

# eScholarship@UMassChan

## Imaging response assessment for oncology: An algorithmic approach

Item Type	Journal Article
Authors	Ruchalski, Kathleen;Dewan, Rohit;Sai, Victor;McIntosh, Lacey J;Braschi-Amirfarzan, Marta
Citation	<p>&lt;p&gt;Ruchalski K, Dewan R, Sai V, McIntosh LJ, Braschi-Amirfarzan M. Imaging response assessment for oncology: An algorithmic approach. Eur J Radiol Open. 2022 Jun 7;9:100426. doi: 10.1016/j.ejro.2022.100426. PMID: 35693043; PMCID: PMC9184854. &lt;a href="https://doi.org/10.1016/j.ejro.2022.100426"&gt;Link to article on publisher's site&lt;/a&gt;&lt;/p&gt;</p>
DOI	<a href="https://doi.org/10.1016/j.ejro.2022.100426">10.1016/j.ejro.2022.100426</a>
Rights	© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license ( <a href="http://creativecommons.org/licenses/by-nc-nd/4.0/">http://creativecommons.org/licenses/by-nc-nd/4.0/</a> ).
Download date	2026-03-14 17:21:54
Item License	<a href="http://creativecommons.org/licenses/by-nc-nd/4.0/">http://creativecommons.org/licenses/by-nc-nd/4.0/</a>
Link to Item	<a href="https://hdl.handle.net/20.500.14038/48641">https://hdl.handle.net/20.500.14038/48641</a>



## Imaging response assessment for oncology: An algorithmic approach

Kathleen Ruchalski<sup>a,\*</sup>, Rohit Dewan<sup>a</sup>, Victor Sai<sup>a</sup>, Lacey J. McIntosh<sup>b,\*\*,1</sup>,  
Marta Braschi-Amirfarzan<sup>c,\*\*\*</sup>

<sup>a</sup> Department of Radiological Sciences, UCLA Los Angeles, CA, United States

<sup>b</sup> University of Massachusetts Chan Medical School / Memorial Health Care, United States

<sup>c</sup> Tufts University School of Medicine, United States

### ARTICLE INFO

#### Keywords:

Response assessment  
RECIST  
Treatment outcomes  
Cancer imaging

### ABSTRACT

Treatment response assessment by imaging plays a vital role in evaluating changes in solid tumors during oncology therapeutic clinical trials. Response Evaluation Criteria in Solid Tumors (RECIST) 1.1 is the reference standard imaging response criteria and provides details regarding image acquisition, image interpretation and categorical response classification. While RECIST 1.1 is applied for the majority of clinical trials in solid tumors, other criteria and modifications have been introduced when RECIST 1.1 outcomes may be incomplete. Available criteria beyond RECIST 1.1 can be explored in an algorithmic fashion dependent on imaging modality, tumor type and method of treatment. Positron Emission Tomography Response Criteria in Solid Tumors (PERCIST) is available for use with PET/CT. Modifications to RECIST 1.1 can be tumor specific, including mRECIST for hepatocellular carcinoma and mesothelioma. Choi criteria for gastrointestinal stromal tumors incorporate tumor density with alterations to categorical response thresholds. Prostate Cancer Working Group 3 (PCWG3) imaging criteria combine RECIST 1.1 findings with those of bone scans. In addition, multiple response criteria have been created to address atypical imaging responses in immunotherapy.

### 1. Introduction to imaging treatment response

In cancer care, evaluating changes in tumor size has become a well-accepted objective metric of treatment response in oncology therapeutic clinical trials. Using changes in size in sites of disease to determine treatment response of promising therapies continues to play an increasingly important role for drug discovery. One of the initial attempts to formalize this concept was an evaluation of simulated tumor size reproducibility by oncologists in 1976 and the effect of measurement variation on defining an objective response rate amongst patients in therapeutic clinical trials [1,2]. The World Health Organization (WHO) furthered this initiative with proposing a standardized response classification of treatment response differentiated by thresholds of

change in tumor size, which included the categories: complete response, partial response, no change and progressive disease; as evaluated on clinical exam or radiograph [3]. Since then, use of cross-sectional imaging emerged as a standard method to detail anatomic distribution of tumor, quantitative measurements and changes in tumor size. Response Evaluation Criteria in Solid Tumors (RECIST) was introduced to modernize and provide further clarifications for more uniform reporting of clinical trial results [4]. With further modifications, RECIST 1.1 has become the reference standard for imaging treatment response assessment [5]. However, over time, with emerging new classes of cancer treatments and improved understanding of cancer biology on imaging, additional treatment or tumor specific response criteria have also been adopted. These response criteria can be used in place of RECIST 1.1, or

*Abbreviations:* RECIST, Response Evaluation Criteria in Solid Tumors.

\* Correspondence to: UCLA Department of Radiological Sciences, 757 Westwood Plaza, Ste 1621, Los Angeles, CA 90095–1721, United States.

\*\* Correspondence to: University of Massachusetts Chan Medical School / Memorial Health Care, Division of Oncologic and Molecular Imaging, 55 Lake Avenue, North, Worcester, MA 01655, United States.

\*\*\* Correspondence to: Tufts University School of Medicine, Cancer Imaging Director, Lahey Health Medical Center, 41 Mall Road Burlington, MA 01805, United States.

*E-mail addresses:* [kruchalski@mednet.ucla.edu](mailto:kruchalski@mednet.ucla.edu) (K. Ruchalski), [Lacey.McIntosh@umassmemorial.org](mailto:Lacey.McIntosh@umassmemorial.org) (L.J. McIntosh), [marta.braschiamirfarzan@lahey.org](mailto:marta.braschiamirfarzan@lahey.org) (M. Braschi-Amirfarzan).

<sup>1</sup> ORCID: 0000–0003–2891–6558

<https://doi.org/10.1016/j.ejro.2022.100426>

Received 29 March 2022; Received in revised form 17 May 2022; Accepted 18 May 2022

Available online 7 June 2022

2352-0477/© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

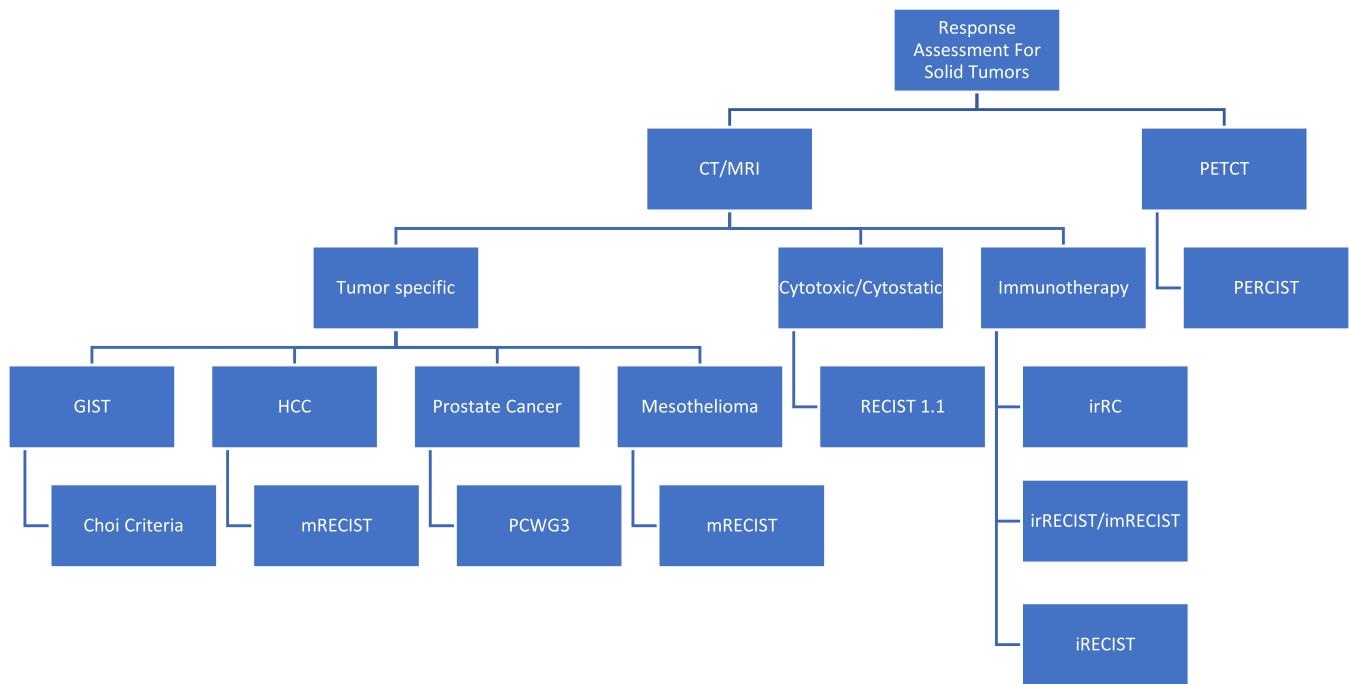


Fig. 1. Algorithmic approach to imaging response criteria selection.



Fig. 2. RECIST 1.1 markings in a 56-year-old man with adrenal cortical carcinoma with a right adrenal mass target lesion (arrow) measured as 38 mm in greatest diameter. Non-measurable disease is noted by peritoneal carcinomatosis (circle) and malignant ascites.

often as a supplemental method in addition to RECIST 1.1 to capture treatment/tumor specific predictive and prognostic information. Determining which response criteria to apply can be considered in an algorithmic fashion, predicated on imaging modality, tumor type, and method of treatment (Fig. 1).

## 2. Response criteria for solid tumors (RECIST) 1.1

The most commonly used response assessment criteria for solid tumors is RECIST 1.1 [5]. This criteria provides a standardized structure to the acquisition, review, measurement and reporting of imaging in oncology clinical trials [5]. By RECIST 1.1, baseline imaging is performed just prior (ideally within 4 weeks) to initiating therapy. Up to five tumors (two per organ system) are selected, measured and then followed over time. These target lesions must meet a minimum size threshold of 10 mm longest diameter for solid tumors and 15 mm short axis for lymph nodes. The relevant measurement of each tumor is added together to form the “sum of diameters”, a numerical representation of tumor burden from which future imaging time points will be compared

[5]. Any additional lesions beyond these target lesions are deemed non-target lesions and are qualitatively assessed, similar to additional sites of truly non-measurable disease such as ascites, pleural or pericardial effusion, sclerotic bone metastases, lymphangitic carcinomatosis (Fig. 2) [5,6].

At each subsequent imaging timepoint, target lesions are re-measured in a similar fashion and a sum of diameters is calculated. This value is compared to either the baseline or if available, nadir (best response scan) to determine if there has been a significant change in tumor size. Disease progression (PD) is defined as a relative increase in 20% or more (with an absolute increase of at least 5 mm) of the sum of diameters when compared to baseline or nadir. Development of any new malignant lesion(s) also meets criteria for disease progression. Partial response (PR) represents a decrease in sum of diameters by at least 30% from baseline. Complete response (CR) is the disappearance of all lesions. Stable disease (SD) represents an increase in tumor size less than 20% or decrease less than 30%. Non-target disease is also assessed, although qualitatively at each time point; categorized as either completely resolved, unequivocally worsened, or neither resolved nor progressed.

RECIST 1.1 has been shown to be a good evaluator of treatment response for both classic chemotherapy and targeted agents, and remains the reference standard in response assessment for solid tumors [7]. However, additional response criteria have been created when patterns of response due to certain tumor-type biology or mechanisms of action of treatment agents is not adequately captured by RECIST 1.1 (Table 1).

## 3. Immunotherapy

Immune checkpoint inhibitors have transformed advanced cancer care, and for numerous tumor types have resulted in significant improvements in patients’ survival and quality of life [8]. In the past 7 years over 85 new oncology indications for antibodies directed against the programmed death (PD-1) or programmed death ligand (PD-L1) pathway have been approved by the US Food and Drug Administration [9]. Immune checkpoint inhibitors mechanistically differ from other cytotoxic and cytostatic agents, with T cell regulation specific to tumor

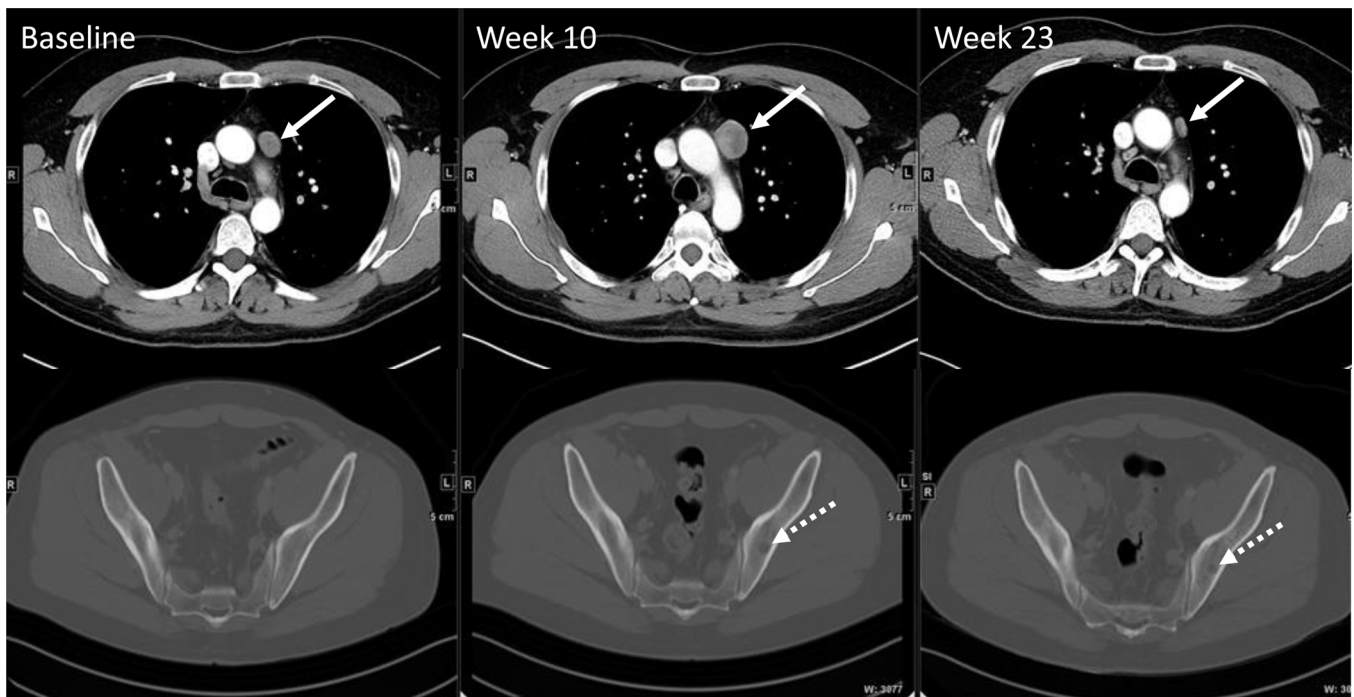
**Table 1**  
Dummy.

	Baseline Characteristics		Categorical Responses			
	No. target lesions	Measurable disease	CR	PR	SD	PD
RECIST 1.1	5 lesions ≤2 per organ	Soft tissue ≥ 10 mm in diameter; lymph nodes ≥ 15 mm short axis	Disappearance of all target and non-target lesions	≥ 30% decrease in sum of diameters (SOD)	Nether PR nor PD	≥ 20% increase in SOD (absolute ≥5 mm); New lesions; Unequivocal increased nontarget disease
PERCIST	Single tumor with highest SUL <sub>peak</sub> in 1.2 cm ROI	SUL <sub>peak</sub> ≥ 1.5 times the mean SUL in liver ± 2 standard deviations	Decrease in FDG uptake of all target and non-target lesions below background blood-pool	Decrease by ≥ 30% in the target measurable tumor with a 0.8 unit decline in SUL <sub>peak</sub>	Unchanged or a less than 30% increase or decrease in SUL <sub>peak</sub>	30% and 0.8 unit increase in SUL <sub>peak</sub> , unequivocal progression of FDG avid non-target disease or new FDG avid lesions
mRECIST mesothelioma	Pleural disease: ≥ 2 locations at 3 different axial levels	Short axis pleural thickening; ≥ 10 mm	Disappearance of all target and non-target lesions	≥ 30% reduction in total tumor measurement	Nether PR nor PD	≥ 20% increase in total tumor measurement over nadir; New lesions
mRECIST hepatocellular carcinoma	2 liver lesions 5 lesions total	Liver: intra-lesion arterial enhancement; 10 mm in diameter Porta hepatitis lymph nodes; ≥ 20 mm short axis; All others by RECIST 1.1	Disappearance of intra-tumoral arterial enhancement in all target lesions and resolved non-target lesions	≥ 30% decrease in SOD of viable tumor (Liver: area of arterial enhancement)	Nether PR nor PD	≥ 20% increase in SOD of viable target lesions, New lesions, Unequivocal increased nontarget disease
Choi criteria	5 lesions ≤2 per organ	Soft tissue ≥ 10 mm in diameter; lymph nodes ≥ 15 mm short axis	Disappearance of all lesions	Decrease in size ≥ 10% OR Decrease in tumor density ≥ 15%	Nether PR nor PD	Increase in tumor size ≥ 10% (without PR criteria by tumor density); New lesions; New intratumoral nodules or increased size of existing intratumoral nodules
PCWG3	RECIST 1.1: 5 lesions ≤2 per organ	RECIST 1.1: Soft tissue ≥ 10 mm in diameter; lymph nodes ≥ 15 mm short axis	Soft tissue: Disappearance of all lesions Bone scan: Disappearance of all lesions	<b>Soft tissue:</b> ≥ 30% decrease in sum of diameters (SOD) <b>Bone scan:</b> not specified	Nether PR nor PD	<b>Soft tissue:</b> ≥ 20% increase in SOD (absolute ≥5 mm); New lesions; Unequivocal increased nontarget disease <b>Bone Scan:</b> 2 or more new lesions confirmed ≥ 6 weeks by at least 2 additional new lesions
Immunotherapy – irRC	Up to 10 visceral and 5 cutaneous lesions (≤5 per organ)	No minimum size lesion in 2 dimensions (Sum of the product of the diameters (SPD))	Disappearance of all target and non-target lesions	≥ 50% decrease in tumor burden (SPD)	Nether PR nor PD	≥ 25% increase in tumor burden (SPD of target lesions and new lesions) from nadir * New measurable lesions: ≥ 5 × 5 mm, up to 5 per organ, up to 10 visceral, 5 cutaneous
– irRECIST/ imRECIST	5 lesions ≤2 per organ	Soft tissue ≥ 10 mm in diameter; lymph nodes ≥ 15 mm short axis	Disappearance of all target and non-target lesions	≥ 30% decrease in TMTB from baseline	Nether irPR nor irPD	≥ 20% (and 5 mm absolute) increase in TMTB New lesions: added to TMTB
– iRECIST	5 lesions ≤2 per organ	Soft tissue ≥ 10 mm in diameter; lymph nodes ≥ 15 mm short axis	Disappearance of all target and non-target lesions	≥ 30% decrease in SOD from baseline	Nether iPR nor iPD	<b>iUPD:</b> RECIST 1.1 PD <b>iCPD:</b> further increased tumor: ≥ 5 mm sum of target lesions OR new target lesions, further increase non-target or new lesions, increased number new lesions

cells resulting in an enhanced native immune response against tumors [8, 10, 11], as opposed to direct cytotoxic or cytostatic drug effects on tumors from traditional and other targeted chemotherapies. Due to this different biology, unconventional tumor response patterns can be seen, including pseudoprogression [11,12]. Pseudoprogression is defined as a treatment response which occurs after an initial increase in tumor burden or development of new lesions which would otherwise be classified as disease progression by RECIST 1.1(Fig. 3) [13]. As such misclassification could prematurely discontinue an otherwise beneficial therapy, numerous immune-specific related response criteria have been created to account for this atypical pattern, including irRC (immune-related response criteria), irRECIST (immune-related RECIST), imRECIST (immune-modified RECIST), and iRECIST (immunotherapy

RECIST) [12–16]. While each criteria differs slightly, a common feature is allowance for treatment beyond disease progression defined by RECIST 1.1 in patients who are not experiencing clinical deterioration and require additional imaging as confirmation of disease progression.

As the first immune-specific criteria to be formulated, irRC was adopted from the WHO criteria [12]. As such, irRC allowed for measurement of the sum of product diameters (SPD) of up to 10 visceral lesions (5 lesions per organ) and 5 cutaneous lesions. For treatment assessment, new lesions did not represent disease progression. Instead, the SPD of any new lesions was added to the SPD of the selected target lesions to represent a total tumor burden. Thresholds of response remained similar to those of WHO criteria, and included a > =50% decrease in tumor burden for partial response and a > =25% increase in



**Fig. 3.** Pseudoprogression in a 46-year-old-man with metastatic melanoma treated with anti-programmed death-1 (PD-1) immunotherapy. A mediastinal lymph node metastasis (white arrow) significantly increases in size at first follow up (week 10) but is sub-10 mm short axis and no longer pathologic in size by week 23. A new lytic bone lesion (dashed white arrow) is also present at week 10, and is slightly smaller by week 23.

tumor burden for disease progression [12].

However, use of bidimensional measurements by irRC limited direct comparisons to clinical trials in which unidimensional assessments by RECIST 1.1 were used. Bidimensional measurements were also shown to result in higher variability in measurement [11]. Therefore, irRECIST was introduced as a merging of concepts specific for immunotherapy from irRC with conventional RECIST. Measurable disease was unified with RECIST 1.1 and defined as lesions  $\geq 10$  mm longest diameter. RECIST 1.1 categorical thresholds were also utilized, with  $\geq 30\%$  decrease for partial response and  $\geq 20\%$  increase for progressive disease. However, aspects of irRC were also included. For treatment assessment, both the target disease and any new lesion(s) were summed together to be the numerical representation of total tumor burden and from which categorical response is calculated. Disease progression also required confirmation by two consecutive observations at least 4 weeks apart [14].

irRECIST definitions had been created as a construct to compare reproducibility of bidimensional versus unidimensional measurements in irRC. Therefore, imRECIST was introduced to provide further details necessary for criteria implementation and analysis of image based outcome measures such as progression free survival (PFS) and best overall survival [15]. Again relying on the constructs of RECIST 1.1, imRECIST defines target lesions by unidimensional measurements with target lesion criteria including number and measurability per RECIST 1.1. Categorical thresholds of at least 20% increase in size for disease progression from baseline/nadir and at least 30% decrease in size from baseline for partial response are also inherited by imRECIST. Like irRECIST, new lesions do not constitute disease progression but when measurable are incorporated into the total tumor burden. When new lesions are nonmeasurable they do not result in disease progression. Unlike RECIST 1.1, worsening of non-target disease does not contribute to progressive disease, but can contribute to complete response if all non-target lesions disappear. Therefore, disease progression is only determined by the measurable disease. However imRECIST progression is not considered progression for progression free survival assessment if the subsequent confirmatory study has a categorical response of SD, PR

or CR [15].

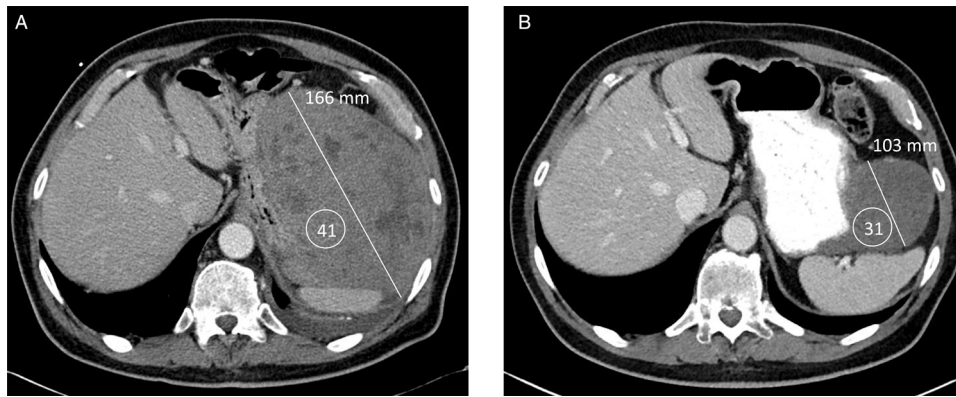
The RECIST working group introduced iRECIST in 2017 as a method to standardize data collection from immunotherapy clinical trials [16]. With iRECIST the main principles of RECIST 1.1. hold true, except for assessment of disease progression. Initial disease progression is the same for both iRECIST and RECIST 1.1, and is defined as an  $\geq 20\%$  increase in sum of diameters (absolute 5 mm increase) from baseline/nadir, development of new lesions or unequivocal worsening of non-target disease. For iRECIST, new lesions should be differentiated into new measurable and new non-measurable lesions, with a maximum of 5 new lesions (2 per organ). This initial disease progression is defined as unconfirmed progressive disease (iUPD) in iRECIST. A follow up imaging timepoint 4–8 weeks later is recommended if the patient is clinically stable. If there is a further increase ( $\geq 5$  mm) of the target sum, further worsening of non-target disease and/or increase in the new measurable or nonmeasurable lesions either in number or size (sum  $\geq 5$  mm) then progressive disease is confirmed (iCPD) [16,17].

### 3.1. PET-CT

Multimodality imaging with  $^{18}\text{F}$ -FDG PET/CT can provide insight to the anatomic distribution of tumor and information on physiologic glucose metabolism [18]. PET/CT is commonly used in various clinical scenarios for initial diagnosis, staging, restaging and treatment response assessment [18]. Methods have been proposed to standardize both, the acquisition and interpretation of PET/CT for its use in clinical trials.

#### 3.1.1. Positron emission tomography response criteria in solid tumors (PERCIST)

PERCIST 1.0 was introduced in 2009, designed to create a standardized approach to baseline selection of metabolic disease and reliable, reproducible assessment of treatment response on  $^{18}\text{F}$ FDG PET/CT [19]. A single target lesion is selected at baseline upon finding the tumor with the highest FDG uptake and is then measured by placing a 1.2 cm diameter region of interest (ROI) over the area of highest FDG uptake [19]. For quantitative measurement, SUV should be corrected for lean



**Fig. 4.** Use of Choi Criteria for a 72-year-old man with gastrointestinal stroma tumor treated with Imatinib. A left upper quadrant mass arising from the gastric fundus is noted at baseline (A) and measures 166 mm (white line) in longest dimension, with average Hounsfield Units (HU) equal to 41. This lesion decreases in size to 103 mm, with average HU = 31. This tumor has decreased in size by 38% with 24% decrease in density, consistent with partial response.

body mass (SUL) to measure tumor peak standardized uptake value corrected for lean body mass (SUL peak) [19–21].

As a reference value, mean SUL and standard deviation obtained from a 3 cm diameter spherical volume of interest in the right hepatic lobe is defined as normal background  $^{18}\text{F}$ FDG. For a tumor to be considered measurable at baseline, its SUL peak must measure at least 1.5 times the mean SUL measured in the liver plus or minus two standard deviations [19,20].

On follow up  $^{18}\text{F}$ FDG PET/CT, maximal SUL peak is again measured from the most metabolically active tumor, which may not necessarily be the same target at baseline [19]. The percent change in SUL peak from baseline is then calculated and reported as a continuous variable, along with the number of weeks since treatment has begun [19,20].

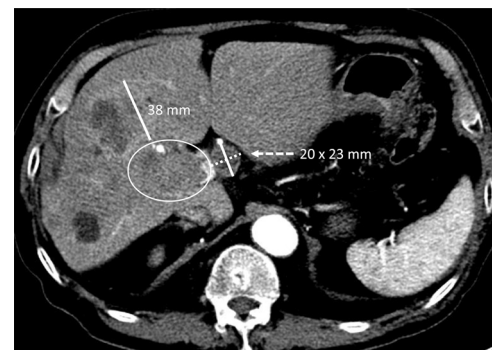
Categorical responses can also be reported. A complete metabolic response (CMR) is defined as a decrease in FDG uptake of all target and non-target lesions below background blood-pool. A partial metabolic response (PMR) is defined as a decrease by at least 30% and at least 0.8 unit decline in SUL peak in the most avid lesion from each timepoint (may be different lesions) with < 30% increase in SUL or size of target or nontarget lesions, and no new FDG-avid lesions in a pattern suggestive of cancer. Stable metabolic disease (SMD) represents unchanged or a less than 30% increase or decrease in SUL peak. Progressive metabolic disease (PMD) is a result of a 30% and 0.8 unit increase in SUL peak from baseline, unequivocal progression of FDG avid non-target disease or the development of new FDG avid lesions in a pattern suggestive of cancer. Visibly increased extent of tumor with a greater than 75% increase in total lesion glycolysis will also result in PMD [19,20].

### 3.2. Technical considerations:

Standardization of image acquisition requires well-calibrated and well-maintained PET/CT scanners. For uniform patient preparation, patients should be fasting for at least 4–6 h prior to imaging and have a serum glucose level < 200 mg/dL. The baseline PET should be obtained 50–70 min from radiotracer injection with all other subsequent imaging performed within 15 min from the baseline timing [20]. Patients should be imaged on the same PET scanner each time, using the same injected dose  $\pm$  20% of radioactivity [20]. Background liver uptake should consistently be within 0.3 SUL unit from study to study [20].

#### 3.2.1. Tumor specific criteria

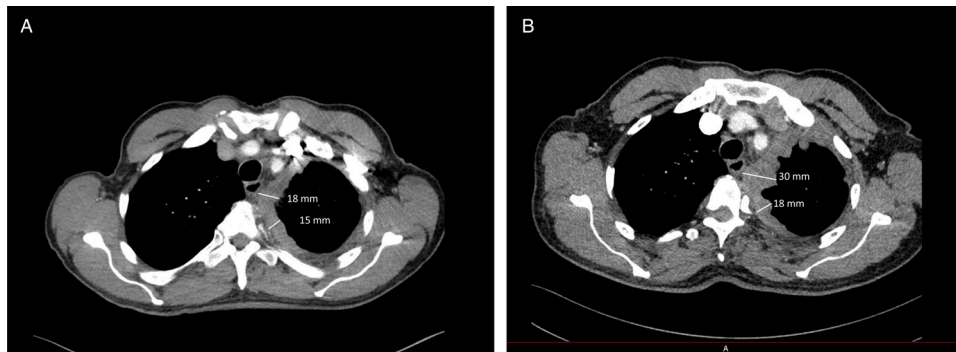
**3.2.1.1. Gastrointestinal stromal tumors.** Gastrointestinal stromal tumors (GISTs) are the most common mesenchymal tumors of the gastrointestinal tract and most commonly arise in the stomach, small intestine, rectum, colon and esophagus [22]. In the metastatic setting, tumor deposits are most commonly seen in the liver and peritoneal



**Fig. 5.** mRECIST for hepatocellular carcinoma. An 81-year-old man with multifocal hepatocellular carcinoma with 38 mm arterially hyperenhancing tumor in the right lobe selected as a target lesion for mRECIST by excluding regions of tumor necrosis (single white line). Enlarged portocaval lymph node measuring 20 mm short axis (dashed line) meets pathologic size criteria by mRECIST. Portal vein tumor thrombus is selected as a non-target lesion (circle).

cavity. Imatinib mesylate, a small-molecule tyrosine kinase inhibitor, received initial approval in 2002 for the treatment of metastatic GIST and has resulted in dramatic improvements in survival and patient outcomes [22,23]. However, it was shown that actual changes in tumor size were small and use of RECIST 1.1 can underestimate tumor response [24,25]. Instead, treatment efficacy was associated with significant changes in tumor density, enhancement of intratumoral tumor nodules and tumor vessels when evaluated with contrast enhanced CT [26]. Therefore modifications to CT response evaluation criteria to include changes in tumor size and density were proposed specifically to assess for treatment response to imatinib in patients with GIST [26], called the Choi criteria. Complete response is defined by the disappearance of all lesions. Partial response is defined by a decrease in size by at least 10% or a decrease in tumor density (Hounsfield Unit (HU)) by at least 15% on CT (Fig. 4). Progressive disease occurs with an increase in tumor size by at least 10% and does not meet criteria of partial response by tumor density (HU) on CT. New lesions, new intratumoral nodules, or increase in size of existing intratumoral nodules also defined disease progression [26]. It has been shown that use of Choi criteria better correlated with time to progression and disease-specific survival compared to RECIST [25]. However, it has also been shown that use of RECIST 1.1 could also provide prognostic information, with absence of disease progression indicating improved survival [27].

**3.2.1.2. Hepatocellular carcinoma.** Hepatocellular carcinoma (HCC) demonstrates characteristic imaging features on multiphasic imaging,



**Fig. 6.** mRECIST for mesothelioma. An 82-year old man with malignant pleural mesothelioma progressing on carboplatin and pemetrexed. Short axis measurements of pleural thickening perpendicular to the mediastinum and chest wall are compared at baseline (A) and follow up (B).

including arterial phase hyperenhancement with portal venous or delayed washout [28]. Modifications to RECIST (mRECIST) have been created to include an evaluation for treatment related alterations in viable tumor, as measured by arterial enhancement. Decreased or resolved arterial phase hyperenhancement is likely indicative of response evidenced by tumor necrosis and may occur regardless of changes in tumor size [29–32].

Using mRECIST, up to two liver lesions can represent target lesions if they are well delineated and demonstrate non-rim arterial enhancement measuring at least 10 mm in greatest diameter and excluding regions of tumor necrosis (Fig. 5) [31]. It is suggested to not include liver lesions which are infiltrative or not well margined, those which have undergone prior local therapy, as well as malignant portal vein thrombosis as target lesions [30]. mRECIST criteria also increase the size threshold to 20 mm short axis for porta hepatic lymph nodes, including portocaval and gastrohepatic lymph nodes to be considered pathologic and measured as target lesions [30,31]. Any other extra-hepatic sites of disease can be accounted similar to RECIST 1.1 as target and non-target disease.

Categorical responses by mRECIST are determined in part by evaluating for the presence and greatest diameter of arterial enhancement on subsequent imaging of the target lesions. A complete response represents resolution of all intra-tumoral arterial enhancement in target and nontarget liver disease as well as disappearance of any additional extrahepatic lesions. In the setting of malignant portal vein thrombus, complete resolution of enhancement is also required for complete response [31]. A decrease in the sum of diameters of arterial hyperenhancing liver lesions and any additional extra-hepatic target lesions from baseline by at least 30% is defined as partial response. Stable disease represents a category in which neither definition of partial response nor disease progression are met. Disease progression is a result of an increase in the sum of the diameters (including arterial enhancement of liver lesions) by at least 20% (with 5 mm absolute increase). Development of new lesion(s) and/or significant worsening of non-target disease also represents disease progression. [30,31]. New liver lesions must measure at least 10 mm in size and demonstrate imaging characteristics of hepatocellular carcinoma with arterial phase enhancement with portal venous or delayed washout [29,31].

### 3.3. Technical considerations

Multiphase imaging by CT or MRI, including at least arterial and portal venous phase imaging is required for mRECIST evaluation and assessment of arterial hypervascularity [30]. Given alterations in the degree of tumor enhancement can at times alone be a result in differences of contrast timing, standardization of image acquisition is essential [31]. In addition, obtaining pre-contrast T1 weighted imaging when MRI is performed can assist in differentiating intrinsically T1 hyperintense lesions or hemorrhage from true intra-lesional enhancement [31].

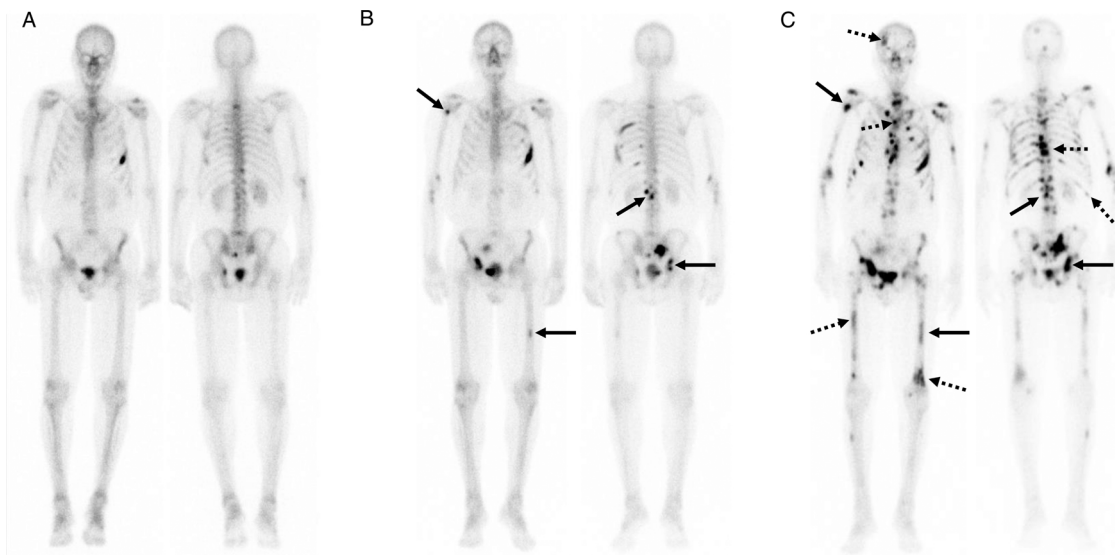
### 3.4. Mesothelioma

Malignant pleural mesothelioma is an uncommon neoplasm which can arise from the pleura. Unilateral rind-like nodular pleural thickening, interlobar fissural thickening and pleural effusion can commonly be seen by imaging [33]. The natural circumferential tumor growth along the pleura by mesothelioma is not well characterized by RECIST 1.1 due to the response assessment's spherical assumptions [34]. Instead, modifications (mRECIST) have been developed to capture short axis pleural thickness perpendicular to the chest wall or mediastinum on axial imaging [34,35]. Areas of pleural thickness of at least 10 mm in short axis thickness can be measured in up to two locations at three separate axial levels along the pleura, giving preference to tumor in the upper thorax (above carina) and regions of greatest pleural thickness (Fig. 6). These pleural measurements are then summed to represent a single diameter [34,36]. Any non-pleural sites of metastases can also be accounted for as target or non-target disease per RECIST 1.1 [36]. These areas of pleural thickening are re-measured on post-baseline imaging at the same level to determine categorical response by mRECIST. A complete response represents disappearance of all target and non-target disease. Partial response results from a decrease in total tumor measurement by at least 30%. Stable disease is measured tumor burden which does not meet the threshold for either partial response nor disease progression. Disease progression results from an increase in 20% or more of total measured tumor [34].

### 3.5. Prostate cancer

Prostate cancer is the most common cancer amongst men and is known to have high inter and intra-patient heterogeneity of disease biology [37,38]. When metastatic, tumor most commonly spreads to bones, lymph nodes, liver, and lungs [38]. Given this disease distribution, radionuclide bone scanning and conventional CT and MRI are commonly used in synergy for detection of metastases and response assessment, with assessments previously shown to be associated with overall survival [39]. While next generation imaging techniques, including whole body MRI and prostate-specific membrane antigen (PSMA) PET/CT have been shown to be more sensitive in detecting metastases, they may be used at baseline, but are not yet routinely used in all timepoints in therapeutic clinical trials [38, 40, 41] with continued reliance of  $^{99m}\text{Tc}$  bone scan.

The Prostate Cancer Clinical Trials Working Group 3 (PCWG3) recommendations provide guidelines for baseline assessment and serial follow up of patients with prostate cancer in clinical trials. Taking a more holistic approach, these guidelines recommend integrating serial imaging assessments with other predictive biomarkers, including blood-based biomarkers (eg. PSA and circulating tumor cells), patient reported outcome measures to assess health-related quality of life and/or biopsy results. Instead of focusing on evaluating for the first evidence of disease



**Fig. 7.** Prostate Cancer Working Group 3. A 71-year-old man with castration resistant metastatic prostate adenocarcinoma (Gleason 9, 5 +4 at diagnosis) being treated with enzalutamide. At baseline (A), there are tracer avid lesions in the left first rib, upper thoracic spine and pelvis. At the first follow up (B) there are  $\geq 2$  new tracer avid lesions. For example, new lesions seen in the right humerus, lumbar spine, right pelvis, left femur (black arrows), consistent with unconfirmed progression. At the second follow up (C) there is persistence of new lesions seen at first follow up (black arrows), plus  $\geq 2$  additional new lesions. For example, new lesions seen in the skull, sternum, spine, ribs, pelvis, and bilateral lower extremities (dashed black arrows), consistent with confirmed progression.

progression, PCWG3 emphasizes data integration to better determine when patients are no longer clinically benefiting, and treatment should be discontinued [42].

For imaging response assessment, PCWG3 relies on RECIST 1.1 for extraskelatal imaging response assessment [42]. However, these guidelines also recommend collecting additional image-based information to better capture anatomic distribution and tumor heterogeneity. Similar to RECIST 1.1, lymph nodes at least 15 mm short axis can be measured as target lesions, and lymph nodes measuring 10–15 mm are considered pathologic [5,42]. Per RECIST 1.1, lymph nodes are considered an organ system, and only two target lesions can be included from the same organ system [5]. PCWG3 recommends recording up to five lymph nodes and defining them as either pelvic (locoregional) or extrapelvic (metastatic eg. retroperitoneal, mediastinal, thoracic or other) in location. A more detailed description of anatomic disease burden is also suggested by PCWG3, including recording individual sites of disease spread (eg. lung, liver, adrenal, central nervous system) separately and to include up to five lesions per organ site. With respect to progression, PCWG3 also recommends differentiating radiographic disease progression by growth of existing lesions versus development of new lesions [42].

Imaging with  $^{99m}\text{Tc}$ -methylene diphosphonate radionuclide bone scintigraphy is used for evaluating bone disease by PCWG3. Pre-treatment bone disease is recorded on baseline bone scan. In the setting of worsening bone disease, a “2 + 2” rule is used to control for potential tumor flare; defined as a paradoxical worsening of bone disease due to bone healing. By this rule, disease progression by only bone disease is defined as the appearance of 2 or more new lesions by bone scan which must be then confirmed 6 or more weeks later and with the appearance of at least 2 additional new lesions (Fig. 7) [43,44]. Enlargement of pre-existing bone lesions by bone scan does not meet criteria for disease progression [38].

#### 4. Conclusion

Image-based outcome measures are more commonly being used as intermediate endpoints in clinical trials and for regulatory approval [45]. A fundamental understanding of imaging response assessment and available imaging response criteria is essential for patient care and trial

reporting. While RECIST 1.1 remains the reference standard for evaluating solid tumors, multiple additional criteria are also available to select from when evaluating certain tumor types, assessing response to immunotherapy or incorporating PET imaging.

#### References

- [1] C.G. Moertel, J.A. Hanley, The effect of measuring error on the results of therapeutic trials in advanced cancer, *Epub 1976/07/01*, *Cancer*. 38 (1) (1976) 388–394, [https://doi.org/10.1002/1097-0142\(197607\)38:1<388::aid-cncr2820380156>3.0.co;2-a](https://doi.org/10.1002/1097-0142(197607)38:1<388::aid-cncr2820380156>3.0.co;2-a).
- [2] L. Fournier, L.-F. de Geus-Oei, D. Regge, D.-E. Oprea-Lager, M. D’Anastasi, L. Bidaut, T. Bäuerle, E. Lopci, G. Cappello, F. Lecouvet, M. Mayerhoefer, W. G. Kunz, J.J.C. Verhoeff, D. Caruso, M. Smits, R.-T. Hoffmann, S. Gourtsoyianni, R. Beets-Tan, E. Neri, N.M. deSouza, C.M. Deroose, C. Caramella, Twenty years on: RECIST as a biomarker of response in solid tumours an EORTC imaging group – ESOI joint paper, *Front. Oncol.* (2022) 11, <https://doi.org/10.3389/fonc.2021.800547>.
- [3] A.B. Miller, B. Hoogstraten, M. Staquet, A. Winkler, Reporting results of cancer treatment, *Epub 1981/01/01*, *Cancer*. 47 (1) (1981) 207–214, [https://doi.org/10.1002/1097-0142\(19810101\)47:1<207::aid-cncr2820470134>3.0.co;2-6](https://doi.org/10.1002/1097-0142(19810101)47:1<207::aid-cncr2820470134>3.0.co;2-6).
- [4] P. Therasse, S.G. Arbuck, E.A. Eisenhauer, J. Wanders, R.S. Kaplan, L. Rubinstein, J. Verweij, M. Van Glabbeke, A.T. van Oosterom, M.C. Christian, S.G. Gwyther, New guidelines to evaluate the response to treatment in solid tumors, *JNCI: J. National Cancer Institute* 92 (3) (2000) 205–216, <https://doi.org/10.1093/jnci/92.3.205>.
- [5] E.A. Eisenhauer, P. Therasse, J. Bogaerts, L.H. Schwartz, D. Sargent, R. Ford, J. Dancy, S. Arbuck, S. Gwyther, M. Mooney, L. Rubinstein, L. Shankar, L. Dodd, R. Kaplan, D. Lacombe, J. Verweij, New response evaluation criteria in solid tumours: revised RECIST guideline (version 1.1), *European J. Cancer* 45 (2) (2009) 228–247, <https://doi.org/10.1016/j.ejca.2008.10.026>.
- [6] M. Nishino, J.P. Jagannathan, N.H. Ramaiya, A.D. Van den Abbeele, Revised RECIST guideline version 1.1: what oncologists want to know and what radiologists need to know, *Epub 2010/07/24*, *AJR Am. J. Roentgenol.* 195 (2) (2010) 281–289, <https://doi.org/10.2214/ajr.09.4110>.
- [7] S. Litière, G. Isaac, E.G.E.D. Vries, J. Bogaerts, A. Chen, J. Dancy, R. Ford, S. Gwyther, O. Hoekstra, E. Huang, N. Lin, Y. Liu, S. Mandrekar, L.H. Schwartz, L. Shankar, P. Therasse, L. Seymour, obotR.W. Group, RECIST 1.1 for response evaluation apply not only to chemotherapy-treated patients but also to targeted cancer agents: a pooled database analysis, *J. Clin. Oncol.* 37 (13) (2019) 1102–1110, <https://doi.org/10.1200/jco.18.01100>.
- [8] K. Esfahani, L. Roudaia, N. Buhlaiga, S.V. Del Rincon, N. Papneja, W.H. Miller Jr., A review of cancer immunotherapy: from the past, to the present, to the future. *Curr Oncol.*, *Epub 2020/04/01* 27 (Suppl 2) (2020) S87–S97, <https://doi.org/10.3747/co.27.5223>.
- [9] J.A. Beaver, R. Pazdur, The wild west of checkpoint inhibitor development, *New England J. Med.* (2021), <https://doi.org/10.1056/NEJMp2116863>.

- [10] A.H. Sharpe, K.E. Pauken, The diverse functions of the PD1 inhibitory pathway, *Nature Rev. Immunol.* 18 (3) (2018) 153–167, <https://doi.org/10.1038/nri.2017.108>.
- [11] M. Nishino, H. Hatabu, F.S. Hodi, Imaging of cancer immunotherapy: current approaches and future directions, *Radiology* 290 (1) (2019) 9–22, <https://doi.org/10.1148/radiol.2018181349>.
- [12] J.D. Wolchok, A. Hoos, S. O'Day, J.S. Weber, O. Hamid, C. Lebbé, M. Maio, M. Binder, O. Bohnsack, G. Nichol, R. Humphrey, F.S. Hodi, Guidelines for the evaluation of immune therapy activity in solid tumors: immune-related response criteria, *Clin. Cancer Res.* 15 (23) (2009) 7412–7420, <https://doi.org/10.1158/1078-0432.Ccr-09-1624>.
- [13] E. Borcoman, A. Nandikolla, G. Long, S. Goel, C.L. Tourneau, Patterns of response and progression to immunotherapy, *Am. Soc. Clin. Oncol. Educational Book* (38) (2018) 169–178, <https://doi.org/10.1200/edbk.200643>.
- [14] M. Nishino, A. Giobbie-Hurder, M. Gargano, M. Suda, N.H. Ramaiya, F.S. Hodi, Developing a common language for tumor response to immunotherapy: immune-related response criteria using unidimensional measurements, *Epub 2013/06/06, Clin. Cancer Res.: An official J. Am. Association for Cancer Res.* 19 (14) (2013) 3936–3943, <https://doi.org/10.1158/1078-0432.CCR-13-0895>.
- [15] F.S. Hodi, M. Ballinger, B. Lyons, J.-C. Soria, M. Nishino, J. Taberner, T. Powles, D. Smith, A. Hoos, C. McKenna, U. Beyer, I. Rhee, G. Fine, N. Winslow, D.S. Chen, J.D. Wolchok, Immune-modified response evaluation criteria in solid tumors (imRECIST): refining guidelines to assess the clinical benefit of cancer immunotherapy, *J. Clin. Oncol.* 36 (9) (2018) 850–858, <https://doi.org/10.1200/jco.2017.75.1644>.
- [16] L. Seymour, J. Bogaerts, A. Perrone, R. Ford, L.H. Schwartz, S. Mandrekra, N. U. Lin, S. Litière, J. Dancy, A. Chen, F.S. Hodi, P. Therasse, O.S. Hoekstra, L. K. Shankar, J.D. Wolchok, M. Ballinger, C. Caramella, G.E. de Vries, R. Group, iRECIST: guidelines for response criteria for use in trials testing immunotherapeutics, *Epub 2017/03/02, Lancet Oncol.* 18 (3) (2017) e143–e152, [https://doi.org/10.1016/S1470-2045\(17\)30074-8](https://doi.org/10.1016/S1470-2045(17)30074-8).
- [17] P.B. Bach, J.N. Mirkin, T.K. Oliver, et al., Benefits and harms of ct screening for lung cancer: a systematic review, *JAMA* 307 (22) (2012) 2418–2429, <https://doi.org/10.1001/jama.2012.5521>.
- [18] H. Jadvar, P.M. Colletti, R. Delgado-Bolton, G. Esposito, B.J. Krause, A.H. Jagaru, H. Nadel, D.I. Quinn, E. Rohren, R.M. Subramaniam, K. Zukotynski, J. Kauffman, S. Ahuja, L. Griffith, Appropriate use criteria for 18F-FDG PET/CT in restaging and treatment response assessment of malignant disease, *Journal of Nuclear Med.* 58 (12) (2017) 2026–2037, <https://doi.org/10.2967/jnumed.117.197988>.
- [19] O.J.H. Lodge, M.A. Wahl, R.L. Practical PERCIST: a simplified guide to PET response criteria in solid tumors I.O, *Radiology* 280 (2) (2016) 576–584, <https://doi.org/10.1148/radiol.2016142043>.
- [20] R.L. Wahl, H. Jacene, Y. Kasamon, M.A. Lodge, From RECIST to PERCIST: evolving considerations for PET response criteria in solid tumors, *Suppl 1, J Nucl Med.* 50 (Suppl 1) (2009) 122S–150SS, <https://doi.org/10.2967/jnumed.108.057307>.
- [21] T. Tirkes, M.A. Hollar, M. Tann, M.D. Kohli, F. Akisik, K. Sandrasegaran, Response criteria in oncologic imaging: review of traditional and new criteria, *RadioGraphics* 33 (5) (2013) 1323–1341, <https://doi.org/10.1148/rg.335125214>.
- [22] S.H. Tirumani, J.P. Jagannathan, K.M. Krajewski, A.B. Shinagare, H. Jacene, N. H. Ramaiya, Imatinib and beyond in gastrointestinal stromal tumors: a radiologist's perspective, *Am. J. Roentgenol.* 201 (4) (2013) 801–810, <https://doi.org/10.2214/AJR.12.10003>.
- [23] G.D. Demetri, M. von Mehren, C.D. Blanke, A.D. Van den Abbeele, B. Eisenberg, P. J. Roberts, M.C. Heinrich, D.A. Tuveson, S. Singer, M. Janicek, J.A. Fletcher, S. G. Silverman, S.L. Silberman, R. Capdeville, B. Kiese, B. Peng, S. Dimitrijevic, B. J. Druker, C. Corless, C.D.M. Fletcher, H. Joensuu, Efficacy and safety of imatinib mesylate in advanced gastrointestinal stromal tumors, *New England J. Med.* 347 (7) (2002) 472–480, <https://doi.org/10.1056/NEJMoa020461>.
- [24] H. Choi, C. Charnsangavej, S.D. Faria, E.P. Tamm, R.S. Benjamin, M.M. Johnson, H.A. Macapinlac, D.A. Podoloff, CT evaluation of the response of gastrointestinal stromal tumors after imatinib mesylate treatment: a quantitative analysis correlated with FDG PET findings, *Am. J. Roentgenol.* 183 (6) (2004) 1619–1628, <https://doi.org/10.2214/ajr.183.6.01831619>.
- [25] R.S. Benjamin, H. Choi, H.A. Macapinlac, M.A. Burgess, S.R. Patel, L.L. Chen, D. A. Podoloff, Charnsangavej C. We Should Desist Using RECIST, at Least in GIST, *J. Clin. Oncol.* 25 (13) (2007) 1760–1764, <https://doi.org/10.1200/jco.2006.07.3411>.
- [26] H. Choi, C. Charnsangavej, S.C. Faria, H.A. Macapinlac, M.A. Burgess, S.R. Patel, L. L. Chen, D.A. Podoloff, R.S. Benjamin, Correlation of computed tomography and positron emission tomography in patients with metastatic gastrointestinal stromal tumor treated at a single institution with imatinib mesylate: proposal of new computed tomography response criteria, *J. Clin. Oncol.* 25 (13) (2007) 1753–1759, <https://doi.org/10.1200/jco.2006.07.3049>.
- [27] A.L. Cesne, M.V. Glabbeke, J. Verweij, P.G. Casali, M. Findlay, P. Reichardt, R. Issels, I. Judson, P. Schöffski, S. Leyvraz, B. Bui, P.C.W. Hogendoorn, R. Sciort, J.-Y. Blay, Absence of progression as assessed by response evaluation criteria in solid tumors predicts survival in advanced gI stromal tumors treated with imatinib mesylate: the intergroup EORTC-ISG-AGITG phase III trial, *J. Clin. Oncol.* 27 (24) (2009) 3969–3974, <https://doi.org/10.1200/jco.2008.21.3330>.
- [28] S.H. McEvoy, C.J. McCarthy, L.P. Lavelle, D.E. Moran, C.P. Cantwell, S.J. Skehan, R.G. Gibney, D.E. Malone, Hepatocellular carcinoma: illustrated guide to systematic radiologic diagnosis and staging according to guidelines of the american association for the study of liver diseases, *RadioGraphics.* 33 (6) (2013) 1653–1668, <https://doi.org/10.1148/rg.336125104>.
- [29] R. Lencioni, J.M. Llovet, Modified RECIST (mRECIST) assessment for hepatocellular carcinoma, *Epub 2010/02/23, Semin Liver Dis* 30 (1) (2010) 52–60, <https://doi.org/10.1055/s-0030-1247132>.
- [30] J.M. Llovet, S. Ricci, V. Mazzaferro, P. Hilgard, E. Gane, J.-F. Blanc, A.C. de Oliveira, A. Santoro, J.-L. Raoul, A. Forner, M. Schwartz, C. Porta, S. Zeuzem, L. Bolondi, T.F. Greten, P.R. Galle, J.-F. Seitz, I. Borbath, D. Häussinger, T. Giannaris, M. Shan, M. Moscovici, D. Voliotis, J. Bruix, Sorafenib in advanced hepatocellular carcinoma, *New England J. Med.* 359 (4) (2008) 378–390, <https://doi.org/10.1056/NEJMoa0708857>.
- [31] J.M. Llovet, R. Lencioni, mRECIST for HCC: performance and novel refinements, *Epub 2020/01/20, J Hepatol.* 72 (2) (2020) 288–306, <https://doi.org/10.1016/j.jhep.2019.09.026>.
- [32] R. Lencioni, New data supporting modified RECIST (mRECIST) for hepatocellular carcinoma, *Epub 2013/02/06, Clin. Cancer Res.* 19 (6) (2013) 1312–1314, <https://doi.org/10.1158/1078-0432.Ccr-12-3796>.
- [33] Z.J. Wang, G.P. Reddy, M.B. Gotway, C.B. Higgins, D.M. Jablons, M. Ramaswamy, R.A. Hawkins, W.R. Webb, Malignant pleural mesothelioma: evaluation with CT, MR imaging, and PET, *RadioGraphics.* 24 (1) (2004) 105–119, <https://doi.org/10.1148/rg.241035058>.
- [34] R.J. van Klaveren, J.G.J.V. Aerts, H. de Bruin, G. Giaccone, C. Manegold, J.P. van Meerbeek, Inadequacy of the RECIST criteria for response evaluation in patients with malignant pleural mesothelioma, *Lung Cancer* 43 (1) (2004) 63–69, [https://doi.org/10.1016/S0169-5002\(03\)00292-7](https://doi.org/10.1016/S0169-5002(03)00292-7).
- [35] A.S. Tsoo, G.W. Gladish, R.R. Gill, Revised modified RECIST criteria in malignant pleural mesothelioma (Version 1.1): a step forward in a long race, *Epub 2018/06/25, J. Thorac. Oncol.* 13 (7) (2018) 871–873, <https://doi.org/10.1016/j.jtho.2018.05.003>.
- [36] A.S. Tsoo, L. Garland, M. Redman, K. Kernstine, D. Gandara, E.M. Marom, A practical guide of the Southwest Oncology Group to measure malignant pleural mesothelioma tumors by RECIST and modified RECIST criteria, *J. Thorac. Oncol.* 6 (3) (2011) 598–601, <https://doi.org/10.1097/JTO.0b013e318208c83d>.
- [37] M.S. Litwin, H.-J. Tan, The diagnosis and treatment of prostate cancer: a review, *JAMA* 317 (24) (2017) 2532–2542, <https://doi.org/10.1001/jama.2017.7248>.
- [38] R. Perez-Lopez, N. Tunariu, A.R. Padhani, W.J.G. Oyen, S. Fanti, H.A. Vargas, A. Omlin, M.J. Morris, Bono Jd, Koh D-M. Imaging Diagnosis and Follow-up of Advanced Prostate Cancer: Clinical Perspectives and State of the Art, *Radiology* 292 (2) (2019) 273–286, <https://doi.org/10.1148/radiol.2019181931>.
- [39] M.J. Morris, A. Molina, E.J. Small, J.S. de Bono, C.J. Logothetis, K. Fizazi, P. de Souza, P.W. Kantoff, C.S. Higano, J. Li, T. Kheoh, S.M. Larson, S.L. Matheny, V. Naini, T. Burzykowski, T.W. Griffin, H.I. Scher, C.J. Ryan, Radiographic progression-free survival as a response biomarker in metastatic castration-resistant prostate cancer: COU-AA-302 results, *Epub 2015/01/26, J. Clin. Oncol.* 33 (12) (2015) 1356–1363, <https://doi.org/10.1200/JCO.2014.55.3875>.
- [40] O. Sartor, J.S. de Bono, Metastatic prostate cancer, *New England J. Med.* 378 (7) (2018) 645–657, <https://doi.org/10.1056/NEJMra1701695>.
- [41] Schöder H., Hope TA, Knopp M., Kelly WK, Michalski JM, Lerner SP, Tawab-Amiri A., Mann BS, Lin DW, Yu EY, Chen RC, Beach GC, Reeves SA, Group MotW, Shankar LK. Considerations on Integrating Prostate-Specific Membrane Antigen Positron Emission Tomography Imaging Into Clinical Prostate Cancer Trials by National Clinical Trials Network Cooperative Groups. *Journal of Clinical Oncology*.0(0):JCO.21.02440. doi: 10.1200/jco.21.02440. PubMed PMID: 35015566.
- [42] H.I. Scher, M.J. Morris, W.M. Stadler, C. Higano, E. Basch, K. Fizazi, E. S. Antonarakis, T.M. Beer, M.A. Carducci, K.N. Chi, P.G. Corn, J.Sd Bono, R. Dreicer, D.J. George, E.I. Heath, M. Hussain, W.K. Kelly, G. Liu, C. Logothetis, D. Nanus, M.N. Stein, D.E. Rathkopf, S.F. Slovin, C.J. Ryan, O. Sartor, E.J. Small, M.R. Smith, C.N. Sternberg, M.-E. Taplin, G. Wilding, P.S. Nelson, L.H. Schwartz, S. Halabi, P.W. Kantoff, A.J. Armstrong, Trial design and objectives for castration-resistant prostate cancer: updated recommendations from the prostate cancer clinical trials working group 3, *J. Clin. Oncol.* 34 (12) (2016) 1402–1418, <https://doi.org/10.1200/jco.2015.64.2702>.
- [43] D.E. Rathkopf, T.M. Beer, Y. Loriot, C.S. Higano, A.J. Armstrong, C.N. Sternberg, J. S. de Bono, B. Tombal, T. Parli, S. Bhattacharya, D. Phung, A. Krivosik, H.I. Scher, M.J. Morris, Radiographic progression-free survival as a clinically meaningful end point in metastatic castration-resistant prostate cancer: the PREVAIL randomized clinical trial, *JAMA Oncol.* 4 (5) (2018) 694–701, <https://doi.org/10.1001/jamaoncol.2017.5808>.
- [44] H.I. Scher, S. Halabi, I. Tannock, M. Morris, C.N. Sternberg, M.A. Carducci, M. A. Eisenberger, C. Higano, G.J. Bubley, R. Dreicer, D. Petrylak, P. Kantoff, E. Basch, W.K. Kelly, W.D. Figg, E.J. Small, T.M. Beer, G. Wilding, A. Martin, Hussain M. design and end points of clinical trials for patients with progressive prostate cancer and castrate levels of testosterone: recommendations of the prostate cancer clinical trials working group, *J. Clin. Oncol.* 26 (7) (2008) 1148–1159, <https://doi.org/10.1200/jco.2007.12.4487>.
- [45] J.A. Beaver, L.J. Howie, L. Pelosof, T. Kim, J. Liu, K.B. Goldberg, R. Sridhara, G. M. Blumenthal, A.T. Farrell, P. Keegan, R. Pazdur, P.G. Kluetz, A 25-year experience of US food and drug administration accelerated approval of malignant hematology and oncology drugs and biologics: a review, *JAMA Oncol.* 4 (6) (2018) 849–856, <https://doi.org/10.1001/jamaoncol.2017.5618>.