





# Addressing resistance to PD-1/PD-(L)1 pathway inhibition: considerations for combinatorial clinical trial designs

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## ABSTRACT

With multiple PD-(L)1 inhibitors approved across dozens of indications by the US Food and Drug Administration, the number of patients exposed to these agents in adjuvant, first-line metastatic, second-line metastatic, and refractory treatment settings is increasing rapidly. Although some patients will experience durable benefit, many have either no clinical response or see their disease progress following an initial response to therapy. There is a significant need to identify therapeutic approaches to overcome resistance and confer clinical benefits for these patients. PD-1 pathway blockade has the longest history of use in melanoma, non-small cell lung cancer (NSCLC), and renal cell carcinoma (RCC). Therefore, these settings also have the most extensive clinical experience with resistance. In 2021, six non-profit organizations representing patients with these diseases undertook a year-long effort, culminating in a 2-day workshop (including academic, industry, and regulatory participants) to understand the challenges associated with developing effective therapies for patients previously exposed to anti-PD-(L)1 agents and outline recommendations for designing clinical trials in this setting. This manuscript presents key discussion themes and positions reached through this effort, with a specific focus on the topics of eligibility criteria, comparators, and endpoints, as well as tumor-specific trial design options for combination therapies designed to treat patients with melanoma, NSCLC, or RCC after prior PD-(L)1 pathway blockade.

## INTRODUCTION: IMMUNE CHECKPOINT INHIBITION AND MECHANISMS OF RESISTANCE

With the US Food and Drug Administration (FDA) approving immune checkpoint inhibitors (ICIs) across multiple indications, the number of patients exposed to ICIs for adjuvant, first-line or second-line metastatic, and refractory treatment settings is increasing rapidly. While a minority of patients will achieve durable clinical responses, many others will demonstrate no response or will progress following an initial period of response. Identifying therapies that can overcome resistance and confer clinical benefits

for these patients, therefore, represents an area of significant unmet clinical need.

Patients with melanoma, non-small cell lung cancer (NSCLC), and renal cell carcinoma (RCC) have had the longest history with ICI treatment. As a result, patients with these three solid tumors who have documented therapeutic resistance to PD-(L)1 inhibitors pose an increasingly difficult clinical conundrum for treating oncologists. Despite some unique considerations among the three cancer types, efforts to tackle this problem for each of these tumor types can benefit from focused input from basic science researchers defining mechanisms of ICI resistance as well as clinical investigators, clinicians, and patient advocates across cancer types to facilitate clinical development of treatments targeting those ICI resistance mechanisms.

Over the past two decades, fundamental discoveries of the mechanisms by which tumors evade the host immune response have successfully translated into therapeutic opportunities. The advent of ICIs such as CTLA-4 and PD-(L)1 inhibitors has dramatically improved clinical outcomes across solid tumors. These ICIs improve immune activation by inhibiting negative regulatory pathways for tumor immune evasion. Genomic changes, chemokines, and dynamic processes that shift toward immunosuppression can lead to ICI treatment resistance.<sup>1,2</sup>

To identify key considerations and develop consensus among experts, a consortium of patient advocacy organizations, including the LUNgevity Foundation, Kidney Cancer Cure (KCCure), Melanoma Research Alliance, Melanoma Research Foundation, and Friends of Cancer Research, joined together to launch a working group effort (including leading clinicians, industry leaders, and regulatory officials) to discuss the issues related to



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**WHAT IS ALREADY KNOWN ON THIS TOPIC**

- Immune checkpoint inhibitor resistance is clearly emerging in multiple cancer types – with most prior clinical experience in NSCLC, RCC, and melanoma – and therefore most patient populations with ICI resistant disease.
- In order to consolidate lessons learned and develop best practices for clinical development in refractory disease, a workshop of expert clinical investigators, patient advocates, and industry partners was convened.

**WHAT THIS WORKSHOP DISCUSSION ADDS**

- In order to study patients carefully in ICI-resistant populations, best practices for clinical trials should include patient stratification for prior therapies.
- Overall, relaxing inclusion criteria (for example, allowing multiple lines of prior therapies as well as stable treated brain metastases) is recommended as consensus for future trials in ICI-resistant populations.
- For combinations of novel agents in ICI-refractory disease, contribution of parts should be addressed with cohorts treated with single agents. However PD-(L)1 inhibitor monotherapy used in sequence for prior ICI-refractory disease may have limited efficacy/enrollment.

**HOW THIS MANUSCRIPT MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY**

- Highlight the importance of ICI resistance, as patients with melanoma, RCC, and NSCLC (and many other solid tumors) are progressing past their initial ICI-based treatments.
- Provide principles for designing future trials for ICI-refractory populations.

**Figure 1** Keypoints summarizing takeaways. ICI, immune checkpoint inhibitor; NSCLC, non-small cell lung cancer; RCC, renal cell carcinoma.

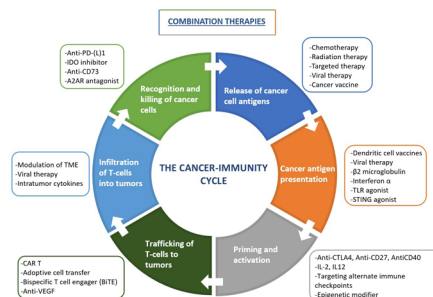
ICI resistance in patients with melanoma, NSCLC, and RCC.

This effort built on the 2019 work of Friends of Cancer Research<sup>3</sup> to identify rational trial designs for evaluating combination therapies for tumors that have progressed after anti-PD-(L)1 therapy and the resistance-related definitions and recommendations put forth by the Society for Immunotherapy of Cancer (SITC) Immunotherapy Resistance Taskforce in 2020.<sup>4</sup> The working group designed a collaborative process, culminating in a 2-day virtual workshop in October 2021 to identify and tackle shared challenges in conducting clinical trials for patients previously exposed to anti-PD-(L)1 therapy across the three tumor types. This paper summarizes meeting findings and subsequent recommendations for future trials (figure 1).

### Treatment resistance overview

To date, only a few immune-regulatory pathways have been successfully targeted with ICIs for patient benefit. Response rates of 30–45% have been reported with single-agent anti-PD-(L)1 therapy for certain solid tumor front-line metastatic settings.<sup>5–7</sup> At best, some regimens reach near 50% objective response rates with combination treatments, as reported in melanoma, lung, and renal cancers.<sup>8–11</sup> In the majority of patients treated with ICIs, however, tumors can exhibit either primary resistance or secondary/acquired resistance after initial response.

The most common strategy to overcome primary resistance is developing combination therapies that can attack multiple targets simultaneously. ICIs have been added to front-line combinations for chemo-immunotherapy approaches in NSCLC<sup>10</sup> and anti-angiogenic immunotherapy approaches in RCC.<sup>12–14</sup> However, crosstalk



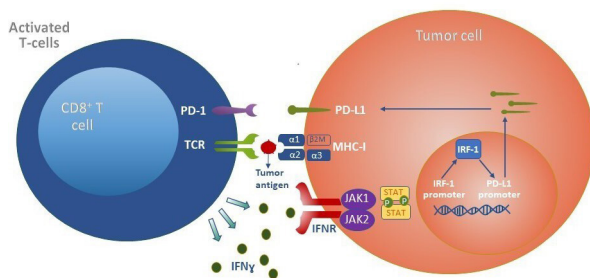
**Figure 2** Cancer-immunity cycle and potential mechanisms to overcome resistance. TME, tumor microenvironment.

between T cells, antigen-presenting cells, and cancer cells occurs within the tumor microenvironment (TME) and includes many more molecules and interactions.<sup>15</sup> Moreover, the immune response against cancer is not limited to the TME. Many molecular interactions play a role in the process, from T-cell activation after recognition of a cancer antigen, immune cell trafficking to cancer cells, infiltration of these cells into the tumor, and killing of the target cancer cell. This process has been termed the “Cancer-Immunity Cycle” (figure 2). The tumor cell can escape from immune surveillance at several points within this cycle.<sup>16</sup> The most complex and least understood parts of immune resistance involve the dynamic processes taking place in the steps of this cycle that lead to acquired resistance.

### Mechanisms of resistance

Generally, tumors with low tumor mutational burden or low immune cell infiltration in the TME (cold tumors) respond poorly to immunotherapies.<sup>17,18</sup> Therefore, the TME affects the immune response and, thus, the success of the treatment, both in immune activation and in cytotoxicity of tumor cells. Changes in TME content can contribute to immunotherapy resistance.<sup>19,20</sup> PD-L1 can be found expressed in the TME both constitutively and due to immune activation.<sup>21</sup> For anti-PD-(L)1 therapy to be effective, there must be a pre-existing T-cell-mediated immune response. Interferon-gamma, released from T cells and natural killer cells, causes the expression of various genes that provide immune activation via the Janus kinase/signal transducer and activator of transcription (JAK/STAT) pathway, and JAK1/2 mutations make up one mechanism identified for primary resistance (figure 3).<sup>22–24</sup>

Beyond the expression of specific molecules, it has been shown that intact tumor antigen presentation is critical to T-cell activation. The expression of MHC class I and II, which are involved in antigen presentation, engage the T cell through the T-cell receptor, and key chemokines are released, which change the TME immune activation level.<sup>25</sup> Through a series of elegant studies, acquired and/or selected mutations in  $\beta 2$  microglobulin, a component of MHC class I molecules, have been implicated in the impaired T-cell antigen recognition, immune activation,



**Figure 3** IFN- $\gamma$ -JAK-STAT pathway mediated PD-1 upregulation. IFN- $\gamma$  upregulates PD-L1 expression on tumor cells by activating the JAK/STAT pathway. Increased PD-L1 expression induces immune escape and improves sensitivity to PD-(L)1 inhibitors. Some genomic alterations of JAK1/2 can cause primary resistance to immunotherapy.  $\beta$ 2M, beta-2 microglobulin; IFNR, interferon receptor; IRF-1, IFN regulatory factor 1; JAK, Janus activated kinase; MHC-I, major histocompatibility complex-1; PD-1, programmed death-1; PD-L1, programmed death-ligand 1; STAT, signal transducer and activator of transcription; TCR, T-cell receptor.

and interferon-gamma release, seen in acquired ICI resistance.<sup>26 27</sup>

Understanding the mechanisms of ICI resistance will enable the next generation of treatment trials to target those mechanisms. Considering the potential synergistic effects, combining treatment methods is an effective method for overcoming immunotherapy resistance. Finally, as future scientific advances improve the understanding of more ICI resistance pathways, further therapeutic approaches targeting those pathways can be developed.

## BACKGROUND: DEFINING THE CHALLENGE AND OPPORTUNITIES FOR PROGRESS

### Unmet medical need among patients exposed to immunotherapy

Mechanisms of ICI resistance are not clearly understood. A better understanding of ICI resistance mechanisms will not only enable the identification of predictive and prognostic biomarkers but also inform which combinations will be effective and, importantly, how to sequence these therapeutic regimens. There is currently a dearth of clinical data on effective subsequent treatment options in patients who have disease progression on ICIs. Clearly, a better understanding of ICI resistance mechanisms will be an important guide for designing effective strategies for clinical development in the post-ICI setting.<sup>28–30</sup>

### Need to develop consensus on optimal trial designs to overcome ICI resistance

The lack of consistent clinical definitions of primary and acquired ICI resistance, and the lack of uniform criteria, including criteria for response and progression, are barriers to clinical trials and drug development for post-ICI disease. Without consistent clinical definitions of ICI resistance, a clinical trial enrolling post-ICI patients would have difficulty selecting a homogeneous patient

cohort. To date, early trials in this setting have adopted a 6-month cut-off to define primary (duration of prior PD-(L)1 therapy being <6 months) versus acquired (prior PD-(L)1 therapy for  $\geq$ 6 months) resistance; however, efforts are ongoing to create a more nuanced definition.<sup>13</sup>

The studies to be designed may need to be handled on a tumor-specific basis, as suggested by Schoenfeld *et al*, as tumor biology differs between histologies.<sup>31</sup> For a better understanding of resistance mechanisms and their difference between tumor types, serial tumor biopsies should be obtained in clinical trials. These biopsies can use panels of biomarkers to associate with clinical outcomes, thus allowing for correlation of tumor responses with candidate predictive biomarkers—of both response and resistance. In addition, ongoing analysis of existing patient samples collected since the introduction of ICIs, including those collected in “negative” trials, will provide us with important data.

It is, however, necessary to acknowledge the feasibility and difficulties of serial biopsies within the scope of these clinical trial designs. In obtaining research-related serial biopsies, it is important to ensure proper informed consent with careful risk assessment. Liquid biopsies may soon replace conventional biopsies as a less invasive method, as sequencing technologies improve in sensitivity and specificity for long-term monitoring.

Several candidate biomarkers are being investigated as predictive for ICI responses. These include the PD-(L)1 level as well as transcriptome gene expression signatures. However, it is not enough to find what is predictive for tumor response to ICIs. Standardizing definitions and methods, for example, to uniformity in definitions of positive or negative PD-L1 status, can improve our understanding of what is transferrable or not across cancer types. In NSCLC, for example, low PD-(L)1 expression is linked to ICI resistance.<sup>32–34</sup> For NSCLC, the most used and FDA-approved methodology for PD-(L)1 expression is the tumor proportion score (TPS),<sup>35 36</sup> the percentage of viable tumor cells showing partial or complete membrane staining. For other tumors, PD-(L)1 protein expression is determined by using combined positive score,<sup>37</sup> which is the number of PD-(L)1 staining cells (tumor cells, lymphocytes, macrophages) divided by the total number of viable tumor cells. Measuring PD-(L)1 expression is further complicated by the variety of antibodies (eg, Ventana PD-(L)1 (SP142) for atezolizumab, Dako 73-10 for avelumab, Ventana PD-(L)1 (SP263) for durvalumab, Dako 28-8 pharmDx for nivolumab) and different cut-offs to define positivity in each tumor type. The panel, therefore, called for consistency across biomarker definitions as they are developed, which will enable more consistent patient selection and analysis in subsequent post-IO trials.

### Clinical trial endpoints

Overall survival (OS) remains the gold standard clinical endpoint for randomized registrational trials. Because demonstration of OS benefit often requires large numbers of patients and long follow-up periods,



alternative endpoints in immunotherapy trials have been explored, with progression-free survival (PFS) successfully used as a primary endpoint (and surrogate of OS) for registrational trials in the metastatic setting. Given both the difficulty of assessing the overall benefit from early radiographic progression, as well as the prolonged duration of effect in patients who have marked responses to checkpoint inhibitor regimens, landmark OS or PFS have also been proposed as intermediate endpoints (eg, for accelerated approval), but require validation before being used for regulatory approval.<sup>38</sup>

Overall response rate (ORR) is more useful in early analyses and/or in signal-seeking studies than in RCTs with registrational intent. Evaluation of ORR does not always require a comparator and thus is often used in single-cohort studies as an endpoint for accelerated approval. However, ORR may need a comparator for combination treatments to isolate contribution of effect in order to guide subsequent randomized trials. Cross-study comparisons with ORR may also be problematic due to the heterogeneity of different study populations with disparate potentials to respond. Moreover, unless there is a large treatment effect, the apparent clinical benefit seen with this early endpoint may not always translate into PFS or OS improvements.

## SPECIFIC CONSIDERATIONS AND RECOMMENDED TRIAL DESIGN CRITERIA

### Non-small cell lung cancer

Efforts are ongoing among the thoracic oncology community to define primary and acquired resistance to immunotherapy, recognizing that this is a key trial design question when developing new treatments for both advanced and earlier-stage lung cancer. Unfortunately, success with either novel agent monotherapy or combination immune-checkpoint modulation for patients with PD-(L)1 resistant tumors have been limited.<sup>34 39 40</sup> Thus, many development programs for novel, multiple immunotherapy combinations for NSCLC have moved to the first-line setting, typically adding a novel checkpoint inhibitor to a PD-(L)1 backbone.<sup>41–43 44</sup>

Limited data reported thus far indicate that patients with acquired tumor resistance may have a better prognosis irrespective of the next line of therapy used. A recent systematic review of 59 trials with I-O therapy in NSCLC found that in patients with PFS >6 months with stable disease (SD), outcomes were similar to those with partial response, defining a population of “SD responders.”<sup>45</sup> These similar outcomes were observed when either standard chemotherapy or investigational agents were used as next line of therapy.<sup>46 47</sup>

Specific challenges in the lung cancer space include defining resistance when the initial PD-(L)1 therapy is given in combination with other agents, most frequently chemotherapy. Here, at least a proportion of tumors are likely responding to the chemotherapy component rather than to immunotherapy and would be more

appropriately triaged to an immunotherapy-resistant group for next-line treatment. It is possible that early use of novel technologies, eg, ctDNA and/or immune monitoring with T-cell receptor (TCR) sequencing, may allow more refined definitions of clinical benefit from combination immunotherapy treatment, thus allowing appropriate patient selection for ICI resistance trials.<sup>48</sup>

Patients with NSCLC harboring actionable driver mutations (eg, EGFR, ALK, ROS-1) generally have poor outcomes with ICIs.<sup>49 50</sup> However, effective therapeutic options are limited when patients progress on front-line targeted therapies, and ICI outcomes in patients with actionable driver mutations remain an important question for sequential trials. Therefore, the panel advocated that this group of patients should be included when designing clinical trials for refractory NSCLC.

It is possible that combining agents that are not primarily immunologic in their mechanism of action with PD-(L)1 pathway blockade may have a synergistic effect. As an example, initial data from phase I and II trials of lenvatinib with pembrolizumab were encouraging, driving a phase III trial of this combination (LEAP 007). LEAP 007 was conducted in the PD-(L)1 naïve setting in patients whose PD-(L)1 TPS is greater than or equal to 1%, and although the study showed longer median PFS for the combination, it met futility criteria for overall survival.<sup>51</sup> Other therapies with mechanisms to augment immunotherapy effects are direly needed. With promising early data from both antibody–drug conjugates and DNA damage repair inhibitors, it is likely that combinations of novel agents, not primarily immunologic in mechanism of action, with PD-(L)1 pathway blockade will still be a major focus in the ICI-resistant NSCLC setting. The panel had consensus to define patient populations carefully and for post-ICI trials to be as inclusive as possible of patients with prior treatments.

### Renal cell carcinoma

There are now five ICI-based combinations available for clinical use in the front-line setting in RCC, including the combination of nivolumab with ipilimumab or an anti-PD-(L)1 therapy with one of several tyrosine kinase inhibitors (TKIs) targeting the vascular endothelial growth factor (VEGF) receptor.<sup>11–14</sup> These combinations have extended survival outcomes and shown long-term disease control rates (3-year PFS rates); however, treatment resistance develops in the majority of cases. Understanding the critical mechanisms of resistance and effective sequential therapies are necessary to improve therapeutic options in ICI-refractory disease.

Because the first-line immunotherapy combinations are different in their mechanisms of action, resultant resistance mechanisms will also differ. Therefore, in clinical trials for patients with refractory metastatic RCC, an important consideration should be made to include information on prior therapies, as well as stratification on any randomized efforts to ensure the balance between patients who were treated with nivolumab and

ipilimumab as opposed to an immunotherapy/VEGF receptor-targeting regimen. Patient selection based on prior therapies can be done in trial design in designated separate cohorts, or as stratification based on prior therapies.<sup>52</sup> These prior treatments should be specifically detailed in the eligibility criteria for ongoing and future trials for refractory disease.

The panel also focused on being inclusive in the refractory RCC trial population to allow situations more specific to the RCC patient population. For example, the panel advocated for sufficient flexibility in the inclusion criteria for lower thresholds for glomerular filtration rates (as many patients have had prior nephrectomies causing impaired renal function), for patients with prior non-life-threatening immune-related adverse events, and for patients with stable, treated brain metastases which are common in RCC. These relaxed criteria have been previously developed by an ASCO—Friends of Cancer Research working group and subsequently integrated as inclusion criteria for National Cancer Institute (NCI) Cancer Therapy Evaluation Program trials.<sup>53</sup> Finally, given the likelihood of patients with metastatic RCC who may have received multiple lines of therapies, it is important to avoid limiting the number of prior lines of therapies. These eligibility considerations should be considered to include more diversity of disease in future industry-funded and investigator-initiated trials.

## Melanoma

The treatment of patients with advanced melanoma has been transformed by the development of ICIs. With the approval of ipilimumab in 2011, pembrolizumab and nivolumab in 2014, two dual checkpoint inhibitor combinations—ipilimumab and nivolumab in 2015 and nivolumab and relatlimab (an anti-LAG3 agent) in 2022—as well as the first triplet approval in 2020 (vemurafenib, cobimetinib, and atezolizumab), immunotherapy has become the dominant standard-of-care treatment modality for patients with melanoma.<sup>9 5455 56 57</sup> Unfortunately, the majority of patients do not have prolonged PFS and will require additional systemic therapy after initial treatment with frontline ICIs.

Importantly, data leading to these approvals are mainly in the adjuvant and frontline settings.<sup>58</sup> There are no routine biomarkers to predict which treatment should be used for a particular patient either as initial therapy or in the event of disease progression. To that end, there is very little known about the benefit of any of these treatments in the post-PD-(L)1 setting.<sup>59</sup> SWOG S1616 was a recent NCI-sponsored effort that addressed this question. Patients with metastatic melanoma who were primarily refractory to a frontline anti-PD-(L)1 monotherapy but naive to a CTLA-4 inhibitor were randomized 3:1 to the combination of nivolumab and ipilimumab or ipilimumab alone, respectively.<sup>60 61</sup> Patients treated with the combination had an improved PFS as well as an ORR of 28%, compared with 9% for those treated with single-agent

ipilimumab. Unfortunately, this trial was initially designed prior to the establishment of definitions for acquired resistance by SITC and other professional societies. Therefore, even with the impressive results that showed a benefit for patients who received combination ipilimumab/nivolumab, there remains a question whether this applies to the patient population who had an initial response to an immunotherapy treatment followed by acquired resistance.<sup>33</sup>

To develop better treatment strategies in the anti-PD-(L)1 resistance space, there are many factors that need to be considered when planning clinical trials. First of these critical factors, nearly half of patients with metastatic melanoma have a V600E mutation of *BRAF* in their tumors. Since 2011, patients with melanoma have had access to potent, highly selective inhibitors targeting the *BRAF* V600E mutation. *BRAF* inhibitors have also been combined with MEK inhibitors. This combination blocks the growth and proliferation of cells that have *BRAF* mutations. Patients with tumors containing *BRAF* mutations should be considered separately, particularly given good early response to *BRAF*/MEK combination therapies. Therapeutic strategies with or without ICIs must consider the availability of alternative regimens for these patients. Finally, the panel recommended that trials for patients with anti-PD-(L)1 resistant melanoma need to account for whether patients have received prior *BRAF*-targeted therapy.

While designing a clinical trial for sequential use in ICI resistance, apart from currently targetable mutations, a second critical factor is the type of resistance pattern to immunotherapy (primary vs acquired).<sup>59</sup> Retrospective analyses suggest that patients with primary resistance have worse clinical outcomes.<sup>62</sup> Thus, when a randomized trial is planned, the type of resistance could be considered as a stratification factor in randomized trials and also for patient selection in single-cohort studies.

A third important consideration for melanoma trials, as for RCC trials above, is the presence or absence of brain metastases and whether these are treated, stable, and/or symptomatic. And finally, the initial therapy received (single-agent, combination) and whether it was in the adjuvant or metastatic setting should also be key considerations.

In summary, for future trials including patients with melanoma resistant to anti-PD-(L)1 therapy, pertinent patient characteristics to consider include tumor *BRAF* mutation status, the pattern of resistance, extent of central nervous system metastases, first-line treatment regimen, and the treatment setting of prior therapy. Accounting for these factors will help with patient selection and more homogeneous patient populations.

## FUTURE WORK

### Ongoing challenges for sequencing therapies and overcoming ICI resistance

With the ongoing challenges of ICI resistance, defining optimal treatment sequencing is of particular importance. One prospective effort from ECOG-ACRIN, the DREAMSeq trial, enrolled patients with metastatic BRAF-mutant melanoma, and randomized to either first-line targeted BRAF/MEK combinations followed by immunotherapy on progression, or the reverse sequence.<sup>63</sup> This trial was completed and recently reported, demonstrating that patients with tumors containing *BRAF* mutations receive more benefit from frontline treatment with the ipilimumab–nivolumab combination, as opposed to frontline therapy with the BRAF/MEK inhibitors, dabrafenib, and trametinib. With expanding therapeutic options in each disease type, such sequencing trials are clinically critical to defining optimal sequential approaches.

Sequencing trials have been an ongoing central principle for adjuvant clinical trials. The therapies employed in the adjuvant setting are typically the same agents used in the metastatic setting, so adjuvant trials essentially ask whether early treatment for micrometastatic disease is better than delayed treatment in the metastatic setting for solely the patients who have disease recurrence. Adjuvant cytotoxic therapy was generally considered to be more effective in the micrometastatic/minimal residual disease setting, but it is uncertain if this principle applies to patients treated with ICIs. These questions will become more common as more patients receive ICIs in the approved adjuvant disease settings across an increasing number of tumor types. Furthermore, both clinicians and researchers must ask if patients who have disease progression after adjuvant ICIs are truly ICI resistant and whether re-treatment or escalation of treatment will be effective.

Pertinent to the adjuvant versus metastatic disease discussions, some researchers have suggested that giving ICI in the presence of more tumor burden can potentially enhance an immune-based anti-tumor response. This is the strategy behind giving neoadjuvant therapy in combination with ICIs, a strategy recently approved in NSCLC, and shown to have a dramatic benefit in melanoma, but yet to show substantial impact in RCC.<sup>64</sup>

Offering ICIs in earlier lines of treatment adds treatment pressure for resistant clones of cancer cells. Clinicians and researchers are tasked with the quandary of subsequent treatment selection for patients who have already experienced immunotherapy. Therefore, defining windows after adjuvant therapy, where ICIs are thought still to be effective strategies, is critically important for trials enrolling patients who have had prior adjuvant ICI treatment. Trials are already underway across melanoma, NSCLC, and RCC to find efficacious treatments in PD-(L)1 refractory disease with some allowance for treatment in the adjuvant setting (example trials include NCT03991130, NCT03833440, NCT05068427, NCT03385486, NCT05061134, NCT04250246, NCT04987203, and NCT03793166).

### Salvage alternative immunotherapy versus enhancing frontline options

The development path for a new immunotherapy or immunotherapy combination has often included launching clinical trials with registration intent in the frontline setting in the selected patient populations most likely to benefit. Another approach would explore the efficacy and, ideally, biomarkers of benefit in smaller, randomized trials such as a randomized phase II trial or even a phase II/III study which includes an interim analysis before enrolling the entire phase III cohort. In fact, such an approach was used in the RELATIVITY 047 trials<sup>65</sup> and the ECOG-ACRIN 6141 trial. In addition, establishing efficacy in an ICI-resistant population would likely justify moving a second-line or later regimen into the frontline space. Most importantly, while it is critical to optimize frontline therapy, the greatest unmet needs in the field are to determine which currently approved frontline regimens should be offered and to develop salvage treatment options for patients with anti-PD-(L)1 resistant disease.

### Determining contribution of effect: demonstrating single-agent activity/inactivity versus definitive activity of anti-PD-(L)1 combinations in PD-(L)1 resistant disease

The FDA has published a guidance document<sup>66</sup> regarding demonstration of the contribution of components when developing two or more investigational agents in combination for a particular condition. One challenge is delineating the contribution of effect from a novel agent and any potential activity from switching the PD-(L)1 targeted agent. While the contribution of effect from the novel agent is a key consideration in this setting, there is substantially less equipoise that switching between PD-1 pathway directed agents has a clinically significant effect. Concern has also been raised about potential lack of equipoise if, for example, a single-agent PD-(L)1 antibody trial arm was a requirement for phase III trials testing a PD-(L)1-based combination in patients with disease progression on a frontline PD-(L)1 antibody regimen.

Most critically, it is incumbent on the sponsor and investigators to design a development strategy that can clearly evaluate whether an effective combination requires each of the regimen's agents to be effective. The simplest example would be a plan to develop as a combination in the anti-PD-(L)1 resistant disease with Drug X plus an anti-PD-(L)1. If effective, it is not hard to understand that Drug X adds value to the patient since the patient previously developed progressive disease on anti-PD-(L)1 therapy; however, it is not clear whether Drug X needs to be used in combination with anti-PD-(L)1.

Conversely, it is important that the contribution of effect from any novel agent be assessed, particularly in settings where the novel agent has not been approved. This can occur from data sets arising from external trials, for example, data on single-agent activity in a similar PD-(L)1-resistant population from prior phase I or phase



II trials or from a single-agent cohort (with an early stopping rule) within a registrational phase III trial. Therefore, wherever possible, consensus opinion is to minimize or eliminate single-agent PD-(L)1 inhibitor therapy cohorts for trials that focus on PD-(L)1 refractory disease.

A randomized design that includes a cohort treated with single-agent Drug X and a cohort treated with the combination of Drug X plus anti-PD-(L)1 therapy may be an appropriate design, considering what is known about the anti-PD-(L)1 therapy effect in that given population. If the anti-PD-(L)1 therapy effect alone is not known, then an additional arm of monotherapy may be included, with a planned futility analysis to drop any ineffective therapies. Furthermore, if there was evidence from other clinical trials with Drug X that showed benefit as a single agent, but the trial of the combination suggests significantly more benefit, then a single-agent Drug X cohort may not be necessary. In general, the workshop panel recommended minimizing cohorts of patients when possible, while also providing enough justification for contribution of components when testing novel agents in combination with anti-PD-(L)1 therapy.

## CONCLUSION

As frontline immunotherapy approaches expand across multiple solid tumors, addressing ICI resistance represents the next frontier in cancer research. The disease types of interest combined in this workshop represented the three solid tumor types with the earliest approvals of ICIs, thereby the most patients who have now developed resistant disease. Through this workshop, we explored putative mechanisms of immunotherapy resistance and discussed commonalities across tumor types for designing the next wave of trials for immunotherapy-resistant disease. As a notable limitation, this workshop summary is not comprehensive in addressing all the complexities of combination therapy clinical trial design. Stratifying for prior therapies remains a common priority for future trial design in post-ICI settings across tumor types. Many PD-(L)1 resistance mechanisms are likely yet to be discovered. Finally, many questions on optimal treatment sequencing or combinations still remain for NSCLC, melanoma, and renal cell carcinoma, and uniformity of clinical trial design in the refractory disease setting will improve future clinical development of effective therapies.

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## REFERENCES

- Pardoll DM. The blockade of immune checkpoints in cancer immunotherapy. *Nat Rev Cancer* 2012;12:252–64.
- Topalian SL, Drake CG, Pardoll DM. Immune checkpoint blockade: a common denominator approach to cancer therapy. *Cancer Cell* 2015;27:450–61.
- Opportunities for combination drug development. 2019. Available: [https://www.focr.org/sites/default/files/pdf/Combo\\_Drug\\_Development\\_Whitepaper.pdf](https://www.focr.org/sites/default/files/pdf/Combo_Drug_Development_Whitepaper.pdf)
- Kluger HM, Tawbi HA, Ascierto ML, et al. Defining tumor resistance to PD-1 pathway blockade: recommendations from the first meeting of the SITC Immunotherapy Resistance Taskforce. *J Immunother Cancer* 2020;8:e000398.
- Robert C, Schachter J, Long GV, et al. Pembrolizumab versus ipilimumab in advanced melanoma. *N Engl J Med* 2015;372:2521–32.
- Reck M, Rodríguez-Abreu D, Robinson AG, et al. Pembrolizumab versus chemotherapy for PD-L1-positive non-small-cell lung cancer. *N Engl J Med* 2016;375:1823–33.
- McDermott DF, Lee J-L, Ziobro M, et al. Open-label, single-arm, phase II study of pembrolizumab monotherapy as first-line therapy in patients with advanced non-clear cell renal cell carcinoma. *J Clin Oncol* 2021;39:1029–39.
- Postow MA, Chesney J, Pavlick AC, et al. Nivolumab and ipilimumab versus ipilimumab in untreated melanoma. *N Engl J Med* 2015;372:2006–17.
- Schadendorf D, Hodi FS, Robert C, et al. Pooled analysis of long-term survival data from phase II and phase III trials of ipilimumab in unresectable or metastatic melanoma. *J Clin Oncol* 2015;33:1889–94.
- Gandhi L, Rodríguez-Abreu D, Gadgeel S, et al. Pembrolizumab plus chemotherapy in metastatic non-small-cell lung cancer. *N Engl J Med* 2018;378:2078–92.
- Motzer RJ, Tannir NM, McDermott DF, et al. Nivolumab plus ipilimumab versus sunitinib in advanced renal-cell carcinoma. *N Engl J Med* 2018;378:1277–90.
- Motzer RJ, Powles T, Burotto M, et al. Nivolumab plus cabozantinib versus sunitinib in first-line treatment for advanced renal cell carcinoma (checkmate 9ER): long-term follow-up results from an open-label, randomised, phase 3 trial. *Lancet Oncol* 2022;23:888–98.
- Motzer R, Alekseev B, Rha S-Y, et al. Lenvatinib plus pembrolizumab or everolimus for advanced renal cell carcinoma. *N Engl J Med* 2021;384:1289–300.
- Rini BI, Plimack ER, Stus V, et al. Pembrolizumab plus axitinib versus sunitinib for advanced renal-cell carcinoma. *N Engl J Med* 2019;380:1116–27.
- Mittal D, Gubin MM, Schreiber RD, et al. New insights into cancer immunoevasion and its three component phases — elimination, equilibrium and escape. *Curr Opin Immunol* 2014;27:16–25.
- Chen DS, Mellman I. Oncology meets immunology: the cancer-immunity cycle. *Immunity* 2013;39:1–10.
- Rooney MS, Shukla SA, Wu CJ, et al. Molecular and genetic properties of tumors associated with local immune cytolytic activity. *Cell* 2015;160:48–61.
- Bonaventura P, Shekarian T, Alcazer V, et al. Cold tumors: a therapeutic challenge for immunotherapy. *Front Immunol* 2019;10:168.
- Turner MD, Nedjai B, Hurst T, et al. Cytokines and chemokines: at the crossroads of cell signalling and inflammatory disease. *Biochim Biophys Acta* 2014;1843:2563–82.
- Gorbachev AV, Kobayashi H, Kudo D, et al. CXC chemokine ligand 9/monokine induced by IFN- $\gamma$  production by tumor cells is critical for T cell-mediated suppression of cutaneous tumors. *J Immunol* 2007;178:2278–86.
- Taube JM, Klein A, Brahmer JR, et al. Association of PD-1, PD-1 ligands, and other features of the tumor immune microenvironment with response to anti-PD-1 therapy. *Clin Cancer Res* 2014;20:5064–74.
- García-Díaz A, Shin DS, Moreno BH, et al. Interferon receptor signaling pathways regulating PD-L1 and PD-L2 expression. *Cell Rep* 2017;19:1189–201.
- Zaretsky JM, García-Díaz A, Shin DS, et al. Mutations associated with acquired resistance to PD-1 blockade in melanoma. *N Engl J Med* 2016;375:819–29.
- Shin DS, Zaretsky JM, Escuin-Ordinas H, et al. Primary resistance to PD-1 blockade mediated by JAK1/2 mutations. *Cancer Discov* 2017;7:188–201.
- Paschen A, Melero I, Ribas A. Central role of the antigen-presentation and interferon- $\gamma$  pathways in resistance to immune checkpoint blockade. *Annu Rev Cancer Biol* 2022;6:85–102.
- Emoto M, Neuhaus O, Emoto Y, et al. Influence of beta 2-microglobulin expression on gamma interferon secretion and target cell lysis by intraepithelial lymphocytes during intestinal *Listeria monocytogenes* infection. *Infect Immun* 1996;64:569–75.
- D'Urso CM, Wang ZG, Cao Y, et al. Lack of HLA class I antigen expression by cultured melanoma cells FO-1 due to a defect in B2m gene expression. *J Clin Invest* 1991;87:284–92.
- Ornstein MC, Pal SK, Wood LS, et al. Individualised axitinib regimen for patients with metastatic renal cell carcinoma after treatment with checkpoint inhibitors: a multicentre, single-arm, phase 2 study. *Lancet Oncol* 2019;20:1386–94.
- Atkins MB, Lee SJ, Chmielowski B, et al. Combination dabrafenib and trametinib versus combination nivolumab and ipilimumab for patients with advanced BRAF-mutant melanoma: the dreamseq trial-ECOG-ACRIN EA6134. *J Clin Oncol* 2023;41:186–97.
- Ascierto PA, Mandalà M, Ferrucci PF, et al. Sequencing of ipilimumab plus nivolumab and encorafenib plus binimetinib for untreated BRAF-mutated metastatic melanoma (SECOMBIT): a randomised, three-arm, open-label phase II trial. *J Clin Oncol* 2023;41:212–21.
- Schoenfeld AJ, Antonia SJ, Awad MM, et al. Clinical definition of acquired resistance to immunotherapy in patients with metastatic non-small-cell lung cancer. *Ann Oncol* 2021;32:1597–607.
- Cristescu R, Mogg R, Ayers M, et al. Pan-tumor genomic biomarkers for PD-1 checkpoint blockade-based immunotherapy. *Science* 2018;362:eaar3593.
- Hugo W, Zaretsky JM, Sun L, et al. Genomic and transcriptomic features of response to anti-PD-1 therapy in metastatic melanoma. *Cell* 2016;165:35–44.
- Rizvi NA, Hellmann MD, Snyder A, et al. Cancer immunology. mutational landscape determines sensitivity to PD-1 blockade in non-small cell lung cancer. *Science* 2015;348:124–8.
- Roach C, Zhang N, Corigliano E, et al. Development of a companion diagnostic PD-L1 immunohistochemistry assay for pembrolizumab therapy in non-small-cell lung cancer. *Appl Immunohistochem Mol Morphol* 2016;24:392–7.
- Garon EB, Rizvi NA, Hui R, et al. Pembrolizumab for the treatment of non-small-cell lung cancer. *N Engl J Med* 2015;372:2018–28.
- Burtneß B, Harrington KJ, Greil R, et al. Pembrolizumab alone or with chemotherapy versus cetuximab with chemotherapy for recurrent or metastatic squamous cell carcinoma of the head and neck (KEYNOTE-048): a randomised, open-label, phase 3 study. *Lancet* 2019;394:1915–28.
- Anagnostou V, Yarchoan M, Hansen AR, et al. Immuno-oncology trial endpoints: capturing clinically meaningful activity. *Clin Cancer Res* 2017;23:4959–69.
- Curigliano G, Gelderblom H, Mach N, et al. Phase I/II clinical trial of sabatolimab, an anti-TIM-3 antibody, alone and in combination with atezolizumab, an anti-PD-1 antibody, in advanced solid tumors. *Clin Cancer Res* 2021;27:3620–9.
- Hellmann MD, Gettinger S, Chow LQM, et al. Phase 1 study of epacadostat in combination with atezolizumab for patients with previously treated advanced nonsmall cell lung cancer. *Int J Cancer* 2020;147:1963–9.
- Herbst RS, Giaccone G, de Marinis F, et al. Atezolizumab for first-line treatment of PD-L1-selected patients with NSCLC. *N Engl J Med* 2020;383:1328–39.
- Reck M, Rodríguez-Abreu D, Robinson AG, et al. Five-year outcomes with pembrolizumab versus chemotherapy for metastatic non-small-cell lung cancer with PD-L1 tumor proportion score  $\geq 50$ . *J Clin Oncol* 2021;39:2339–49.
- Sezer A, Kilickap S, Gümüş M, et al. Cemiplimab monotherapy for first-line treatment of advanced non-small-cell lung cancer with PD-L1 of at least 50%: a multicentre, open-label, global, phase 3, randomised, controlled trial. *Lancet* 2021;397:592–604.
- Cho BC, Abreu DR, Hussein M, et al. Tiragolumab plus atezolizumab versus placebo plus atezolizumab as a first-line treatment for PD-L1-selected non-small-cell lung cancer (CITYSCAPE): primary and follow-up analyses of a randomised, double-blind, phase 2 study. *Lancet Oncol* 2022;23:781–92.
- Luo J, Wu S, Rizvi H, et al. Deciphering radiological stable disease to immune checkpoint inhibitors. *Ann Oncol* 2022;33:824–35.
- Park SE, Lee SH, Ahn JS, et al. Increased response rates to salvage chemotherapy administered after PD-1/PD-L1 inhibitors in patients with non-small cell lung cancer. *J Thorac Oncol* 2018;13:106–11.



- 47 Besse B, Awad M, Forde P, *et al.* OA07.08 Hudson: an open-label, multi-drug, biomarker-directed, phase II platform study in patients with NSCLC, who progressed on anti-PD (L) 1 therapy. *J Thorac Oncol* 2021;16:S118–9.
- 48 Au L, Hatipoglu E, Robert de Massy M, *et al.* Determinants of anti-PD-1 response and resistance in clear cell renal cell carcinoma. *Cancer Cell* 2021;39:1497–518.
- 49 Borghaei H, Paz-Ares L, Horn L, *et al.* Nivolumab versus docetaxel in advanced nonsquamous non-small-cell lung cancer. *N Engl J Med* 2015;373:1627–39.
- 50 Herbst RS, Baas P, Kim D-W, *et al.* Pembrolizumab versus docetaxel for previously treated, PD-L1-positive, advanced non-small-cell lung cancer (KEYNOTE-010): a randomised controlled trial. *Lancet* 2016;387:1540–50.
- 51 Yang JC-H, Luft A, De La Mora Jiménez E, *et al.* 1200 pembrolizumab (Pembro) with or without lenvatinib (Lenva) in first-line metastatic NSCLC with PD-L1 TPS  $\geq 1\%$  (LEAP-007): a phase III, randomized, double-blind study. *Annals of Oncology* 2021;32:S1429–30.
- 52 Allaf ME, Kim SE, Master VA, *et al.* PROSPER: phase III randomized study comparing perioperative nivolumab versus observation in patients with renal cell carcinoma (RCC) undergoing nephrectomy (ECOG-ACRIN EA8143). *JCO* 2021;39:TPS4596.
- 53 Kim ES, Bruinooge SS, Roberts S, *et al.* Broadening eligibility criteria to make clinical trials more representative: American Society of Clinical Oncology and Friends of Cancer Research joint research statement. *J Clin Oncol* 2017;35:3737–44.
- 54 Atkins MB, Lotze MT, Dutcher JP, *et al.* High-dose recombinant interleukin 2 therapy for patients with metastatic melanoma: analysis of 270 patients treated between 1985 and 1993. *J Clin Oncol* 1999;17:2105–16.
- 55 Ascierto PA, Long GV, Robert C, *et al.* Survival outcomes in patients with previously untreated BRAF wild-type advanced melanoma treated with nivolumab therapy: three-year follow-up of a randomized phase 3 trial. *JAMA Oncol* 2019;5:187–94.
- 56 Robert C, Thomas L, Bondarenko I, *et al.* Ipilimumab plus dacarbazine for previously untreated metastatic melanoma. *N Engl J Med* 2011;364:2517–26.
- 57 Hamid O, Robert C, Daud A, *et al.* Five-year survival outcomes for patients with advanced melanoma treated with pembrolizumab in KEYNOTE-001. *Ann Oncol* 2019;30:582–8.
- 58 Luke JJ, Rutkowski P, Queirolo P, *et al.* Pembrolizumab versus placebo as adjuvant therapy in completely resected stage IIb or IIC melanoma (KEYNOTE-716): a randomised, double-blind, phase 3 trial. *Lancet* 2022;399:1718–29.
- 59 Pires da Silva I, Ahmed T, McQuade JL, *et al.* Clinical models to define response and survival with anti-PD-1 antibodies alone or combined with ipilimumab in metastatic melanoma. *J Clin Oncol* 2022;40:1068–80.
- 60 Zimmer L, Apuri S, Eroglu Z, *et al.* Ipilimumab alone or in combination with nivolumab after progression on anti-PD-1 therapy in advanced melanoma. *Eur J Cancer* 2017;75:47–55.
- 61 Vanderwalde AM, Latkovic-Taber M, Hu-Lieskovan S, *et al.* Combining ipilimumab (IPI) and nivolumab (nivo) in advanced melanoma following progression on a PD-1 inhibitor (SWOG S1616). *JCO* 2018;36:TPS9597.
- 62 Amaral T, Seeber O, Mersi E, *et al.* Primary resistance to PD-1-based immunotherapy-A study in 319 patients with stage IV melanoma. *Cancers (Basel)* 2020;12:1027.
- 63 Atkins MB, Lee SJ, Chmielowski B, *et al.* DREAMseq (doublet, randomized evaluation in advanced melanoma sequencing): a phase III trial—ECOG-ACRIN EA6134. *JCO* 2021;39:356154.
- 64 Spicer J, Wang C, Tanaka F, *et al.* Surgical outcomes from the phase 3 checkmate 816 trial: nivolumab (NIVO) + platinum-doublet chemotherapy (chemo) vs chemo alone as neoadjuvant treatment for patients with resectable non-small cell lung cancer (NSCLC). *JCO* 2021;39:8503.
- 65 Tawbi HA, Schadendorf D, Lipson EJ, *et al.* Relatlimab and nivolumab versus nivolumab in untreated advanced melanoma. *N Engl J Med* 2022;386:24–34.
- 66 Guidance for industry: codevelopment of two or more new investigational drugs for use in combination. n.d. Available: <https://www.fda.gov/media/80100/download>