Treatment sequencing in metastatic castrate-resistant prostate cancer

Oliver Sartor1, Silke Gillesen2

Six different treatments have demonstrated improved survival in phase III trials targeted to patients with metastatic castration-resistant prostate cancer (mCRPC). Front-line therapeutic options for mCRPC include docetaxel, sipuleucel-T, abiraterone and radium-223. Post-docetaxel options include cabazitaxel, abiraterone, enzalutamide and radium-223. Despite much progress in recent years, much is yet unknown and debates occur over optimal treatment choices and sequences. None of the new agents have been compared to one another, thus physicians in practice today must make choices based on non-randomized comparisons, toxicity considerations and various assumptions. Abiraterone is now moving into the front line mCRPC space given recent regulatory approvals and enzalutamide will follow soon. Both of the hormonal agents have less toxicity when compared to chemotherapeutic options and both of these hormonal agents are expected to be used in a considerable number of mCRPC patients in the years ahead. Little data are available for the post-abiraterone or post-enzalutamide setting. In this review the currently available sequencing data are summarized and interpreted. It is now clear that cross resistance is a potential issue between various treatments, especially those agents that target the androgen axis. This review highlights the need for additional studies to optimize the current treatments for these patients.


Keywords: abiraterone; cabazitaxel; castrate-resistant; docetaxel; enzalutamide; radium-223; sipuleucel-T

INTRODUCTION

Much progress has been made in metastatic castrate-resistant prostate cancer (mCRPC). Regulatory approvals have been numerous over the past two decades and now a variety of new therapies have become available for treatment of these patients. The availability of new therapies has yielded a conundrum as none of these new therapies have been directly compared to one another.

How can therapies for mCRPC best be utilized? Is there an optimal sequence of therapies? What therapy is best used in individual patients? Despite much progress, these questions are unanswered. Herein we make a brief review of the current literature and emphasize data that are relevant to sequencing and therapeutic selection. Despite many new trials, much is unknown. No comprehensive review of sequencing data in mCRPC is available in the literature and the purpose of this manuscript is to provide such a review with a particular emphasis on an up to date perspective including abstracts at recent meetings.

To obtain data for this review we have comprehensively reviewed the literature for each of the approved mCRPC agents in Medline searches and also reviewed recent abstracts from the American Society of Clinical Oncology meetings, the American Society of Clinical Oncology Genitourinary Cancer meetings and meetings of the European Society of Medical Oncology.

BACKGROUND

Initially, prior to 2004, therapies provided palliative benefit but not overall survival (OS) benefit (Table 1). That changed in 2004 with the approval of docetaxel/prednisone for initial treatment of mCRPC. Two trials were pivotal for that approval, TAX327 and SWOG 9916.1,2 Both used mitoxantrone/prednisone in the control group and both trials enrolled patients without prior chemotherapy. Both trials showed an OS benefit in favour of docetaxel, a taxane that binds to microtubules and inhibits microtubular polymerization. Docetaxel/prednisone became the standard of care for treating mCRPC. The docetaxel/estramustine combination has never been approved by any regulatory agency and the estramustine has side effects that can be avoided without compromising docetaxel effectiveness. Thus docetaxel/estramustine combinations are rarely used today.

After 2004, some trials adapted by clearly defining the "post-docetaxel" space (Table 2). The first trial to demonstrate an OS benefit in this space was the TROPIC3 trial which compared the novel taxane cabazitaxel and mitoxantrone. Both arms also contained prednisone. Cabazitaxel also inhibits microtubular polymerization and this agent was approved in 2010. Subsequently, in 2011 and 2012, two additional trials were successful in prolonging survival in the post-docetaxel space. These included COU-3014 and AFFIRM5. The active agents in these trials were abiraterone/prednisone and enzalutamide, respectively. The comparator arms were placebo/prednisone and placebo, respectively. Both of these trials conclusively demonstrated the value of further targeting androgen receptor (AR) signalling in “hormone-refractory” prostate cancer. Abiraterone inhibits androgen synthesis by binding to and inhibiting CYP17, a critical component of androgen synthesis pathways in the adrenal, testis, and tumor. Enzalutamide binds to the...
androgen receptor (AR) and serves as a potent androgen antagonist thereby preventing ligand-bound AR translocation into the nucleus. Given that both abiraterone and enzalutamide inhibit androgen signalling, instead of referring to patients progressing after castration as "hormone-refractory", the current preferred term is now "castrate-resistant".

Two additional trials, IMPACT and ALSYMPCA using sipuleucel-T® and radium-223³, respectively, demonstrated an improvement in OS with trial designs distinct from those trials previously mentioned. The IMPACT trial utilized sipuleucel-T (an autologous cellular immunotherapy targeted to prostatic acid phosphatase) in patients with asymptomatic or minimally symptomatic mCRPC without visceral metastases. Patients could be enrolled whether or not docetaxel had been previously administered but the chemotherapy free interval had to be at least 3 months and the vast majority (85%) of patients were chemotherapy naive. The control arm in IMPACT consisted of reinfusion of a portion of the patient's mononuclear cells that had been collected but unexposed to antigen stimulation. A crossover design allowed application of antigen exposed cells after documented radiographic progression.

In the ALSYMPCA trial using radium-223³, both the eligibility and control groups were different from other trials. Radium-223 is a bone-seeking alpha particle emitter. Eligibility included only symptomatic mCRPC patients with bone metastases but no visceral metastatic disease. "Symptomatic" was defined simply as taking any form or analgesics (opiates or non-opiates) for pain. Patients with lymph nodes larger than 3 cm were also excluded. Patients enrolled could have been post-docetaxel, or refuse docetaxel, or have been judged unfit for docetaxel by their physician. Patients were randomized to six doses of radium or placebo. Standard of care (SOC) treatments were allowed in addition to the radium or placebo. SOC excluded radiopharmaceuticals, chemotherapy, and experimental agents but included various hormonal therapies and external beam radiation (except hemi-body fields). SOC therapies could be administered per investigator judgment. In the statistical analysis plan, a pre-specified analysis of OS was to be performed after stratifying for docetaxel use (yes/no) prior to trial entry. The trial demonstrated an overall OS benefit for radium treated patients. The stratified OS data demonstrated radium benefit regardless of docetaxel pre-treatment or not. Thus the regulatory approval did not specify docetaxel use for patients eligible for radium-223.

The COU-302⁴ trial was the first trial to trigger regulatory approval in patients specifically and entirely dedicated to the pre-chemotherapy mCRPC space. Patients were asymptomatic or minimally symptomatic and had received no prior chemotherapy and had no visceral metastases. The trial had co-primary endpoints, radiographic progression-free survival (rpFS) and overall survival. The endpoint of rpFS was strongly positive at the time of an interim analysis (P < 0.001) but the overall survival endpoint was not formally met as the O'Brien-Fleming boundary was not breached. The actual P value for OS at interim was 0.0097 and the pre-specified P value required by O'Brien-Fleming methodology was ≤0.0008. Secondary endpoints such as time to PSA progression, time to performance status (PS) decrease, time to opioids, and time to chemotherapy were significantly delayed in those receiving abiraterone/prednisone as compared to placebo/prednisone. We note that the time to chemotherapy in both arms, but especially in the abiraterone arm was quite long considering the time to PSA progression, PS decline, and radiographic deterioration. Regulatory authorities have approved abiraterone/prednisone in the pre-chemotherapy mCRPC space, and this is an important event that is currently changing patterns of care.

An additional regulatory approval is anticipated in 2014. The PREVAIL trial comparing enzalutamide and placebo in patients with asymptomatic and minimally symptomatic mCRPC patients with no prior chemotherapy. In contrast to the COU-302 trial, in PREVAIL patients with visceral metastases were eligible (except

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### Table 1: Regulatory approvals and endpoints in the United States in castrate-resistant prostate cancer

<table>
<thead>
<tr>
<th>Year</th>
<th>Agent</th>
<th>Endpoint</th>
<th>Control arm</th>
<th>Setting</th>
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<tbody>
<tr>
<td>1981</td>
<td>Estramustine</td>
<td>Response</td>
<td>Diethylstilbestrol</td>
<td>CRPC</td>
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<td>1993</td>
<td>Strontium-89</td>
<td>Pain</td>
<td>Placebo</td>
<td>Post-radiation</td>
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<td>1996</td>
<td>Mitoxantrone/prednisone</td>
<td>Pain</td>
<td>Prednisone</td>
<td>Front line</td>
</tr>
<tr>
<td>1997</td>
<td>Samarium-153 leiodoronam</td>
<td>Pain</td>
<td>Placebo</td>
<td>mCRPC</td>
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<tr>
<td>2002</td>
<td>Zoledronic acid</td>
<td>Skeletal events</td>
<td>Placebo+standard of care</td>
<td>mCRPC</td>
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<td>2004</td>
<td>Docetaxel/prednisone</td>
<td>Survival</td>
<td>Mitoxantrone/ prednisone</td>
<td>Front line</td>
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<tr>
<td>2010</td>
<td>Sipuleucel-T</td>
<td>Survival</td>
<td>Unstimulated immune cells</td>
<td>Mostly pre-docetaxel</td>
</tr>
<tr>
<td>2010</td>
<td>Cabazitaxel/prednisone</td>
<td>Survival</td>
<td>Mitoxantrone/ prednisone</td>
<td>Post-docetaxel</td>
</tr>
<tr>
<td>2010</td>
<td>Denosumab-standard of care</td>
<td>Skeletal events</td>
<td>Zoledronic acid</td>
<td>mCRPC</td>
</tr>
<tr>
<td>2011</td>
<td>Abiraterone/prednisone</td>
<td>Survival</td>
<td>Prednisone</td>
<td>Post-docetaxel</td>
</tr>
<tr>
<td>2012</td>
<td>Enzalutamide</td>
<td>Survival</td>
<td>Placebo</td>
<td>Post-docetaxel</td>
</tr>
<tr>
<td>2012</td>
<td>Abiraterone/prednisone</td>
<td>Survival and Radiographic PFS</td>
<td>Prednisone</td>
<td>Pre-docetaxel</td>
</tr>
<tr>
<td>2013</td>
<td>Radium-223-standard of care</td>
<td>Survival</td>
<td>Placebo-standard of care</td>
<td>Pre- and post-docetaxel</td>
</tr>
</tbody>
</table>

PFS: progression-free survival; CRPC: castrate-resistant prostate cancer; mCRPC: metastatic castrate-resistant prostate cancer

### Table 2: Trials demonstrating a survival benefit in metastatic castrate-resistant prostate cancer

<table>
<thead>
<tr>
<th>Group</th>
<th>Trial</th>
<th>Visceral disease allowed</th>
<th>HR</th>
<th>Survival (month)</th>
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<tr>
<td>Front line</td>
<td>Docetaxel/prednisone vs Mitoxantrone/prednisone</td>
<td>TAX 327¹</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Sipuleucel-T vs control</td>
<td>IMPACT²</td>
<td>No</td>
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<td>Abiraterone/prednisone vs Placebo/prednisone</td>
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<td>Enzalutamide vs Placebo</td>
<td>PREVAIL³</td>
<td>Yes</td>
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<td>Post-DOC</td>
<td>Cabazitaxel/prednisone vs Mitoxantrone/prednisone</td>
<td>TROPIC³</td>
<td>Yes</td>
<td>0.70</td>
</tr>
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<td></td>
<td>Abiraterone/prednisone vs Placebo/prednisone</td>
<td>COU-301⁴</td>
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<td></td>
<td>Enzalutamide vs Placebo</td>
<td>AFFIRM⁶</td>
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<td>0.63</td>
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<tr>
<td>Front line and post-DOC</td>
<td>Radium-223/BSC vs placebo/BSC</td>
<td>ALSYMPCA⁷</td>
<td>No</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

BSC: best standard of care; DOC: docetaxel

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brain metastases). A press release from the company indicated that
the data monitoring committee had stopped the trial at an interim
analysis. Both primary endpoints (rPFS and OS) indicated efficacy
of enzalutamide in this setting ($P < 0.001$ for each). In this case the
O’Brien-Fleming boundary for the OS endpoint was breached. At the
time of this manuscript submission, regulatory authorities have yet
to opine on this trial but given the OS benefit it would be surprising
if approval were not granted.

Taken together, present front-line mCRPC options in the United
States shown to improve survival include docetaxel/prednisone,
sipuleucel-T, abiraterone/prednisone, or radium (Table 2). Post-
docetaxel options that prolong survival include cabazitaxel/prednisone,
abiraterone/prednisone, enzalutamide, or radium-223. No agent has yet
improved survival when co-administered with docetaxel/prednisone
despite multiple attempts (including randomized trials with calcitriol,
GVAX, atrasentan, zibotentan, aflibercept, bevacizumab, dasatinib,
lenalidomide, strontium, and zoledronate).

**PROBLEMATIC ISSUES WITH CURRENT DATA**
The sequencing of CRPC treatments into a pre- and post-docetaxel
space is artificial. This artificiality was simply built on the chronology
of drug development and is not justified on a biological basis. It is
noteworthy that none of the newer agents, either in the front-line or
post-docetaxel space, have been compared head to head (see Table 2).
Instead control groups consisted of mitoxantrone/prednisone, placebo,
prednisone, or “standard care”. Each trial with a currently approved
agent has utilized treatments in the control group that today are
regarded as being sub-optimal. Further, we note that some trials include
patients with visceral disease and others do not. This is delineated in
Table 2. Taken together we conclude that the optimal front-line therapy
and the optimal post-docetaxel therapy are debatable for mCRPC
patients given lack of appropriate comparisons. Thus physicians
in practice today must make choices based on non-randomized
comparisons, an assessment of toxicities, and various assumptions
rather than true “level one” data.

The optimal sequence of therapies is much discussed, but there is
little consensus in expert opinion given the lack of data in settings other
than post-docetaxel. Cabazitaxel/prednisone, abiraterone/prednisone,
radium-223, and/or enzalutamide represent reasonable options
for many docetaxel pre-treated patients. Abiraterone/prednisone,
enzalutamide, sipuleucel-T, and/or radium-223 might represent
alternatives to docetaxel/prednisone as a first line therapy.

Of note front-line abiraterone, sipuleucel-T, and radium-223 were
tested in asymptomatic or mildly symptomatic patients without visceral
metastases. The enzalutamide pre-chemotherapy trial included only
those who were asymptomatic or minimally symptomatic but did not
exclude those with visceral metastatic disease. The radium-223
phase III trial included only symptomatic patients without visceral
disease but many patients receiving radium in the ALSYMPCA trial
actually had minimal analgesic use and would have also been eligible
for the front line trials with abiraterone/prednisone, enzalutamide, or
sipuleucel-T. Docetaxel was tested in mCRPC patients both with and
without symptoms, and in those with and without visceral metastases.

Since abiraterone/prednisone was approved as first line mCRPC
therapy in the United States in 2012, the importance of the post-
abiraterone setting is clear. If abiraterone therapy is first line, what
therapy should follow? Enzalutamide in the pre-docetaxel space has
very recently been shown to improve OS in this setting and it is now
clear that enzalutamide will soon be available in this space as well.
What therapies should follow after progression on enzalutamide? There
is no current evidence, as no randomized trials have been performed
in this setting.

**CAVEATS REGARDING THE CURRENT SEQUENCING ERA**
The amount of second-line efficacy data available in the situations
other than the post-docetaxel space is limited and predominately
retrospective at this time. Regardless, it is timely to review current data
as it will be quite a long time before randomized trials are available and
clinicians are obligated to make decisions for their patients at this time
regardless of whether or not pristine data are available.

Attempting to review non-randomized trials is problematic
from several perspectives. First there is no standardization reporting.
Herein we attempt to capture PSA decline >50% rates, confirmed PSA
>50% decline rates, no PSA response as best response, time to PSA
progression, soft tissue response rates by RECIST, duration of therapy,
and progression-free survival (PFS) (see Table 3). It is also important
to highlight where there are some data and where there are no data.
We have combined both phase II and III trials in our table and this
is important for readers to note as the reliability of phase III data is
generally much higher than phase II data. PFS is often measured quite
differently from trial to trial and thus PFS is particularly problematic
to compare. For instance, some trials utilized PSA as a marker of
progression and some did not. Some trials used two new lesions
on a bone scan, and some trials required additional progression on
subsequent scans.

In this review, conceptual rather than exhaustive discussions are
utilized. Regardless we believe that these findings are important in terms
of understanding the current therapeutic landscape and for designing
the next generation of trials. This review will be methodical, even
though the datasets are small and mostly retrospective (see Table 3).
Within any well designed sequencing trials, one must always be aware
that the patients treated with the second therapy have more advanced
disease and are more likely to have negative prognostic factors such as
a reduced performance status, pain, visceral metastases, high lactate
dehydrogenase (LDH), high PSA, and/or a low hemoglobin. Thus
lower response rates for second line therapies may simply be due to a
higher burden of disease and worse prognostic indicators. Further, in
examining small single institution trials there are potential unknown
biases in patient selection and followup that might or might not apply
to a more general patient population.

**POST-ABIRATERONE DATA**
Given the importance of abiraterone/prednisone, particularly as an
emerging front-line therapy, the sequencing discussions regarding
this agent are particularly critical. As noted above, many clinicians
now start abiraterone/prednisone as first line mCRPC therapy but
the consequences of that decision on subsequent therapies are not
well delineated.

Mezynski and colleagues from the de Bono group have published
a retrospective review of docetaxel in the post-abiraterone space
suggesting the possibility of cross-resistance between these two agents.
The response rate as measured by 50% PSA decline was 66% versus
45%-57% in other docetaxel trials. The time to PSA progression
(4.6 months) post-docetaxel in the Mezynski study whereas the time
to PSA progression or progression from any cause was 6.3 months
in the SWOG 9916 trial. Time to PSA progression was not stated in
the TAX327 trial but the duration of PSA response was 7.7 months.
The median number of docetaxel doses in the Mezynski report was
6 as compared to a median number of 9.5 in TAX327 trial. The best
response as no PSA response was 34% for docetaxel in the post-
Table 3: Synopsis of selected first-, second- and third-line trials in metastatic castrate-resistant prostate cancer

<table>
<thead>
<tr>
<th>Treatment and line of treatment</th>
<th>PSA&lt;sub&gt;50&lt;/sub&gt; decline (%)</th>
<th>PSA&lt;sub&gt;50&lt;/sub&gt; ≥50% decline confirmed (%)</th>
<th>Best PSA response is no response (%)</th>
<th>Median treatment duration (month) (%)</th>
<th>RECIST response rate (%)</th>
<th>Radiographic PFS median (month)</th>
<th>Median PSA progression (months)</th>
<th>Phase</th>
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<tr>
<td>First-line DOC&lt;sup&gt;1&lt;/sup&gt;</td>
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<td>45</td>
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<td>14</td>
<td>NR</td>
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<td>III</td>
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<td>NR</td>
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</tr>
<tr>
<td>Third-line CBZ&lt;sup&gt;13&lt;/sup&gt;&lt;sup&gt;17&lt;/sup&gt;</td>
<td>30</td>
<td>NR</td>
<td>NR</td>
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<td>NR</td>
<td>NR</td>
<td>Retro</td>
</tr>
</tbody>
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ABI: abiraterone; CBZ: cabazitaxel; DOC: docetaxel; ENZ: enzalutamide; PFS: progression-free survival; Retro: retrospective study; NR: not reported

abiraterone setting<sup>19</sup> as compared to a recent trial which reports a 14% rate when docetaxel is given first line.<sup>11</sup> Interestingly of the 8 patients who did not respond to abiraterone (defined as "best PSA response being progression), none responded to docetaxel post-abiraterone. In another, even smaller retrospective study of 14 patients presented by Aggarwal et al.,<sup>22</sup> the PSA response rate was 43%, but the median time to progression was 4.2 months. Taken, though these data are derived from relatively small studies, taken together these data suggest a significant possibility of cross-resistance when docetaxel is given post-abiraterone.

POST-DOCETAXEL AND ABRIRATERONE

Cabazitaxel has been evaluated as third line therapy in patients previously treated with both docetaxel and abiraterone in two retrospective studies. In a combined French/UK experience<sup>14</sup> reported in abstract form, a median of 6 cycles of cabazitaxel were administered (4.1 months), which is similar to data from the TROPIC trial. A total of 49% of these cabazitaxel patients had a >50% PSA decline, which compared to a confirmed >50% decline rate of 39% in the TROPIC study. In the combined French/UK retrospective experience, of the 35 patients with RECIST evaluable disease, 7 (20%) had a partial response. This compares to a 14% RECIST response rate in TROPIC. These data suggest that the response to cabazitaxel are not impaired post-abiraterone however other studies (vide infra) may not be consistent with these observations.

A 68 patient Dutch study<sup>14</sup> recently reported in abstract form for third line cabazitaxel in patients previously treated with both docetaxel and abiraterone. This study also reported on cabazitaxel post-docetaxel giving a nice comparison of second and third line cabazitaxel. The median duration of third line cabazitaxel treatment was approximately 85 days (2.8 months) as compared to 150 days (4.9 months) for patients treated with cabazitaxel second line (post-docetaxel) in this study. In the phase III TROPIC study, the median duration of cabazitaxel treatment was approximately 4.1 months. In the Dutch study, the biochemical PFS was approximately 4 months for third line cabazitaxel patients as compared to a PSA progression in TROPIC of 6.4 months.

Best response equalled no response in approximately 22% of the third line cabazitaxel treated patients as compared to 8% of post-docetaxel patients treated with second line cabazitaxel in the Dutch study. PSA decline rates of >50% were not reported. Contrary to the initial French/UK report, these data suggest that abiraterone may induce some degree of cross-resistance with cabazitaxel. We point out that this conclusion is tempered by the fact that cabazitaxel was third line therapy in the Dutch study and second line therapy for the majority of patients in TROPIC.

In an Israeli retrospective analysis,<sup>14</sup> 24 patients received cabazitaxel after docetaxel and abiraterone. A median of 4 cycles of cabazitaxel were administered. The majority of these patients were treated with 20 mg m<sup>–2</sup> of cabazitaxel instead of the FDA approved dose of 25 mg m<sup>–2</sup>. The PSA response rate was 30%. PFS and other parameters of activity were not reported. This study may also suggest some degree of abiraterone induced cross-resistance with cabazitaxel, albeit it is difficult to interpret because of the lower dose of cabazitaxel used and the fact that again cabazitaxel was given third line in this small study.

Enzalutamide treatment as third line therapy after docetaxel and after abiraterone has been evaluated in three studies. In the first study,<sup>14</sup> with data prospectively collected in a German "Named Patient Access Program," the activity of enzalutamide was clearly diminished post-abiraterone with "no PSA response" as best response in 49% of patients. This compares to only 17% of patients in a phase I/II study of enzalutamide post-docetaxel.<sup>15</sup> The >50% PSA decline rate with enzalutamide in this setting was 29% compared to 54% in the AFFIRM phase III trial conducted in the post-docetaxel setting. In a subset analysis of the Named Patient Access program, a >50% PSA decline to enzalutamide was observed in 7/16 (44%) patients previously achieving a >50% PSA decline with abiraterone. Of the patients with no decline in PSA as best response after abiraterone, 3/14 (21%) had a 50% decline in PSA after enzalutamide. Thus a "no response" to initial abiraterone treatment could not predict a "no response" to subsequent enzalutamide. The median PFS duration was not clearly stated in this study.
In a second retrospective study of enzalutamide conducted in post-docetaxel patients also treated with prior abiraterone, 39 patients were treated and 22 (56%) had no PSA decline as their best response. A total of 9 patients (23%) had a PSA decline of >50% but only 5 of these patients had a confirmed >50% PSA decline. Thus many of the reported declines in PSA were short-lived. Of the 15 patients with a >50% PSA response after abiraterone, 2 had >50% PSA response to enzalutamide. Of the 22 patients without a response to abiraterone, 2 had a >50% PSA response to enzalutamide. The median duration of treatment was only 2.9 months and median time to progression was 2.8 months. This compares to a median time to progression of 8.3 months in the phase III post-docetaxel AFFIRM trial. In the AFFIRM trial the RECIST response rate was 29% as compared to a RECIST response rate of 4% in this retrospective analysis. Thus, although the data are minimal, there is clear evidence of cross-resistance between abiraterone and enzalutamide but one could not exclude a response to enzalutamide by looking at an individual's prior data while taking abiraterone. Regardless the duration of enzalutamide treatment in the third line setting is short, measuring less than 3 months.

In a third small review of enzalutamide predominantly in the post-docetaxel, post-orteronel space, 20 patients received treatment in a Greek "Named Patient Access Program". Orteronel is another CYP17 inhibitor similar to abiraterone but not FDA approved. A number of these patients had also previously received additional chemotherapy including 4 patients with prior cabazitaxel treatment. In this heavily pre-treated patient population, 8/20 (40%) patients had no PSA response as their best response to enzalutamide but 9/20 (45%) had a >50% PSA decline. No PFS was reported. These data are consistent with the others, CYP17 inhibitors decrease enzalutamide responses but some patients can still respond as measured by PSA declines.

POST-ENZALUTAMIDE STUDIES

For the novel antiandrogen enzalutamide there are no published data evaluating use of docetaxel or cabazitaxel after enzalutamide. This is important given that the trial comparing enzalutamide to placebo (PREVAIL) in the chemotherapy-naive setting will likely change the future paradigm of sequencing as this trial demonstrated an OS benefit for enzalutamide.

POST-DOCETAXEL AND ENZALUTAMIDE

Studies of abiraterone in patients previously treated with both docetaxel and enzalutamide have been reported in two separate retrospective studies. Both of these report a dramatic decrease in the activity of abiraterone compared to that expected. PSA >50% decline response rates are far less than expected at 13% and 8% respectively versus 29%-51% expected from phase II-III studies with abiraterone in the post-docetaxel space. PFS after abiraterone was reduced from expectations as well, measuring 2.7 months in the post-enzalutamide and post-docetaxel setting, however PFS was not clearly defined in this third line study so direct comparisons are not possible with the phase III data. No PSA response as the best response to abiraterone in this setting was 63%-78% which compares to 11% in the phase II trial of abiraterone post-docetaxel. These data need to be interpreted with caution because a high proportion of patients in these series were PS 2 (29% and 23% respectively). These data suggest that enzalutamide induces clear cross-resistance to abiraterone and that cross-resistance is near complete. Overall it would appear that the cross-resistance induced by prior enzalutamide treatment on subsequent abiraterone is greater than vice-versa.

POST-CABAZITAXEL STUDIES

The Dutch group of Wissing and colleagues examined retrospectively the activity of abiraterone in the second line setting (post-docetaxel) or the third line setting (post-docetaxel and post-cabazitaxel). The activity or abiraterone was quite similar in both of these settings suggesting that that cabazitaxel induces little cross-resistance to abiraterone. The median treatment duration for abiraterone second line was approximately 130 days as compared to 110 days for third line treatment. The median biochemical PFS was 2.7 months for both second and third line cabazitaxel. The best response being no biochemical response was approximately 31% and 28%, respectively.

POST-RADIUM STUDIES

No formal post-radium studies have been reported. In one abstract a prospective analysis of chemotherapy safety post-radium was presented. Conclusions were limited as not all time points were available for analysis but there did not appear to be overt signs of excessive toxicity. There is no reason to suspect from mechanistic studies that radium and the newer hormonal agents should provoke cross-resistance making these agents potentially quite amenable to combination therapy with non-overlapping toxicities.

OVERALL SYNOPSIS

We would like to fully acknowledge the limitations of this analysis. There is a paucity of prospective multi-institutional data. We have been careful to distinguish prospective from retrospective but have relied on retrospective data for much of this discussion. Much of the data cited herein are available in abstract but not in peer-reviewed form. Abstracts may represent incomplete data sets and many abstracts are never published in the peer-review because of various deficiencies. Individuals treated with subsequent therapies typically have more advanced disease and may have a lower PS as well; these factors may be important in the lower response rates for subsequent therapies.

Despite the limitations, several conclusions appear appropriate. Abiraterone and enzalutamide pre-treatments have a profound effect on the activity of one another. The activity of abiraterone after enzalutamide is quite minimal compared to what might otherwise be expected. The activity of enzalutamide post-abiraterone is diminished but some patients may have responses as measured by PSA. The duration of that response appears more limited than expected, suggesting cross-resistance. We point out that data to date for enzalutamide and abiraterone sequencing are in the post-docetaxel setting and if docetaxel were not used that it is possible that there would be differences in the current data. Data to date however suggest that whichever of these agents is used first will markedly diminish the activity of the second. We note that both enzalutamide and abiraterone target the ligand in the androgen-axis. Neither has a direct action on ligand independent androgen receptor activity. We suspect that splice-variants of the androgen receptor (which lack a ligand binding domain) are linked to resistance patterns for both of these agents.

Abiraterone may diminish the activity of subsequent docetaxel but the studies are small and retro-spective and cannot be considered definitive at this time. In some studies, but not others, abiraterone may also diminish the activity of cabazitaxel. Clearly more clinical data are needed with cabazitaxel in this setting. Little is known about the activity of docetaxel or cabazitaxel in the post-enzalutamide space. This is clearly an area of unmet need given the lack of activity with abiraterone.

Preclinical data recently published describes impaired efficacy of docetaxel, cabazitaxel and enzalutamide in an abiraterone-resistant prostate cancer cell line and also impaired efficacy of docetaxel, cabazitaxel and enzalutamide in an abiraterone-resistant prostate cancer cell line and also impaired efficacy of docetaxel,
cabazitaxel and abiraterone in an enzalutamide resistant prostate cancer cell line. All four substances inhibited androgen receptor nuclear translocation in vitro what could be a possible explanation for partial cross-resistance of these drugs. A possible important common mechanism of resistance might be AR splice variants that express a DNA binding domain but no ligand-binding domain. These variants are capable of ligand-independent AR mediated transcription and cause a particular transcriptional response that is distinct from full-length AR.

Abiraterone and enzalutamide are clearly active in the post-docetaxel setting but even here there is some diminished effectiveness that we have not focused on herein. Abiraterone appears to be active in the third line setting after both docetaxel and cabazitaxel pre-treatments. Little data are available for enzalutamide in the third line setting. This review underscores the potential importance of the sequencing of new therapies in CRPC but also highlights the fact that there is much we do not know. To date we have little in the way of prospective trials to address sequencing (except in the post-docetaxel setting). Given that abiraterone and enzalutamide are now taking a more front line role in metastatic CRPC, it is clear that more data are needed in both the post-abiraterone and post-enzalutamide space. There is an urgent need for prospective sequencing trials with the newer drugs to find if there is an optimal sequence. It is also clearly necessary to find predictive factors, either clinical or molecular, to assist the clinician in making better treatment decisions in an individualized manner.

Though we have emphasized sequencing in this brief review, it is important to recognize that the studies we have highlighted have implications for combination therapy as well. Effective combinations depend on some degree of independent mechanistic action and agents that do not induce cross-resistance to one another are likely to be the most-effective in combination therapy as well.

AUTHOR CONTRIBUTIONS
Both authors contributed to the conception, writing and final review of the manuscript.

COMPETING INTERESTS
All authors declare no competing interests.

REFERENCES