18F-Alfatide II and 18F-FDG Dual-Tracer Dynamic PET for Parametric, Early Prediction of Tumor Response to Therapy

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A single dynamic PET acquisition using multiple tracers administered closely in time could provide valuable complementary information about a tumor’s status under quasiconstant conditions. This study aimed to investigate the utility of dual-tracer dynamic PET imaging with 18F-Alfatide II (18F-AIF-NOTA-E(PEG4-c(RGDfK))2) and 18F-FDG for parametric monitoring of tumor responses to therapy. Methods: We administered doxorubicin to one group of athymic nude mice with U87MG tumors and paclitaxel protein-bound particles to another group of mice with MDA-MB-435 tumors. To monitor therapeutic responses, we performed dual-tracer dynamic imaging, in sessions that lasted 90 min, starting with injection via the tail vein catheters with 18F-Alfatide II, followed 40 min later by 18F-FDG. To achieve signal separation of the 2 tracers, we fit a 3-compartment reversible model to the time-activity curve of 18F-Alfatide II for the 40 min before 18F-FDG injection and then extrapolated to 90 min. The 18F-FDG tumor time-activity curve was isolated from the 90-min dual-tracer tumor time-activity curve by subtracting the fitted 18F-Alfatide II tumor time-activity curve. With separated tumor time-activity curves, the 18F-Alfatide II binding potential (BP = k3/k0) and volume of distribution (Vd) and 18F-FDG influx rate (k1 × k2/[k0 + k3]) based on the Patlak method were calculated to validate the signal recovery in a comparison with 60-min single-tracer imaging and to monitor therapeutic response. Results: The transport and binding rate parameters K1−K3 of 18F-Alfatide II, calculated from the first 40 min of the dual-tracer dynamic scan, as well as BP and Vd, correlated well with the parameters from the 60-min single-tracer scan (R² > 0.95). Compared with the results of single-tracer PET imaging, 18F-FDG tumor uptake and influx were recovered well from dual-tracer imaging. On doxorubicin treatment, whereas no significant changes in static tracer uptake values of 18F-Alfatide II or 18F-FDG were observed, both 18F-Alfatide II BP and 18F-FDG influx from kinetic analysis in tumors showed significant decreases. For therapy of MDA-MB-435 tumors with paclitaxel protein-bound particles, a significant decrease was observed only with 18F-Alfatide II BP value from kinetic analysis but not 18F-FDG influx. Conclusion: The parameters fitted with compartmental modeling from the dual-tracer dynamic imaging are consistent with those from single-tracer imaging, substantiating the feasibility of this methodology. Even though no significant differences in tumor size were found until 5 d after doxorubicin treatment started, at day 3 there were already substantial differences in 18F-Alfatide II BP and 18F-FDG influx rate. Dual-tracer imaging can measure 18F-Alfatide II BP value and 18F-FDG influx simultaneously to evaluate tumor angiogenesis and metabolism. Such changes are known to precede anatomic changes, and thus parametric imaging may offer the promise of early prediction of therapy response.

Key Words: dual-tracer dynamic PET; parametric imaging; 18F-Alfatide II; 18F-FDG; therapy response


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PET is arguably the most sensitive and specific technique for imaging molecular pathways in vivo in humans. Moreover, the availability of tracers sensitive to different physiologic and pharmacologic variables enables PET to characterize multiple aspects of oncologic pathology, including metabolism, angiogenesis, cellular proliferation, blood flow, and hypoxia (1,2). Given the complexity and heterogeneity of malignant lesions, such complementary information can facilitate comprehensive evaluation of tumors and improve early detection, staging, and monitoring of therapeutic responses (3–7).

For example, Tseng et al. (3) concurrently measured blood flow with 15O-water and glucose metabolism with 18F-FDG in locally advanced breast cancer and reported that a low ratio of glucose metabolism to blood flow predicted a favorable therapeutic response. In our previous studies, we used 18F-FPPRG2D (2-fluoropropionyl-labeled PEGylated dimeric RGD [Arg-Gly-Asp] peptide [PEG3-E(c(RGDfK))2]), a peptide that quantifies integrin αvβ3 expression, and 18F-FDG to evaluate tumor angiogenesis and metabolism modulations in response to the VEGFR TK (vascular endothelial growth factor receptor tyrosine kinase) inhibitor ZD4190 (7), to Abraxane (Celgene Corp.) (6), and to the vascular disruptive fusion protein VEGF (10). Longitudinal imaging results indicated that even though much higher tumor uptake was found in 18F-FDG imaging, therapeutic effect was more clearly reflected by 18F-FPPRG2D imaging. However, the multiple-step synthetic procedure required to prepare 18F-FPPRG2D with relatively low yield may limit its widespread use (9). Consequently, a novel dimeric RGD peptide tracer has been prepared with the reaction of 18F-aluminum fluoride com-
plex to preattached chelator on RGD peptides (10). Without the need of high-performance liquid chromatography purification, the ease of preparation and high imaging qualities make $^{18}$F-AIF-NOTA-PRGD$_2$ (alfatide I) a promising alternative to $^{18}$F-FPRGD$_2$ for PET imaging of α$_v$β$_3$ integrin expression (10–12).

By taking advantage of the distinct kinetics of different tracers, nearly simultaneous multitracer imaging can be achieved by closely staggering tracer injections during a single scan (13–17). Many studies using simulated data have demonstrated the feasibility of signal separation with dual-tracer dynamic PET imaging (13–17). PET imaging with different tracers that partially overlap in time has advantages, relative to PET imaging with widely separated administration of the tracers, by reducing the cost and time of the imaging and by providing complementary information under quasiconstant physiologic conditions (14,18). Dynamic parameters for each tracer may provide more sensitive quantification in tumor therapy monitoring than static tumor uptake values (19). In addition, the radiation dose is reduced in multitracer single-scan imaging, because only 1 CT scan is needed for attenuation correction or coregistration of images for the tracers.

Dynamic PET imaging using $^{18}$F-FDG, followed by irreversible compartmental modeling, has been intensively studied (5). Our previous studies showed that the kinetics of RGD-based peptide tracer satisfies the reversible 3-compartment model (19). In this study, we conducted dynamic imaging with the dual tracers $^{18}$F-AIF-NOTA-E [PEG$_2$-c(RGDfK)$_2$]$_2$ (denoted as $^{18}$F-alfatide II) (20) and $^{18}$F-FDG in xenograft tumor models to monitor tumor therapy response to either doxorubicin or Abraxane. $^{18}$F-alfatide II and $^{18}$F-FDG tumor time–activity curves were separated using compartmental modeling. To validate the signal recovery, the dynamic parameters calculated from dual-tracer time–activity curves were compared with those from single-tracer imaging. Then the tumor response to drug treatment was assessed on the basis of tumor uptake, $^{18}$F-alfatide II binding potential (Bp), and $^{18}$F-FDG influx rate (5,6).

**MATERIALS AND METHODS**

Preparation of Imaging Tracers

The PEG$_4$-E[c(RGDfK)$_2$] was synthesized by C S Bio. The NOTA-NHS ester was obtained from CheMatech. The coupling of NOTA-NHS ester to the amine of RGD peptide was performed using dimethylformamide as the solvent and N,N-diisopropylethylamine as the base. The purity of NOTA-PEG$_2$-E[c(RGDfK)$_2$] was greater than 97% by analytic high-performance liquid chromatography (Rt = 14.2 min) running a linear gradient starting from 5% A (0.1% TFA trifluoroacetic acid in acetonitrile) and 95% B (0.1% TFA in water) for 5 min and increasing to 65% A at 35 min with a flow rate of 1 mL/min. The reaction yield was 69%. Liquid chromatography mass spectrometry: [MH]$^+$ = 1,850.7869 (m/z), calc: 1,849.9322 (C$_{83}$H$_{127}$N$_{23}$O$_{26}$).

The $^{18}$F-fluoride in O-18 water was obtained from the National Institutes of Health cyclotron facility. The radiolabeling of NOTA-PEG$_2$-E[c (RGDfK)$_2$] with $^{18}$F-aluminum fluoride was performed according to a previously published procedure with some modifications (21). The total synthesis time was about 30 min, with a radiochemical yield of 40%–60% and radiochemical purity greater than 95%. The specific activity was about 14.8–37 GBq/μmol at the end of synthesis based on the amount of peptide used and the amount of radioactivity trapped on the C-18 column. The final product was named $^{18}$F-alfatide II ($^{18}$F-AIF-NOTA-E[PEG$_2$-c (RGDfK)$_2$]). $^{18}$F-FDG was purchased from the Nuclear Pharmacy of Cardinal Health and was diluted, as appropriate, with sterile saline.

**Tumor Model and Treatment Protocol**

All animal studies were conducted in accordance with the principles and procedures outlined in the Guide for the Care and Use of Laboratory Animals (22) and were approved by the Institutional Animal Care and Use Committee of the Clinical Center, National Institutes of Health. The U87MG cells expressing high levels of α$_v$β$_3$ integrin (23) and the MDA-MB-435 cells with medium levels of α$_v$β$_3$ integrin expression were purchased from the American Type Culture Collection and cultured in minimum essential medium and Leibovitz L-15 medium supplemented with 10% fetal bovine serum in a humidified atmosphere of 5% CO$_2$ at 37°C, respectively. The tumor models were established by inoculating the right shoulder of 5- to 6-wk-old female athymic nude mice (Harlan Laboratories) subcutaneously with $1 \times 10^7$ U87MG cells or $6 \times 10^6$ MDA-MB-435 cells in 100 μL of phosphate-buffered saline. The mice underwent PET scans when the tumor volume reached 200–400 mm$^3$ (~3–4 wk after inoculation). For the therapy-monitoring study, U87MG tumor–bearing mice in the treated group were given 2 doses of doxorubicin (5 mg/kg/dose) 2 d apart via tail vein injection, whereas the MDA-MB-435 tumor–bearing mice were given 2 doses of Abraxane.
(30 mg/kg/dose) every other day via tail vein injection. All the mice in the control group were injected with the same volume of saline. The detailed therapy and imaging regimen are shown in Table 1. Tumor growth was monitored by measuring tumor size with a caliper every 2 d after the tumors became palpable. The tumor volume was calculated with the formula \( V = \frac{4}{3} \pi r^3 \), where \( V \) and \( r \) were the tumor length and width, respectively, in millimeters.

**Dynamic PET Imaging**

All the PET scans were conducted with an Inveon small-animal PET scanner (Siemens Preclinical Solution). Mice were anesthetized with mixtures of O2 (1 mL/min) and 1.5% isoflurane and kept warm with a heating pad thermostat during the imaging. All data acquisitions were initiated immediately before the tracer injections. The duration of a scan was 60 min for single-tracer imaging and 90 min for \(^{18}\)F-alfatide II/\(^{18}\)F-FDG dual-tracer imaging. A catheter was placed in the tail vein before each scan for tracer administration. For dual-tracer imaging, about 3.7 MBq of \(^{18}\)F-alfatide II was injected through the catheter immediately after the scan was started. Forty minutes later, about 3.7 MBq of \(^{18}\)F-FDG was injected without stopping the scanning. For therapy response monitoring, mice in both control and treated groups underwent dual-tracer dynamic imaging on days 0 and 3. The acquired list-mode data were reconstructed with 3-dimensional ordered-subset expectation maximization, followed by the maximum a posteriori probability algorithm (11). The reconstruction frames were 1 × 5, 1 × 25, 9 × 30, 5 × 60, 5 × 120, and 10 × 240 s for single-tracer dynamic imaging and 1 × 5, 1 × 25, 9 × 30, 10 × 60, 4 × 300, 1 × 240, 12 × 30, 10 × 60, and 7 × 300 s for dual-tracer dynamic imaging.

**Region-of-Interest Quantification and Time–Activity Curves**

The ROIs were drawn over the tumor region with Inveon Research Workplace 3.0 software (Siemens Preclinical Solution), using a procedure reported in our previous study (11). For dual-tracer dynamic imaging, the time–activity curves were generated on the basis of mean pixel intensity of the whole ROI in each frame before the signal separation. A calibration constant was used to convert the mean pixel intensity to MBq/mL for separated time–activity curves. Because the tissue density was assumed to be 1 g/mL, the activity in the ROI was normalized by injected dose and expressed as percentage injected dose per gram (%ID/g) to describe the tissue uptake of the radiotracers. The injected dose for the second tracer, \(^{18}\)F-FDG, was decay-corrected to the starting time of the scan to reflect the real tumor uptake. The tumor uptake of \(^{18}\)F-alfatide II in static image quantification was calculated from the last frame before \(^{18}\)F-FDG injection. \(^{18}\)F-FDG uptake was calculated at the 50-min time point on the restored \(^{18}\)F-FDG time–activity curves.

The arterial input function was drawn on the abdominal aorta (24) on the second frame of PET dynamic image serials. The first frame was left empty purposely to ensure the peak concentration could be captured.

**Dual-Tracer Input Function and Tumor Time–Activity Curve Separation**

The \(^{18}\)F-alfatide II input function was fitted with a triexponential model (25) for the first 40 min of data. The mathematical expression for the model is shown in Equation 1.

\[
C_p = \sum_{i=1}^{3} A_i \cdot \exp(-\lambda_i \cdot (t - \tau)) \quad t \geq \tau, \quad \text{Eq. 1}
\]

where \( C_p \) represents the tracer concentration in plasma. \( A_1, A_2, \) and \( A_3 \) are coefficients of the model, and \( \lambda_1, \lambda_2, \) and \( \lambda_3 \) are the Eigen values of the model. \( \tau \) is the injection delay time.

For tumor time–activity curve separation, a 3-compartment reversible model was used to fit the initial 40 min of \(^{18}\)F-alfatide II data. The dynamic rate constants \( K_1-K_4 \) were determined by fitting the following function for tumor time–activity curve.

\[
C_i = \frac{K_1}{\alpha_2 - \alpha_1} \left[ (k_3 + k_4 - \alpha_1) e^{-\alpha_1 t} + (\alpha_2 - k_3 - k_4) e^{-\alpha_2 t} \right] \otimes C_p + V_b C_p. \quad \text{Eq. 2}
\]

\[
\alpha_1 = \frac{(k_2 + k_3 + k_4) - \sqrt{(k_2 + k_3 + k_4)^2 - 4k_2k_4}}{2} \quad \text{Eq. 3}
\]

\[
\alpha_2 = \frac{(k_2 + k_3 + k_4) + \sqrt{(k_2 + k_3 + k_4)^2 - 4k_2k_4}}{2} \quad \text{Eq. 4}
\]

Here \( C_i \) is the tracer concentration in tumor ROI, and \( V_b \) is the fractional blood volume.

Similarly, \( K_1-k_4 \) were then imported back into the Equations 2–4 to extrapolate the \(^{18}\)F-alfatide II time–activity curve to 90 min. Subsequently, the \(^{18}\)F-FDG tumor time–activity curve was restored by subtracting the fitted 90-min \(^{18}\)F-alfatide II time–activity curve from the overlapping time–activity curve in the dual-tracer imaging.

The fitting method for the input function and the tumor time–activity curves, alike, was unweighted least-squares nonlinear regression. The correlation coefficient \( R^2 \), defined as the ratio of regression sum of squares and the total sum of squares, was calculated to evaluate the goodness of fit (26).

**Kinetic Data Analysis**

The combination \((k_2/k_4)\) and volume of distribution \((V_D = (k_1/k_2) \times \left(1 + k_1/k_4\right))\) were calculated, in addition to \( K_1-k_4 \) for \(^{18}\)F-alfatide II. Bp is associated with the binding affinity, and \( V_D \) reflects the tissue-to-plasma concentration ratio. The Patlak method was performed to calculate the influx rate constant for \(^{18}\)F-FDG, a well-known irreversible tracer. In vivo rate is related to the metabolic rate of glucose (27).

Logan graphical analysis (19) was used in the therapeutic monitoring study to calculate a voxelwise parametric map of \(^{18}\)F-alfatide II Bp values with data from the dynamic whole-body images obtained during the first 40 min of the study (i.e., before injection of \(^{18}\)F-FDG).

**Statistics**

Linear regression was used to compare the results from single-tracer and dual-tracer imaging and evaluated by ANOVA F test to validate the significance of regression, with a \( P \) value of less than 0.05 indicating significant linearity. For therapeutic monitoring, quantitative data were expressed as mean ± SD. Means were compared using the Student \( t \) test. A \( P \) value of less than 0.05 was considered statistically significant.

**RESULTS**

**Time–Activity Curves and Dual-Tracer Time–Activity Curve Separation**

After dynamic acquisition and imaging reconstruction, ROIs were drawn over the abdominal aorta and tumor region to generate the corresponding dual-tracer time–activity curves (Supplemental Fig. 1; supplemental materials are available at http://jnm.snmjournals.org). To evaluate the robustness of the nonlinear regression, a regression coefficient of each animal was calculated and listed in Table 2. \( R^2 \) ranged from 0.92 to 1.0, indicating a good fit for all.

Average U87MG tumor uptake time–activity curves were calculated and are shown in Figure 1A for \(^{18}\)F-alfatide II and Figure 1B for \(^{18}\)F-FDG. In the dual-tracer imaging study, the tumor uptake of \(^{18}\)F-alfatide II was 4.65 ± 1.02 %ID/g at 40 min, and the uptake of \(^{18}\)F-FDG was 11.31 ± 1.61 %ID/g at 50 min. In the

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**Table 1**

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**Table 2**

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<td>11.31 ± 1.61</td>
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single-tracer imaging study, the tumor uptake of $^{18}$F-alfatide II was 4.38 ± 1.43 %ID/g at 40 min, and the uptake of $^{18}$F-FDG was 10.81 ± 0.81 %ID/g at 50 min. There is no significant difference between the values calculated from the single-tracer imaging and dual-tracer imaging. Similarly, the average MDA-MB-435 tumor uptake time–activity curves from the dual-tracer imaging fitted well with those from the single-tracer imaging (Figs. 1C and 1D). The MDA-MB-435 tumor uptake values of $^{18}$F-FDG and $^{18}$F-alfatide II from the dual-tracer imaging were 7.19 ± 1.31 and 2.79 ± 0.47 %ID/g, respectively, and showed no significant difference with those from the single-tracer imaging (6.96 ± 1.13 and 2.73 ± 0.64 %ID/g, respectively).

**Kinetic Parameters Evaluation**

$^{18}$F-alfatide II kinetic parameters, such as $K_1$, $k_2$, and $k_3$, calculated from the 40- and 60-min dynamic scans showed excellent linear correlation ($R^2 > 0.98$), whereas $k_4$ showed modest (but still statistically significant, $P < 0.05$) correlation ($R^2 = 0.76$) (Supplemental Fig. 2). Excellent linear correlations were also found for $V_D$ ($R^2 = 0.95$) and $Bp$ ($R^2 = 0.98$), indicating that $V_D$ and $Bp$ derived from the 40-min scan were consistent with the ones derived from the 60-min scan (Figs. 2A and 2B).

Kinetic parameter comparisons for $^{18}$F-FDG between single- and dual-tracer imaging are shown in Figures 2C and 2D. The correlation coefficients, $R^2$, for tumor influx and uptake between single-tracer and dual-tracer imaging were 0.70 and 0.79, respectively. A significant linear correlation was also observed between these parameters ($P < 0.05$), confirming the feasibility of the signal separation and parameter calculations.

**Evaluation of Tumor Response to Doxorubicin and Abraxane**

After being treated with 2 doses of doxorubicin, the U87MG tumors showed a partial response, reflected by significant growth inhibition at day 5 after the treatment started ($P < 0.05$, Fig. 3A). Tumors in representative static images at 40- and 90-min time points clearly had heterogeneous tracer distribution within the tumor region in both control and treated groups. The parametric maps of $^{18}$F-alfatide II $Bp$ values were also calculated and are shown in Figure 3B.

Through specific binding to integrin $\alpha_v\beta_3$, $^{18}$F-alfatide II was used to evaluate tumor angiogenesis. In untreated tumors, tumor uptake at 40 min after injection showed a slight increase, with a day-3 to day-0 ratio of 1.18 ± 0.36. On treatment, the tumor uptake of $^{18}$F-alfatide II decreased, with a day-3 to day-0 ratio of 0.86 ± 0.15. However, the static tumor uptake ratio showed no significant difference between the control and treated groups at 40 min after injection ($P > 0.05$). The $Bp$ value increased substantially from day 0 to day 3 in the control group, but decreased dramatically in the treated group. Consequently, the day-3 to day-0 ratio decreased significantly ($P < 0.05$) in the treated group.

**Table 2**

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$R^2$ = nonlinear regression correlation coefficient.
Fig. 4: As shown at day 4 after the treatment started (PMDA-MB-435 tumors, reflected by significant growth inhibition from that for the treated group (0.54 ± 0.03) at day 3 (Fig. 3C). The day-3 to day-0 ratio of influx rate was 0.79 for the control group, which was significantly different from that for the treated group (0.54 ± 0.14, P < 0.05).

Treatment with Abraxane also induced a partial response on MDA-MB-435 tumors, reflected by significant growth inhibition at day 4 after the treatment started (P < 0.05, Fig. 4A). As shown in Figure 4B, both treated and control tumors showed positive uptake of 18F-alfatide II and 18F-FDG. Similar to doxorubicin-treated U87MG tumors, the static tumor uptake ratio of both 18F-alfatide II and 18F-FDG showed no significant difference between the control and treated groups (P > 0.05) (Fig. 4C). The day-3 to day-0 ratio of 18F-FDG influx rate was 0.85 ± 0.17 for the control group, which was not significantly different from that for the treated group (0.80 ± 0.24, P > 0.05). The day-3 to day-0 Bp ratio of the treated group (0.66 ± 0.12) is significantly lower than that of the control group (0.97 ± 0.09, P < 0.01) (Fig. 4C).

DISCUSSION

PET imaging using multiple tracers is expected to provide more complementary information than a single PET study using a single tracer and thus might improve tumor diagnosis and therapeutic monitoring. Multiple, separate single-tracer studies to achieve this would be more costly and require longer total scan times, and—because of the delay between scans—wouldn’t provide information under quasiconsistent physiologic conditions.

The fixed-energy γ ray of positron-emitting radioisotopes from the positron-electron annihilation, however, presents significant challenges for imaging multiple tracers simultaneously with 1 PET scan. Since the 1980s, several methods have been developed to separate the superimposed PET signals of multiple-tracer scans (16,28). For example, Koepp et al. (16) performed computer simulations and human PET studies using pairs of 11C-labeled tracers in a single scan to image different neurotransmitter–neuroreceptor systems and demonstrated the feasibility of parameter estimation with compartmental modeling. Rust et al. (17) demonstrated the influence of injection timing, injection order, and relative dose on signal separation based on simulated time–activity curves after staggered injection of 62Cu-pyridvaldehyde-bis[N4-methylthiosemicarbazone] (PTSM) and 62Cu-diacyetyl-bis[N4-methylthiosemicarbazone] (ATSM). Short half-life (t1/2) isotopes, such as 11C (t1/2 = 20.4 min), 13N (t1/2 = 9.97 min), and 62Cu (t1/2 = 9.7 min), were mainly used in these studies to reduce the staggering time between tracer injection and the signal overlap. However, the accuracy of dynamic parameters estimation could be affected because of the limited detectable counts.

With a t1/2 of 109.8 min, 18F is the most widely used positron-emitting radioisotope for PET imaging. Most recently, Kadramas et al. (29) simulated single-scan dual-tracer 3’-deoxy-3’-[18F-fluorothymidine/18F-FDG PET imaging, characterizing the performance of recovered static and dynamic imaging measures for each tracer from dual-tracer datasets. In the current study, we conducted 18F-alfatide II and 18F-FDG dual-tracer dynamic imaging in 1 scan with a 40-min injection separation. After validating the data acquisition and analysis, we successfully applied this strategy to evaluate the tumor response to drug treatment.

The performance of signal separation with overlapping data in dual-tracer imaging is affected mainly by tracer injection order, the dose of each tracer, and the injection delay. In our previous RGD
The reproducibility of $^{18}$F-FDG has been confirmed in tracer imaging on the same mice on the day before the dual-tracer imaging, because it makes the signal of the second tracer stronger. A 1:3 ratio between the first tracer and the second tracer has been calculated from the recovered $^{18}$F-FDG signal appeared to be able to simulate dual-tracer imaging data by performing $^{18}$F-FDG single-tracer PET imaging. $^{18}$F-FDG influx rate showed decreased value on treatment in both control and treated groups but was more pronounced in the treated group ($P < 0.05$). The variance of the $^{18}$F-alfatide II Bp value was more significant than that of $^{18}$F-FDG influx rate, indicating more changes in tumor angiogenesis than metabolism on doxorubicin treatment. Similar findings were also confirmed in the Abraxane treatment. These results also suggest that dynamic analysis with compartmental modeling is more sensitive than the static measurement, substantiating the benefit of kinetic analysis presented in our previous study ($^{19}$).

We have previously used the left ventricle ROI to generate the input function, because there was little myocardial uptake of RGD ($^{19}$). However, this is not appropriate for $^{18}$F-FDG because of the inherent high myocardial uptake. Consequently, the abdominal aorta was chosen to outline the input function for the dual-tracer imaging. Arterial blood sampling wasn’t performed in this study because of the technical challenge. A population-based input function ($^{36}$) or 1 blood sample ($^{25}$) at the end of dynamic imaging may be a good choice in our future studies.

To the best of our knowledge, this is the first experimental dual-tracer dataset to observe angiogenesis and glucose metabolism simultaneously. On the basis of our previous kinetics analysis of RGD peptides, an appropriate injection time separation was chosen, and the signal of the second tracer was reliably recovered using compartmental modeling. Dual-tracer single-scan PET imaging may become a useful method to provide more complete tumor information simultaneously.

**CONCLUSION**

In this study, we performed dual-tracer dynamic imaging using staggered injections of $^{18}$F-alfatide II and $^{18}$F-FDG for simultaneous observation of angiogenesis and metabolism, which serve as sensitive, early markers of tumor responses to therapy. The signal from each tracer was successfully separated with compartmental modeling. The tumor uptake values and dynamic parameters from recovered signals were validated with single-tracer imaging. The dual-tracer imaging was applied to monitor the tumor response to chemotherapy. We found that dual-tracer single-scan imaging can be used to reflect tumor response, and quantitative kinetic parameters calculated from dynamic data are more sensitive than static imaging.

**DISCLOSURE**

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