An update on TroVax® for the treatment of progressive castration-resistant prostate cancer

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Abstract: Prostate cancer is a common human malignancy with few effective therapeutic options for treating advanced castration-resistant disease. The potential therapeutic effectiveness of immunotherapy and vaccines, in particular, has gained popularity based on the identification of prostate-associated antigens, potent expression vectors for vaccination, and data from recent clinical trials. A modified vaccinia Ankara (MVA) virus expressing 5T4, a tumor-associated glycoprotein, has shown promise in preclinical studies and clinical trials in patients with colorectal and renal cell carcinoma. This review will discuss the rationale for immunotherapy in prostate cancer and describe preclinical and limited clinical data in prostate cancer for the MVA-5T4 (TroVax®) vaccine.

Keywords: castration resistance, prostate cancer, TroVax, vaccine

Introduction
Prostate cancer is the second most common malignancy and the sixth most common cause of cancer-related mortality worldwide.¹ The natural history of early diagnosed clinically localized prostate cancer is indolent in the majority of men, with up to 80% having 20-year progression-free survival without local treatment.² The men who develop advanced-stage disease, characterized by distant metastasis, initially undergo a hormone-sensitive period of growth when tumor cell proliferation is dependent on androgen stimulation. The use of androgen deprivation therapy (ADT) is beneficial during this stage of the disease, but management becomes more challenging as tumors evolve to become hormone refractory. New therapeutic options are needed, especially for patients with hormone-resistant tumors.

The terms “hormone-refractory prostate cancer” or “castration-resistant prostate cancer” (CRPC) are used interchangeably to describe prostate adenocarcinoma that progresses despite ADT, resulting in serum testosterone levels below a certain threshold, typically 20–50 ng/dL.³ The definition of when a patient becomes castration resistant can vary and has a distinct impact on the expected median survival. Although, historically, median survival of 12–18 months could be expected for men with CRPC,⁴ a more contemporary report using the first biochemical evidence of progression as the starting point quotes median survivals of 40–68 months, depending on the presence or absence of skeletal metastasis.⁵ Elevated serum prostate-specific antigen (PSA), lactate dehydrogenase, and alkaline phosphatase, as well as the presence of visceral metastasis, anemia, and low performance status, have been shown to portend decreased survival in these men.⁶
Although there exists heterogeneity in defining survival, progression in CRPC is perhaps more prone to variability.\textsuperscript{7,8} The Response Evaluation Criteria In Solid Tumors (RECIST) measure progression radiographically with solid tumor dimensions, but they do not take into account bone scan-detected lesions, abnormal biochemistry, or the quality of life manifestations of metastatic prostate cancer.\textsuperscript{9} The Prostate Cancer Working Group (PCWG) was created in an effort to define clinical trial endpoints that are more specific for prostate cancer, and has expanded the definitions of progression to include quality of life and PSA levels.\textsuperscript{10}

Using any definition, the situation remains that there are few effective therapeutic options for CRPC. Several cytotoxic medications have been studied, with docetaxel, which is currently the first-line therapy, demonstrating a statistically significant (but clinically modest) benefit in PSA response, pain control, improvement in quality of life, and increased median survival.\textsuperscript{11,12} The TAX 327 trial reported that docetaxel every 3 weeks produced a 2.4-month increased median survival over mitoxantrone and had a 0.76 hazard ratio (HR) for death. Subsequent trials with satraplatin failed to demonstrate any benefit over placebo,\textsuperscript{13} and the addition of gemcitabine to docetaxel failed to show any benefit over docetaxel alone.\textsuperscript{14}

Recently, cabazitaxel has shown to have significant activity against CRPC in a Phase III trial. Cabazitaxel extended both median and progression-free survival in men who either progressed during or completed a docetaxel-based treatment regimen compared with mitoxantrone.\textsuperscript{15} Abiraterone acetate, a hormonal agent that irreversibly inhibits CYP17, has shown antitumor activity in docetaxel-treated patients in a Phase II trial.\textsuperscript{16} Recent Phase III data indicate that this agent provides a PSA response as well as a 3.9-month survival benefit ($P < 0.001$) over placebo.\textsuperscript{17} These promising results will likely lead to US Food and Drug Administration (FDA) approval of this agent in the near future. Additional classes of agents currently undergoing study in CRPC include inhibitors of angiogenesis, growth factors, and endothelin. A comprehensive review of these agents may be found in a recent review by Nabhan et al.\textsuperscript{18}

The role the immune system plays in tumor progression and containment is a topic of intense study and has provided a variety of therapeutic strategies for many cancers, including CRPC. Case reports of spontaneous regression of both liquid and solid human malignancies have supported hypotheses of antitumor host immune surveillance, and more recent experimental data in murine models have confirmed that tumor immune surveillance is mediated by cytotoxic lymphocytes and interferon-$\gamma$ production.\textsuperscript{19} Further evidence supporting the potential for immunotherapy against human tumors comes from data on interleukin 2 (IL-2), a cytokine that is critical to the maturation and proliferation of natural killer (NK), CD4+ and CD8+ T lymphocytes. In murine models of human renal cell, gastric, and squamous cell carcinomas, IL-2 was found to directly inhibit tumor growth via IL-2 receptors expressed by tumor cells as well as indirectly through activation of antitumor host NK and T cell responses.\textsuperscript{20} High-dose IL-2 and recombinant interferon-$\alpha$ have shown clinical efficacy in metastatic melanoma and renal cell carcinoma (RCC) and in the adjuvant therapy of stage III melanoma, respectively. High-dose IL-2 can induce durable complete responses in a small but consistent subset of patients.\textsuperscript{21} Furthermore, the combination of IL-2 with adoptive T lymphocytes has shown remarkable activity in metastatic melanoma, especially in the setting of host lymphodepletion.\textsuperscript{22} The importance of T lymphocytes in the development of metastasis has also been suggested in the murine melanoma model in which CD8+ T cell-depleted mice had reduced disseminated tumor cell dormancy.\textsuperscript{23}

**Prostate immunotherapy**

The identification of tumor-associated antigens in prostate cancer cells provides the basis for development of antigen-specific vaccination as a therapeutic approach to prostate cancer. Immunotherapy for prostate cancer has increasingly moved to the forefront of study for CRPC since the FDA approval of sipuleucel-T (APC8015) in April 2010. Sipuleucel-T (Provenge\textsuperscript{®}, Dendreon, Seattle WA) consists of autologous dendritic cells loaded with prostatic acid phosphatase linked to granulocyte-macrophage colony-stimulating factor (GM-CSF). Phase III data from three trials demonstrated a survival benefit of approximately 4 months compared with placebo.\textsuperscript{24–26} Another strategy in development utilizes a poxvirus prime/boost vaccine regimen wherein the viruses express the transgenes for PSA. In this strategy, a recombinant vaccinia virus encoding PSA is used as a priming vector, followed by boosting with recombinant fowlpox virus encoding PSA. Phase II data in patients with PSA recurrence after local therapy for prostate cancer and no evidence of metastatic disease reported a 45% freedom from PSA progression at 19 months. In addition, 46% of the men treated with the prime/boost vaccine regimen had an increase in PSA-reactive T cells, without evidence of an anti-PSA humoral response.\textsuperscript{27} Subsequently, in an effort to increase the potency of the T cell response, several T cell costimulatory molecules were added to the poxviral vectors, including B7.1, ICAM-1, and LFA-3 (designated TRICOM
six-transmembrane epithelial antigen of the prostate. Clini-
HRe for death 0.68, cine also demonstrated an improved overall survival when 
Pvaccine alone (10.1 months vs 6.4 months, HR for death 0.66, a significant improvement in overall survival compared with 
immunotherapy, may be required for tumor progression, and does not 
antigenic target, as 5T4 exhibits selective tumor cell expres-
staining, may be required for tumor progression, and does not 
median overall survival by 8.5 months over a control vector 
treatment group. These encouraging results need to be vali-
dated in a larger Phase III trial. Additional tumor-associated 
antigens undergoing early development include prostate-
specific membrane antigen, prostate stem cell antigen, and 
six-transmembrane epithelial antigen of the prostate. Clinical trial 
data have yet to be reported with these antigens.

The immune response is highly regulated, and T cell 
activation is subject to homeostatic control through a series 
of costimulatory and coinhibitory molecules. Following 
engagement of the T cell receptor with its cognate peptide 
and major histocompatibility complex, the T cell receives a 
“second” or costimulatory signal through CD28, which binds 
to B7.1 and B7.2 on antigen-presenting cells. This second 
signal results in T cell proliferation and cytokine production. 
Shortly after activation, the cytotoxic T lymphocyte antigen 4 
(CTLA-4) is mobilized to the cell surface and binds to B7.1 
and B7.2 with higher affinity than CD28. CTLA-4 serves as 
a coinhibitory receptor, as signaling through CTLA-4 results 
in decreased cytokine production and inhibition of cell cycle 
stimulation. This provides a highly coordinated homeostatic 
 mechanism for brief activation of T cells while avoiding prolonged stimulation and induction of autoimmunity. This 
pathway has also provided another approach for cancer 
immunotherapy. A human monoclonal antibody that targets 
CTLA-4 (ipilimumab) results in a blockade of the coinhibi-
tory signaling mediated by CTLA-4 and allows T cells to 
remain in an activated state for a longer period of time. In 
a recent three-arm randomized Phase III clinical trial, patients 
receiving ipilimumab alone (3 mg/kg) or administered with a 
gp100 peptide vaccine were compared with patients receiving 
gp100 peptide vaccine alone. 

The 5T4 antigen
Fetal placental tissue evades immunosurveillance and invades “host” tissues, which is biologic behavior also displayed 
by neoplasms. Oncofetal antigens have therefore been the 
subject of study as possible diagnostic or therapeutic targets 
for human cancers. 5T4 is a 72kD protein identified on the 
syncitiotrophoblastic epithelium of human placental tissue 
using a murine monoclonal antibody. 5T4 is a cell surface 
glycoprotein that is expressed on a variety of human tumors, 
including breast, ovary, stomach, colorectal, nonseminoma-
tous testis, bladder, and clear cell RCC, whereas expression 
is absent on most normal human tissues and weak on some 
normal epithelia. In contrast to PSA, 5T4 is not cleaved and 
is typically not found circulating in the serum. In vitro stud-
ies demonstrated that cells transfected with 5T4 cDNA had 
disrupted cell–cell contact and increased motility, suggesting 
a role for this molecule in tumor metastasis. This was further 
supported by data demonstrating that increased 5T4 expres-
sion was correlated with tumor invasiveness in a variety of 
human cancers. 5T4 is strongly expressed on the surface 
of most prostate adenocarcinoma cells. Thus, 5T4 is an ideal 
antigenic target, as 5T4 exhibits selective tumor cell expres-
sion, may be required for tumor progression, and does not 
exist in soluble (and potentially immunosuppressive) forms.

Modified vaccinia virus Ankara (MVA)
Modified vaccinia Ankara (MVA) is a vaccinia virus attenuated 
by multiple passages through chick embryo fibroblasts. MVA 
is attractive as a viral vector due to its proven safety 
record as an alternative vaccine against smallpox in immu-
osuppressed hosts. In addition, it has poor replication in 
transformed human cell lines with limited cell–cell spread,
in part due to potent induction of type I interferon from human cells.\textsuperscript{42} Pox viruses such as MVA can be engineered to encode large amounts of transfected DNA, and provide immunogenicity due to the expression of a soluble IL-1-\(\beta\) receptor.\textsuperscript{43} The MVA vector was used to encode human ST4 for vaccination purposes and extensively evaluated in preclinical and clinical settings.

**MVA-ST4 preclinical data**

Recombinant MVA-expressing human ST4 (MVA-hST4; TroVax\textsuperscript{8}, Oxford Biomedica, Oxford, UK) has shown both protective and therapeutic effects against tumors in murine models. Mice inoculated with three doses of MVA-hST4 developed humoral responses to hST4. When these mice were challenged with B16-ST4 melanoma and CT26-ST4 colorectal tumor cells, they had significantly fewer lung tumor nodules than the mice inoculated with vaccine and treatment controls (MVA-LacZ or phosphate buffered saline [PBS]).\textsuperscript{44} In an experiment designed to test MVA-ST4 for treatment efficacy against established tumors, mice were first injected with CT26-ST4 tumors then immunized with two doses of MVA-ST4. The mice treated with MVA-ST4 had a reduction in tumor burden compared with the MVA-LacZ- or PBS-treated controls.\textsuperscript{44} Interestingly, these experiments did show an immunoglobulin G antibody-mediated response, but there was no evidence of a CTL response.\textsuperscript{44} In a follow-up study using the CT26 tumor model, mice depleted of CD8+ T lymphocytes had a completely abrogated response. This suggested that the treatment effect of MVA-ST4 was CD4+ T cell dependent and antibody mediated.\textsuperscript{45}

**MVA-ST4 clinical data**

Table 1 summarizes the clinical and immunologic results of clinical trials using TroVax\textsuperscript{8} to date. TroVax\textsuperscript{8} was administered to 22 patients with metastatic colorectal cancer in a Phase I trial that established its safety and immunogenicity. Fourteen of 17 evaluable patients had a measurable ST4-specific antibody response, and eight patients had a de novo ST4-specific cellular proliferation response.\textsuperscript{46} ST4-specific antibody titers significantly predicted time to progression but not overall survival (\(P = 0.08\) for all patients and \(P < 0.05\) in those who mounted a ST4 antibody response).\textsuperscript{46} Although 50% of the patients did have injection site erythema, there were no serious adverse events attributable to TroVax\textsuperscript{8}.\textsuperscript{46} These encouraging results supported the initiation of Phase II trials of TroVax\textsuperscript{8} for cancer immunotherapy.

TroVax\textsuperscript{8} was further evaluated in three Phase II trials for metastatic colorectal cancer. In the first study, MVA-ST4 monotherapy was administered before and after surgical metastasectomy. There were no serious adverse events, and the serologic and cellular response rates were similar to those in the Phase I trial.\textsuperscript{47} Although this study was not designed to prospectively determine survival, a retrospective analysis found a correlation between ST4 cellular proliferative responses and survival.\textsuperscript{47} Two trials combined MVA-ST4 with multitarget chemotherapy, and both reported an increased magnitude and duration of ST4-specific immune responses compared with the earlier trials.\textsuperscript{48,49} One trial found a significant correlation between ST4 cellular response and progression based on RECIST criteria.\textsuperscript{49} These trials not only established the safety of the concurrent administration of multitarget chemotherapy but also suggested a benefit compared with MVA-ST4 monotherapy after chemotherapy.

TroVax\textsuperscript{8} has been extensively evaluated in patients with metastatic RCC. Three Phase II studies and one multi-institutional, randomized, prospective Phase III trial for metastatic RCC have combined TroVax\textsuperscript{8} with low- and high-dose IL-2, interferon-\(\alpha\), and the multityrosine kinase inhibitor sunitinib. Collectively, these trials reported favorable safety data similar to the colorectal cancer trials.\textsuperscript{51–55} All of the Phase II trials found a significant association between ST4-specific antibody responses and overall survival, and the low-dose IL-2 and TroVax\textsuperscript{8} trial also reported an association between anti-ST4 antibody response and progression-free survival.\textsuperscript{51,53,54}

TRIST (TroVax\textsuperscript{8} Renal Immunotherapy Survival Trial) was the first Phase III study designed to establish the efficacy of TroVax\textsuperscript{8} (MVA-ST4) in patients with RCC. In this study, patients were treated with IL-2, interferon-\(\alpha\), or sunitinib, according to investigator preference, and patients were then randomized to additional therapy with TroVax\textsuperscript{8} or placebo. The vaccine was well tolerated but did not result in enhanced overall survival relative to placebo controls.\textsuperscript{55} However, several subgroup analyses were performed that identified patients for whom MVA-ST4 may be of benefit. Specifically, patients with a favorable prognostic score receiving MVA-ST4 and IL-2 had a survival benefit relative to placebo and IL-2 (HR 0.54).\textsuperscript{55} Furthermore, this study reconfirmed the Phase II finding that high anti-ST4 antibody responses are associated with improved survival.\textsuperscript{55} Another interesting finding was a trend toward improvement in survival for patients with a specific immune response surrogate score that included the ST4-specific antibody titer, hemoglobin level, and hematocrit.\textsuperscript{56} This was developed by assessing various host parameters in 590 patients treated on the Phase III TRIST
## Table 1 Clinical trials using Trovax®

<table>
<thead>
<tr>
<th>Trial</th>
<th>Disease</th>
<th>Phase</th>
<th>n</th>
<th>Concomitant agent(s)</th>
<th>Control</th>
<th>ST4 Immunological response rate</th>
<th>Clinical response</th>
<th>Other conclusion(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harrop et al. Clin Cancer Res. Jun 2006</td>
<td>CRC</td>
<td>II</td>
<td>22</td>
<td>None</td>
<td>None</td>
<td>14/17 (82%)</td>
<td>16/17 (94%)</td>
<td>5/17 (29%)</td>
</tr>
<tr>
<td>Elkord et al. J Immunother. Nov 2008</td>
<td>CRC</td>
<td>II</td>
<td>20</td>
<td>None</td>
<td>None</td>
<td>18/19 (95%)</td>
<td>13/20 (65%)</td>
<td>Not reported</td>
</tr>
<tr>
<td>Harrop et al. Cancer Immunol Immunother. Jul 2008</td>
<td>CRC</td>
<td>II</td>
<td>19</td>
<td>5-FU, leukovorin, irinotecan</td>
<td>None</td>
<td>10/12 (83%)</td>
<td>10/12 (83%)</td>
<td>6/8 (75%) with &gt;50% reduction in CEA, PR in 6/12 (50%), CR in 1/12 (8%)</td>
</tr>
<tr>
<td>Harrop et al. Clin Cancer Res. Aug 2007</td>
<td>CRC</td>
<td>II</td>
<td>17</td>
<td>5-FU, folinic acid, oxaliplatin</td>
<td>None</td>
<td>10/11 (91%)</td>
<td>9/11 (82%)</td>
<td>7/11 (64%) with &gt;50% reduction in CEA, PR in 5/11 (45%)</td>
</tr>
<tr>
<td>Kaufman et al. J Transl Med. Jan 2009</td>
<td>RCC</td>
<td>II</td>
<td>25</td>
<td>IL-2 (high dose)</td>
<td>None</td>
<td>25/25 (100%)</td>
<td>13/23 (57%)</td>
<td>No objective PR, 12/23 (52%) with stabilization</td>
</tr>
<tr>
<td>Hawkins et al. J Immunother. May 2009</td>
<td>RCC</td>
<td>II</td>
<td>11</td>
<td>IFN-alpha</td>
<td>None</td>
<td>11/11 (100%)</td>
<td>5/11 (45%)</td>
<td>No objective PR</td>
</tr>
<tr>
<td>Amato et al. Clin Cancer Res. Nov 2008</td>
<td>RCC</td>
<td>II</td>
<td>25</td>
<td>IL-2 (low dose)</td>
<td>None</td>
<td>21/25 (84%)</td>
<td>5/11 (45%)</td>
<td>Objective response 3/25 (12%), stabilization 6/25 (24%)</td>
</tr>
<tr>
<td>Amato et al. J Immunother. Sep 2009</td>
<td>RCC</td>
<td>II</td>
<td>28</td>
<td>IFN-alpha ($n = 15$)</td>
<td>TroVax alone ($n = 13$)</td>
<td>21/25 (84%)</td>
<td>7/21 (33%)</td>
<td>Disease stabilization in 14 patients: MVA-ST4 plus IFN[alpha] ($n = 7$) vs MVA-ST4 alone ($n = 7$). No difference in PR in clear cell histology patients</td>
</tr>
<tr>
<td>Amato et al. Clin Cancer Res. Nov 2010</td>
<td>RCC</td>
<td>III</td>
<td>733</td>
<td>Sunitinib, IL-2, IFN-alpha ($n = 365$)</td>
<td>Placebo vs 6% placebo</td>
<td>56% in MVA-ST4 patients</td>
<td>Not reported</td>
<td>ST4 antibody response correlated with improved OS. Good prognosis (MSKCC 0) with MVA-ST4 plus IL-2 improved OS compared to placebo plus IL-2 (HR, 0.54; $P = 0.046$)</td>
</tr>
</tbody>
</table>

(Continued)
clinical trial. The immune response surrogate was established as a linear combination of baseline 5T4-specific antibody titers, hemoglobin level, and hematocrit, which were the only variables to remain statistically associated with survival after adjustment for standard of care. The availability of a predictive surrogate for therapeutic responses could enable better patient selection for vaccine treatment. These data need further prospective validation.

**MVA-5T4 clinical data in CRPC**

TroVax® has been evaluated in an open-label Phase II trial in metastatic CRPC patients in which the vaccine was administered either alone or in combination with GM-CSF. The 27 patients evaluated all had progression by PSA, RECIST, or bone scan criteria, despite prior ADT and taxane therapy. Patients with a low performance status or autoimmune disease were excluded. Fourteen patients received TroVax® alone, and 13 patients received TroVax® and 12 cycles of GM-CSF. The study was primarily designed to monitor safety and both antibody and cellular immunologic endpoints. In addition, serum PSA, computed tomography (CT), and bone scan progression were measured. There were no grade 3 or 4 toxicities in either arm of the trial. The most common adverse event reported was injection site irritation. Of the 24 patients evaluable for measurement of immune response, all had anti-5T4 antibody responses, and nine of 24 had a positive 5T4 ELISPOT assay response, without significant differences between the study arms. Overall, 15 of 27 patients had a period of PSA stabilization. Six patients had a decreased PSA velocity, and five patients in the TroVax® and GM-CSF arm had a transient 4-week decrease in PSA of 30% or more that was attributed to the GM-CSF, as no patients in the TroVax® alone arm had a PSA decline. There were no objective responses based on CT or bone scans in either treatment arm. Interestingly, patients in the TroVax® alone arm had an increased time to progression (TTP) compared with the TroVax® and GM-CSF arm (4.05 months vs 2.1 months, \( P = 0.0125 \)). This trend clearly needs to be explored further in larger studies.

At the time of publication, this trial had not met its median survival endpoint; however, a preliminary retrospective analysis was performed to correlate immunologic response with clinical progression. Patients with a positive 5T4 cellular response were found to have a significantly increased median TTP (5.6 months vs 2.3 months, \( P = 0.024 \)) compared with patients who did not.
Although a Phase II trial evaluating TroVax® and docetaxel versus docetaxel alone for CRPC was terminated by its sponsor, a similar study began accrual in September 2010. This trial, NCT01194960, was designed to evaluate the addition of TroVax® to 10 cycles of docetaxel on progression-free survival by RECIST and PCWG2 criteria at week 37. Eligible patients will have demonstrable metastatic disease, will not have had prior chemotherapy, and will remain on ADT to keep serum testosterone under 50 ng/dL. The estimated final data collection date of this study is expected to be mid-2012.

**MVA-5T4 for CRPC: future directions**

TroVax® has now been widely evaluated in cancer patients with a variety of different cancers and in combination with several other agents. These studies have confirmed that vaccination is generally safe and feasible in patients with advanced cancers. To date, the evidence suggests that those patients who develop an immune response after vaccination, particularly a 5T4-specific antibody response, also exhibit improved therapeutic responses. Recent data in RCC showed that there was a correlation between several host factors (ie, hemoglobin level, hematocrit, and 5T4-specific antibody titers) and clinical response; this needs further validation in prospective trials and in other tumors.

The use of TroVax® in combination with other therapies will also be important to further validate in larger series. There is increasing evidence that cytotoxic chemotherapy, radiation therapy, and possibly targeted therapy result in the release of tumor-associated antigens and can elicit an immune response. The addition of vaccines to patients with such antigen release may provide an additive and/or synergistic approach to improve therapeutic responses to other therapeutic modalities. The optimal schedule, dosing, timing, and methods for monitoring responses are all areas that will need to be better evaluated and defined. Recent data from studies of ipilimumab have suggested that the kinetics of antitumor immunity may be very slow and missed by more standard RECIST criteria. This may be overcome by evaluating survival endpoints or using modified response criteria, such as the recently described immune response criteria, in which patients without clinically significant disease progression continue on immunotherapy until a definitive response is seen or clinically meaningful progression occurs.

Although the clinical use of TroVax® for CRPC currently consists of a small number of patients, the preliminary data regarding safety and immunologic responses are in line with those from the CRC and RCC literature. Due to the rather modest objective clinical responses of tumor vaccines, they are increasingly utilized as a component of combination therapy. The current Phase II trial for CRPC is following this trend by combining TroVax® with the current first-line therapy, docetaxel. These data are needed to further establish the safety and potential efficacy of the vaccine, which will need to be validated in a larger and prospective Phase III trial. In addition, the vaccine should be tested in combination with other agents demonstrating activity in CRPC, such as cabazitaxel and abiraterone, and other potential vaccine adjuvants, such as ipilimumab.

The selection of predictive biomarkers would be a major advance in the field and could help select the most appropriate patients for inclusion in vaccine clinical trials. A larger number of patients with CRPC will allow such analyses to be performed. Future studies should include collection of prostate biopsy tissue, urine, and/or serum, when feasible, to assess various biomarkers that identify subgroups of patients that may benefit more from TroVax®. Potential biomarkers might include simple host factors as reported in RCC patients, serum markers (eg, cytokine, chemokines, vascular endothelial growth factor), immune gene polymorphisms, and single gene and genome-wide mutation analyses.

The modest therapeutic responses seen with current vaccines and other immunotherapeutic agents have shed light on the potential clinical benefit with immunotherapy. CRPC represents a logical tumor on which to focus, because vaccines have already shown promise for the disease, 5T4 expression is common, and vaccination is safe, has limited impact on quality of life, and may be combined with other regimens commonly employed in CRPC treatment, such as chemotherapy, radiation therapy, and hormone treatment. The future will depend on establishing well-designed clinical trials that incorporate more appropriate response criteria and correlative laboratory and immune response assays.

**Disclosure**

The authors report no conflicts of interest in this work.

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