) PET imaging is since malignant tumor cells have higher glucose metabolism than normal cells (7). However, renal cancers are prone to exhibit low tracer uptake (8,9).

Whilst there is a wealth of literature addressing the use of 18F-FDG PET/CT in renal tumors, the relationship between PET metabolic measurements obtained from the pretreatment initial staging examination and patients’ survival after long-term follow-up has not been well investigated. Therefore, we investigated the potential predictive role of 18F-FDG PET/CT and metabolic data in the analysis of survival in patients with RCC.

Materials and Methods
Patients
A total of 100 patients [66 men and 34 women; mean age 58.1±11.7 (range: 34-82 years)] with RCC were examined between August 2013 and March 2022 on 18F-FDG PET/CT scans were retrospectively enrolled in the analyses at the initial staging before surgical or oncological treatments. The University of Health Sciences Turkey, Istanbul Training and Research Hospital Clinical Research Ethics Committee approved the study protocol (number: 88, date: 02.03.2022) and the Declaration of Helsinki rules were followed to conduct this study.

18F-FDG PET/CT Scan and Interpretation of Images
18F-FDG doses according to patient weight (3.7 mBq/kg) were injected into the patients when their blood glucose values were <140 mg/dL. Initially, CT (n=68 with contrast-enhanced, n=32 without contrast-enhanced) data followed by PET scan were received 60 min after 18F-FDG injection between the vertex-proximal thigh in an mCT 20 PET/CT scanner (Siemens Molecular Imaging, Hoffman Estates, IL) and all images were examined first visually and then semi-quantitatively. Regions with increased 18F-FDG uptake than background and nearby structures in primary tumors, nodal and distant metastases were recorded. Maximum standardized uptake value (SUVmax) was measured automatically by drawing an elliptical volume of interest to include the pathologo tumoral lesions in the three planes in 18F-FDG PET/CT. The review process was carried out by combining the metabolic findings from the PET component with anatomical information obtained from the CT component. Initial staging images were evaluated to determine whether primary tumor SUVmax (SUVmax-T) predicted patient survival. According to the 8th edition of the American Joint Committee on Cancer 2018 tumor, node, and metastasis (TNM) staging system, the disease stage was determined, and the patients were followed up for at least 5 years or until death to evaluate their survival outcomes (10).

Statistical Analysis
Study data were evaluated by SPSS 25.0 software (IBM, Armonk, NY, USA) and p<0.05 was considered
statistically significant. Numbers and percentages were used to indicate the categorical data. Median and mean with standard deviation values were used to express the quantitative calculations. The relationship between survival and categorical variables was assessed by Pearson chi-squared. Time from PET/CT to death or final analysis of the study was calculated to determine overall survival (OS) and survival curves were performed and compared using the Kaplan-Meier method and Mantel-Cox Log-rank test. Receiver operating characteristic curve (ROC) analysis was used to express the cut-off values for OS. Univariate analyses of SUV\textsubscript{max} on survival outcomes were measured using the Cox regression analysis. Independent variables related to OS were determined by significant factors by using multivariate logistic regression analysis. The data were expressed at a 95% confidence interval (CI).

**Results**

Overall, 65 patients had clear cell RCC, 21 had chromophobe RCC, nine had papillary RCC, and five had unclassified RCC. The clinicopathological TNM staging was stage 1 in 40 patients, stage 2 in 14 patients, stage 3 in 9 patients, and stage 4 in 37 patients. Distant metastases were visualized in 34 patients on \textsuperscript{18}F-FDG PET/CT, and the lungs and bones were the most common sites of distant metastasis (Figure 1). Information on the characteristics of the patients is presented in Table 1. The median follow-up time was 5.61 years (range, 0.01-8.7 years; 0.78 years for deceased patients, 7.78 years for living patients). Fifty-two RCC-related deaths occurred; the remaining 48 patients were alive at the last check.

![Figure 1. Maximal intensity projection (A), axial CT, and fusion PET/CT (B, C) images of a 57-year-old woman with clear cell RCC. The patient had T4 and stage 4 cancer with lung, liver, bone, and lymph node metastases. Primary tumor SUV\textsubscript{max} was 25.1. She died 6 months after the initial evaluation 18F-FDG PET/CT.](image)

| Table 1. Characteristics of the patients |
|----------------------------------------|
| Variables                             | n    |
| Age, median (range)                   | 58 (34-82) |
| Sex                                    | 66 |
| Male                                   | 34 |
| Histopathological type                 |     |
| Clear cell                             | 65 |
| Chromophobe                            | 21 |
| Papillary                              | 9  |
| Unclassified                           | 5  |
| Tumor stage                            |     |
| T1                                     | 46 |
| T2                                     | 22 |
| T3                                     | 20 |
| T4                                     | 12 |
| TNM cancer staging                     |     |
| I                                      | 40 |
| II                                     | 14 |
| III                                    | 9  |
| IV                                     | 37 |
| Nephrectomy                            |     |
| Yes                                    | 66 |
| No                                     | 34 |
| RCC-related death                      | 52 |

TNM: Tumor, node, and metastasis, RCC: Renal cell carcinoma, SUV\textsubscript{max}: Maximum standard uptake value, FDG: Fluorodeoxyglucose
highest sensitivity and specificity, respectively (Table 2). These results suggest that \( \text{SUV}_{\text{max}} \cdot \text{T} \) is a reliable parameter for predicting OS. The patients’ 1-year, 3-year, and 5-year OS rates were 71%, 61%, and 57%, respectively. Furthermore, OS rates were 52% vs. 48% in patients with \( \text{SUV}_{\text{max}} \leq 5.4 \) vs. >5.4 on \(^{18}\text{F}\)-FDG PET/CT. Also, univariate Cox regression analysis identified the values of \( \text{SUV}_{\text{max}} \cdot \text{T} \) as a significant prognostic marker for OS (\( p<0.001 \), Odds ratio: 1.135, 95% CI: 1.098-1.173).

The effect of \( \text{SUV}_{\text{max}} \) on OS was compared with that of possible prognostic markers and the \( \text{SUV}_{\text{max}} \) levels exhibiting statistical significance in univariate analysis were included in the multivariate analysis. The findings of the multivariate analysis are indicated in Table 3. Analysis of \( \text{SUV}_{\text{max}} \) in association with patients’ gender, histological tumor subtypes, and tumor staging at the initial pretreatment period revealed that \( \text{SUV}_{\text{max}} \cdot \text{T} \) was a significant independent prognostic factor of OS in patients with RCC (\( p<0.001 \)). However, cancer staging remained independent significance for OS (\( p>0.001 \)). Regardless of the tumor stage and the histopathological subgroups, patients with a higher \( \text{SUV}_{\text{max}} \) had a shorter OS than patients with a lower \( \text{SUV}_{\text{max}} \) (Figure 4). In this study, the mean OS for 48 patients with \( \text{SUV}_{\text{max}} \leq 5.4 \) was 7.4 years (95% CI: 6.623-8.181), while in 52 patients with \( \text{SUV}_{\text{max}} >5.4 \), the mean OS was 3.3 years (95% CI: 2.349-4.170). Differences in OS among these patients were statistically significant (\( \text{SUV}_{\text{max}} \leq 5.4 \) vs. >5.4, \( p<0.001 \)).

**Discussion**

Oncological PET/CT imaging has proven its importance in diagnosis, staging, evaluation of treatment response, and recurrence detection in most cancer types and is an indispensable modality in this field. Since RCC exhibits low glucose metabolism and tumoral \(^{18}\text{F}\)-FDG uptake, PET/CT is more limitedly preferred as an imaging tool in the initial staging (11,12). However, several researchers have examined the efficacy of \(^{18}\text{F}\)-FDG PET in determining the metabolic and molecular characterization of renal tumors (13,14). In a retrospective study investigating the impact of \( \text{SUV}_{\text{max}} \) levels on patient mortality in renal tumors, it was determined that patients with metastasis lived shorter, liver metastases showed shorter survival, and the lung metastases had higher \( \text{SUV}_{\text{max}} \) levels (15).

Diagnostic values of PET/CT at different \( \text{SUV}_{\text{max}} \) cut-off values in survival analysis are available for RCC in the literature (16,17). Komek et al. (18) investigated the relationship between the mortality results of 21 patients with RCC and showed that \( \text{SUV}_{\text{max}} \) values of \( \geq 4.5 \), obtained from pre-treatment \(^{18}\text{F}\)-FDG PET/CT imaging, resulted in increased mortality. Furthermore, a cut-off value of 8.8 and \( \text{SUV}_{\text{max}} \) values higher than this have been reported as predictors of survival for advanced RCC (19). In this study, we evaluated the patient outcomes and mortality rates according to different \( \text{SUV}_{\text{max}} \) values, which refer to 1-year, 3-year, and 5-year results and we determined the patients’ mortality rates as 29%, 39%, and 43%, respectively (Figure 5). Nakaigawa et al. (20) evaluated 101 patients with RCC during the pretreatment or follow-up period and classified study patients into three subgroups based on their highest
SUV$_{\text{max}}$ levels and reported significant differences in OS for RCC. Subjects were followed for a median of 18 months and the median OS of patients with SUV$_{\text{max}}$ <7.0, ≥7.0, and <12.0, and ≥12.0 was found as 41.9, 20.6, and 4.2 months, respectively. In this study, the median follow-up time of our patients was 5.61 years, and we observed the mean OS as 7.4 and 3.3 years, respectively, for SUV$_{\text{max}}$ ≤5.4 vs. >5.4 levels, with sensitivity and specificity results of 81% and 75%. Additionally, the SUV$_{\text{max}}$ threshold of 7.4 was significant in distinguishing patient mortality and survival within 1 year after PET/CT evaluation (Figure 6).

The use of volumetric measures such as metabolic tumor volume (MTV) and total lesion glycolysis (TLG) provided a correlation with prognosis in published studies (21). Nakajima et al. (22) showed that MTV and TLG calculated from PET data are also important prognostic markers in the survival analysis of RCC patients. Further pre-treatment TLG was found to be an independent indicator of the prognosis of OS in another study (23). Besides PET measurements, the prognostic value of pathological subtypes was investigated, and the clear cell variant was more prone to metastasis than the other two variants and exhibited a poor prognosis, but we did not observe any significant difference between the survival times of the histological

| Table 2. Receiver operating characteristic analysis for the efficacy of SUV$_{\text{max}}$ in predicting mortality relative to patient survival time |
|---|
| SUV$_{\text{max}}$ | Cut-off level | Death | AUC | p value | Sensitivity (%) | Specificity (%) | 95% CI |
|---|---|---|---|---|---|---|---|
| 1-year survival | > 7.4 | 29 | 0.831 | <0.0001 | 75.9 | 77.5 | 0.742-0.898 |
| 3-year survival | >5.5 | 39 | 0.821 | <0.0001 | 84.6 | 67.2 | 0.732-0.891 |
| 5-year survival | >5.5 | 43 | 0.821 | <0.0001 | 83.7 | 70.2 | 0.732-0.891 |
| Overall survival | >5.4 | 52 | 0.837 | <0.0001 | 80.8 | 75.0 | 0.750-0.903 |

SUV$_{\text{max}}$: Maximum standardized uptake value, AUC: Area under curve, CI: Confidence interval

| Table 3. Multivariate logistic regression analysis for patient survival outcomes |
|---|
| Variable | OR | 95% CI | p value |
|---|---|---|---|
| SUV$_{\text{max}}$ | 1.076 | 1.036-1.118 | <0.001 |
| Age | 1.028 | 0.997-1.060 | 0.081 |
| Gender | 0.660 | 0.358-1.218 | 0.184 |
| T-stage | 0.928 | 0.688-1.252 | 0.625 |
| TNM stage | 1.985 | 1.444-2.729 | <0.001 |

SUV$_{\text{max}}$: Maximum standardized uptake value, OR: Odds ratio, CI: Confidence interval, TNM: Tumor, node, and metastasis

Figure 4. Kaplan-Meier survival graphs with log-rank (Mantel-Cox) present significant differences in survival outcomes of study patients classified by SUV$_{\text{max}}$ values. SUV$_{\text{max}}$ >7.5 for 1-year survival (A), SUV$_{\text{max}}$ ≥5.5 for 3-year survival (B), SUV$_{\text{max}}$ >5.5 for 5-year survival (C), and SUV$_{\text{max}}$ >5.4 for overall survival (D) were associated with mortality and shorter OS (p<0.001 for all)

SUV$_{\text{max}}$: Maximum standard uptake value, OS: Overall survival

Figure 5. Axial CT (A), PET (B), and fusion PET/CT (C) images of a 54-year-old man patient with clear cell type RCC. The patient had stage 3 cancer with a T3 tumor on PET/CT performed at the initial staging. Primary tumor SUV$_{\text{max}}$ was 6.5. He died of recurrent metastatic disease 2.7 years after initial evaluation. $^{18}$F-FDG PET/CT PET/CT: Positron emission tomography/computed tomography, RCC: Renal cell carcinoma, SUV$_{\text{max}}$: Maximum standard uptake value, FDG: Fluorodeoxyglucose

Figure 6. Axial CT (A), PET (B), and fusion PET/CT (C) images of a 67-year-old living patient with stage 1 cancer were received 7.4 years ago. He had chromophobe type RCC in the right kidney with a SUV$_{\text{max}}$ value of 3.9 PET/CT: Positron emission tomography/computed tomography, RCC: Renal cell carcinoma, SUV$_{\text{max}}$: Maximum standard uptake value, FDG: Fluorodeoxyglucose
subgroups (24). Tumor size, grading system, various other markers, and different radiopharmaceuticals used in hybrid molecular imaging have been reported in several articles as potential predictors of the prognosis of patients with RCC (25,26,27).

**Study Limitations**

This study had some limitations. First, our retrospective study showed a heterogeneous distribution among pathological subgroups and tumor stages. Also, the differences in the patients’ treatment protocols and follow-up strategies may have affected the survival analyses. Therefore, well-designed prospective studies are required to validate our findings.

**Conclusion**

Patients with high primary tumor SUV\(_{\text{max}}\) had increased mortality rates and shorter survival. SUV\(_{\text{max}}\) and the high-cancer stage were demonstrated as the significant prognostic predictors in patients with RCC. We think that SUV\(_{\text{max}}\) can act as a potential biomarker and reflect the disease prognosis. Evaluation of \(_{18}\)F-FDG accumulation using PET/CT may help plan treatment strategies and predict survival outcomes of these patients at diagnosis.

**Ethics**

**Ethics Committee Approval:** The University of Health Sciences Turkey, Istanbul Training and Research Hospital Clinical Research Ethics Committee approved the study protocol (number: 88, date: 02.03.2022) and the Declaration of Helsinki rules were followed to conduct this study.

**Informed Consent:** Externally peer-reviewed.

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**Authorship Contributions**

Surgical and Medical Practices: G.T., C.G., Ö.F.Ş., E.A., N.E., T.F.Ç., Concept: G.T., C.G., Ö.F.Ş., E.A., N.E., T.F.Ç., Design: G.T., C.G., Ö.F.Ş., E.A., N.E., T.F.Ç., Data Collection or Processing: G.T., C.G., Ö.F.Ş., E.A., N.E., T.F.Ç., Analysis or Interpretation: G.T., C.G., Ö.F.Ş., E.A., N.E., T.F.Ç., Literature Search: G.T., C.G., Ö.F.Ş., E.A., Writing: G.T., T.F.Ç.

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**References**

1. Siegel RL, Miller KD, Fuchs HE, Jemal A. Cancer statistics, 2021. CA Cancer J Clin 2021;71:7-33. Erratum in: CA Cancer J Clin 2021;71:359.
2. Ricketts CJ, De Cubas AA, Fan H, Smith CC, Lang M, Reznik E, Bowlby LR, Gibb EA, Akbani R, Beroukhim R, Bottaro DP, Choueiri TK, Gibbs RA, Goldin AK, Haake S, Hakimi AA, Henske EP, Hsieh JJ, Ho TH, Kanchi RS, Krishnan B, Kwiatkowski DJ, Lui W, Merino MJ, Mills GB, Myers J, Nickerson ML, Reutter VE, Schmidt LS, Shelley CS, Shen H, Shuck B, Signoretti S, Srinivasan R, Tamboli P, Thomas G, Vincent BG, Vocke CD, Wheeler DA, Yang L, Kim WY, Robertson AG; Cancer Genome Atlas Research Network, Spellman PT, Rathmell WK, Lineman WM. The cancer genome atlas comprehensive molecular characterization of renal cell carcinoma. Cell Rep 2018;23:313-326.e5. Erratum in: Cell Rep 2018;23:3698.
3. Ferlay J, Soerjomataram I, Dikshit R, Eser S, Mathers C, Rebelo M, Parkin DM, Forman D, Bray F. Cancer incidence and mortality worldwide: sources, methods and major patterns in GLOBOCAN 2012. Int J Cancer 2013;136:E359-E386.
4. Zhang G, Wu Y, Zhang J, Fang Z, Liu Z, Xu Z, Fan Y. Nomograms for predicting long-term overall survival and disease-specific survival of patients with clear cell renal cell carcinoma. Onco Targets Ther. 2018;11:5535-5544.
5. Klatte T, Rossi SH, Stewart GD. Prognostic factors and prognostic models for renal cell carcinoma: a literature review. World J Urol 2018;36:1943-1952.
6. Shao N, Wang HK, Zhu Y, Ye DW. Modification of American Joint Committee on cancer prognostic groups for renal cell carcinoma. Cancer Med 2018;7:5431-5438.
7. Gofrit ON, Orevi M. Diagnostic challenges of kidney cancer: a systematic review of the role of postoper Don emission tomography-computerized tomography. J Urol 2016;196:648-657.
8. Along P, Picchio M, Zattoni F, Spallino M, Gianelli L, Saladini G, Evangelista L. Recurrent renal cell carcinoma: clinical and prognostic value of FDG PET/CT. Eur J Nucl Med Mol Imaging 2016;43:464-473.
9. Jena R, Narain TA, Singh UP, Srivastava A. Role of postop Don emission tomography/computed tomography in the evaluation of recurrent renal cell carcinoma. Indian J Urol 2021;37:125-132.
10. Amin MB, Greene FL, Edge SB, Compton CC, Gershenson JD, Brookland RK, Meyer L, Gress DM, Byrd DR, Winchester DP. The Eighth Edition AJCC Cancer Staging Manual: continuing to build a bridge from a population-based to a more “personalized” approach to cancer staging. CA Cancer J Clin 2017;67:93-99.
11. Liu Y. The Place of FDG PET/CT in renal cell carcinoma: value and limitations. Front Oncol 2016;6:201.
12. Elahmadiw MA, Elazab MSS, Ahmed S, Salama M. Diagnostic value of F-18 FDG PET/CT for local and distant disease relapse surveillance in surgically treated RCC patients: Can it aid in establishing consensus follow up strategy? Nucl Med Rev Cent East Eur 2018;21:85-91.
13. Noda Y, Kanematsu M, Goshima S, Suzuki N, Hirose Y, Matsunaga K, Nishibori H, Kondo H, Watanabe H, Kawada H, Kawai N, Tanahashi Y, Bae KT. \(_{18}\)F fluorodeoxyglucose uptake in positron emission tomography as a pathological grade predictor for renal clear cell carcinomas. Eur Radiol 2015;25:3009-3016.
14. Takahashi M, Kume H, Koyama K, Nakagawa T, Fujimura T, Monikawa T, Fukayama M, Homma Y, Ohtomo K, Momose T. Preoperative evaluation of renal cell carcinoma by using 18F-FDG PET/CT. Clin Nucl Med 2015;40:936-940.
15. Komek H, Altindag S, Can C, Aguloglu N, Morcali F, Karaoglan H. The effect on survival and mortality of the highest SUV\(_{\text{max}}\) value on metastatic foci in postoperative kidney tumors. Niger J Clin Pract 2018;21:163-169.
16. Toguchi M, Ishigami K, Goya M, Saito S, Murayama S, Nishi A. Efficacy of preoperative 18F-FDG PET/CT in prognostic prediction in patients with renal cell carcinoma. Cancer Diagn Progn 2022;2:216-222.
17. Pankowska V, Malkowski B, Wedrowski M, Wedrowska E, Roszkowski K. FDG PET/CT as a survival prognostic factor in patients with advanced renal cell carcinoma. Clin Exp Med 2019;19:143-148.

18. Komek H, Altindag S, Can C, Aguloglu N, Morcall H, Tuzun A, Kavak S. The prognostic value of preoperative PET/CT evaluation of maximum standardized uptake value in renal cell carcinomas. Ann Ital Chir 2017;88:48-54.

19. Namura K, Minamimoto R, Yao M, Makiyama K, Murakami T, Sano F, Hayashi N, Tateishi U, Ishigaki H, Kishida T, Miura T, Kobayashi K, Noguchi S, Inoue T, Kubota Y, Nakaigawa N. Impact of maximum standardized uptake value (SUVmax) evaluated by 18-Fluoro-2-deoxy-D-glucose positron emission tomography/computed tomography (18F-FDG-PET/CT) on survival for patients with advanced renal cell carcinoma: a preliminary report. BMC Cancer 2010;10:667.

20. Nakaigawa N, Kondo K, Tateishi U, Minamimoto R, Kaneta T, Namura K, Ueno D, Kobayashi K, Kishida T, Ikeda I, Hasumi H, Makiyama K, Kubota Y, Inoue T, Yao M. FDG PET/CT as a prognostic biomarker in the era of molecular-targeting therapies: max SUVmax predicts survival of patients with advanced renal cell carcinoma. BMC Cancer 2016;16:67.

21. Kim D, Lee N, Lee SH, Kim HJ, Hong HS, Park JS, Cho NH, Choi YD, Ham WS, Lee SH, Han WK, Yun M. Metabolic tumour volume on 18F-FDG PET/CT predicts extended pathological T stages in patients with renal cell carcinoma at staging. Sci Rep 2021;11:23486.

22. Nakajima R, Matsuo Y, Kondo T, Abe K, Sakai S. Prognostic value of metabolic tumor volume and total lesion glycolysis on preoperative 18F-FDG PET/CT in patients with renal cell carcinoma. Clin Nucl Med 2017;42:e177-e182.

23. Farnebo J, Grybäck P, Harmenberg U, Laurell A, Wersäll P, Blomqvist LK, Ullén A, Sandström P. Volumetric FDG-PET predicts overall and progression-free survival after 14 days of targeted therapy in metastatic renal cell carcinoma. BMC Cancer 2014;14:408.

24. Leibovich BC, Lohse CM, Crispen PL, Boorjian SA, Thompson RH, Blute ML, Cheville JC. Histological subtype is an independent predictor of outcome for patients with renal cell carcinoma. J Urol 2010;183:1309-1315.

25. Mizuno T, Kamai T, Abe H, Sakamoto S, Kitajima K, Nishioka D, Yuki H, Kambara T, Betzunoh H, Yashi M, Fukabori Y, Kaji Y, Yoshida K. Clinically significant association between the maximum standardized uptake value on 18F-FDG PET and expression of phosphorylated Akt and S6 kinase for prediction of the biological characteristics of renal cell cancer. BMC Cancer 2015;15:1097.

26. Wang X, Li R, Chen R, Huang G, Zhou X, Liu J. Prognostic values of TIGAR expression and 18F-FDG PET/CT in clear cell renal cell carcinoma. J Cancer 2020;11:1-8.

27. Roussel E, Capitania U, Kutikov A, Oosterwijk E, Pedrosa I, Rowe SP, Gorin MA. Novel imaging methods for renal mass characterization: a collaborative review. Eur Urol 2022;81:476-488.