The evolving biology and treatment of prostate cancer

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Since the effectiveness of androgen deprivation for treatment of advanced prostate cancer was first demonstrated, prevention strategies and medical therapies for prostate cancer have been based on understanding the biologic underpinnings of the disease. Prostate cancer treatment is one of the best examples of a systematic therapeutic approach to target not only the cancer cells themselves, but the microenvironment in which they are proliferating. As the population ages and prostate cancer prevalence increases, challenges remain in the diagnosis of clinically relevant prostate cancer as well as the management of the metastatic and androgen-independent metastatic disease states.

Nonstandard abbreviations used: AR, androgen receptor; BPH, benign prostatic hyperplasia; CCL, CC chemokine ligand; CXCL, CXC chemokine ligand; CXCR, CXC chemokine receptor; DHT, dihydrotestosterone; DRE, digital rectal exam; NCCN, National Comprehensive Cancer Network; PIN, prostatic intraepithelial neoplasia; PSA, prostate-specific antigen; PSMA, prostate-specific membrane antigen; SDF-1, stromal-derived factor–1.

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American Cancer Society guidelines for prostate cancer screening

The American Cancer Society, like all of the medical societies, continues not to recommend routine testing for prostate cancer at this time, but does suggest that men talk to their doctors about the benefits, risks, side effects, and controversies associated with early prostate cancer testing and treatment. A PSA blood test and DRE should be offered annually beginning at age 50 to men who have a life expectancy of at least 10 years (8). In men for whom DRE is an obstacle to testing, PSA alone is an acceptable alternative. Men at high risk, including men of sub-Saharan African descent and men with a first-degree relative diagnosed at a younger age (i.e., less than 65 years) should begin testing at age 45. Men at even higher risk of prostate cancer due to more than one first-degree relative diagnosed with prostate cancer before age 65 could begin testing at age 40, although if PSA is less than 1.0 ng/ml, no additional testing is needed until age 45. If PSA is between 1.0 and 2.5 ng/ml, annual testing is recommended. If PSA is greater than 2.5 ng/ml, further evaluation with biopsy should be considered.

Prostate tumorigenesis

Prostate cancers appear to develop over 20–30 years or more (10, 11). While approximately 5%–10% of prostate cancers are thought to occur on an inherited genetic background that makes the host more susceptible to prostate tumorigenesis, these genes have yet to be identified (12). Prostate cancers, like all carcinomas, arise in differentiated epithelial cells and/or progenitor cells in which embryonic pathways are reactivated through the activation of oncogenes and the loss of tumor suppressor genes, which leads to a growth and survival advantage (13). Whether the process of prostate carcinogenesis is the result of DNA damage that occurs in a differentiated cell or a stem cell, it is the result of a complex interplay of genes, the cellular microenvironment, the macroenvironment of the host, and the environment in which the host resides. Multiple genetic changes have been associated with prostate cancer, and these appear to correlate with microscopic changes in cell structure and gland histology (Figure 3) (14–27).

In classic carcinogenesis models, damaging insults to cells are generally classified into those that cause initiating events (DNA damage that starts cells along a tumorigenesis pathway) and those that cause promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation). Early prostate tumorigenesis appears to be associated with a dysplasia that starts with proliferative inflammatory atrophy (PIA) and progresses to prostatic intraepithelial neoplasia (PIN), which in some cases leads to carcinoma (16). Evidence suggests that these early lesions may be initiated by inflammation that occurs with exposure to different infectious agents that cause initiating events (DNA damage) and promotional events (further DNA damage or cell proliferation).
The phase III Prostate Cancer Prevention Trial demonstrated that treatment with the 5α-reductase inhibitor finasteride for 7 years led to a 25% decrease in the incidence of prostate cancer in men over the age of 50 (39). This medication left potency intact and was generally well tolerated. Unfortunately, when the prostate cancers were analyzed by Gleason score, there were an increased number of high-grade prostate cancers (Gleason higher than 7) found in the finasteride arm than in the placebo arm of the trial. The reasons for this remain unclear, but several possible explanations exist. (a) The higher-grade cancers may be the result of the hormone treatment inducing a more poorly differentiated phenotype. This would mimic what is seen after treatment with androgen-ablating agents in men with hormone-refractory prostate cancer. (b) There was an almost 25% reduction in gland volume in the finasteride-treated group; this volume reduction would increase the likelihood that cancer, especially higher-grade cancer, would be sampled in a biopsy procedure. (c) A potential ascertainment bias may also be involved. Because finasteride decreases the symptoms of BPH and decreases PSA increases caused by BPH, men with persistently elevated PSA levels on finasteride would have an increased probability of harboring prostate cancer compared with men with high PSA levels not on finasteride. The study demonstrated a higher sensitivity of detecting prostate cancer in the finasteride arm, and this increased sensitivity may be responsible at least in part for the increased detection of high-grade cancers in that group (40–43). Men enrolled in this trial are still being followed, and further investigation will hopefully clarify these issues. In the meantime, finasteride has not been widely adopted as a chemopreventive agent for prostate cancer. Other agents that target testosterone metabolism by inhibiting 5α-reductase, such as dutasteride, are currently in clinical trial (44).
Understanding that prostate carcinogenesis occurs as a result of interactions between genes and the environment has led to the development of several other potential chemoprevention strategies that are aimed at preventing DNA damage or the proliferation of premalignant cells (Table 1) (15, 45, 46). Antioxidants, which are believed to prevent DNA damage by oxygen free radicals, are in clinical trials and include pomegranate juice, curcumin, vitamin D, vitamin E, selenium, and lycopene (45–48). The Selenium and Vitamin E Cancer Prevention Trial, a phase III randomized, placebo-controlled trial (32,400 enrolled) of selenium (200 μg/d) and/or vitamin E (400 IU/d) supplementation for a minimum of 7 years and a maximum of 12 years was initiated in 2001 to test the effectiveness of these agents to prevent prostate cancer (49).

It has been known for several decades that men from Asian countries have a much lower incidence of prostate cancer, and one hypothesis behind this observation is their high consumption of antioxidants in the form of naturally occurring estrogens (isoflavones) through the ingestion of soy and green tea (50). One such isoflavone, genistein, has been demonstrated to induce the expression of genes involved in defense against oxidative stress (51). In
addition, it has been demonstrated in breast and prostate cancer cells that genistein induces apoptosis and inhibits activation of cell survival genes in the NF-κB and Akt signaling pathways (50). Even though definitive evidence is lacking, many physicians recommend green tea as a preventive measure against prostate cancer.

Other strategies for prostate cancer prevention are also under investigation (Table 1). For reasons that remain unclear, prostate epithelial cells and prostate cancers have high levels of polyamines. These molecules are involved in many biochemical processes including cellular proliferation, cell cycle regulation, and protein
Inhibitor of ornithine decarboxylase, the rate-limiting enzyme in the polyamine synthetic pathway, α-difluoromethylornithine, is being studied as a chemoprevention agent (52). The selective estrogen receptor modulator toremifene is being investigated for its ability to inhibit the evolution of PIN to prostate cancer (53). In addition, 3,3′-diindolylmethane acts as an angiogenesis inhibitor and has been demonstrated to downregulate the androgen receptor and the AKT pathway in prostate cancer cells (54). Exisulind, an inhibitor of cGMP phosphodiesterase that induces apoptosis, has been studied extensively alone and in combination with other agents as both a preventive and a treatment for different stages of prostate cancer (55). Multiple nonsteroidal antiinflammatory drugs, including celecoxib, hold promise as chemoprevention agents for cancer, including prostate (46, 56).

Targeting metastatic prostate cancer for treatment
Although metastatic prostate cancer remains an incurable disease at present, therapy can delay progression. The first step in treatment of metastatic disease is to block testosterone-driven proliferation of prostate cancer cells through androgen deprivation therapy with medical or surgical castration. This causes apoptosis in the majority of the prostate cancer cells and leads to a remission in the majority of patients for 18–36 months (28). During that clinical remission, cells that have escaped the requirement of testosterone to grow continue to proliferate, and a castration-independent clone (hormone refractory, androgen independent) of cells emerges as the predominant phenotype. Median survival time for men with androgen-independent disease is approximately 18–24 months (57). Current research is focused on understanding the molecular events that underlie the transition to androgen independence in order to develop new treatment strategies.

Targeting the androgen-independent prostate cancer cell
As a prostate tumor becomes androgen independent, multiple alternative cellular pathways, some involving the AR and others bypassing it, support tumor cell growth (Figure 4) (28, 29). These

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Chemoprevention agents for prostate cancer, and their presumed mechanism of action, currently in clinical trial</th>
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<tbody>
<tr>
<td>Agent</td>
<td>Mechanism</td>
</tr>
<tr>
<td>Exisulind</td>
<td>Inhibits cGMP phosphodiesterase (55)</td>
</tr>
<tr>
<td>Celecoxib</td>
<td>Inhibits COX-2; increases β-catenin (56)</td>
</tr>
<tr>
<td>Genistein</td>
<td>Multiple effects including downregulation of AR, ERα, PR, EGFR, and IGF1 (50, 51)</td>
</tr>
<tr>
<td>DFMO</td>
<td>Multiple effects caused by inhibited ornithine decarboxylase (52)</td>
</tr>
<tr>
<td>Diindolylmethane</td>
<td>Inhibits angiogenesis (54)</td>
</tr>
<tr>
<td>Toremifene</td>
<td>Selective ER modulator (53)</td>
</tr>
<tr>
<td>Selenium yeast</td>
<td>Antioxidant (49)</td>
</tr>
<tr>
<td>Vitamin D analog</td>
<td>Antioxidant (45)</td>
</tr>
<tr>
<td>Vitamin E</td>
<td>Antioxidant (49)</td>
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<tr>
<td>Pomegranate</td>
<td>Antioxidant (47)</td>
</tr>
<tr>
<td>Lycopene</td>
<td>Antioxidant (48)</td>
</tr>
<tr>
<td>Curcumin</td>
<td>Antioxidant (48)</td>
</tr>
<tr>
<td>Finasteride</td>
<td>Inhibits 5α-reductase (39)</td>
</tr>
<tr>
<td>Dutasteride</td>
<td>Inhibits 5α-reductase (44)</td>
</tr>
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For more information, see ref. 46. ER, estrogen receptor; DFMO, α-difluoromethylornithine; PR, prostaglandin receptor; COX-2, cyclooxygenase-2.

<table>
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<tr>
<th>Table 2</th>
<th>Agents and their presumed targets currently in clinical trial for the treatment of prostate cancer</th>
</tr>
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<tbody>
<tr>
<td>Cell type</td>
<td>Target</td>
</tr>
<tr>
<td>Prostate cancer cell</td>
<td>Aberrant growth factor receptor activation</td>
</tr>
<tr>
<td>Bcl-2</td>
<td>AT101 (73)</td>
</tr>
<tr>
<td>DNA replication</td>
<td>Ixabepolone halichondrin (79–81)</td>
</tr>
<tr>
<td>Histone deacetylase</td>
<td>Satraplatin (77)</td>
</tr>
<tr>
<td>Proteasome</td>
<td>Vorinostat (78)</td>
</tr>
<tr>
<td>Hsp90</td>
<td>Bortezomib (64)</td>
</tr>
<tr>
<td>Clusterin</td>
<td>OSX-O11 (76)</td>
</tr>
<tr>
<td>mTOR</td>
<td>Rapamycin analogs (75)</td>
</tr>
<tr>
<td>? Proliferation</td>
<td>Calcitriol, DN-101 (82)</td>
</tr>
<tr>
<td>Endothelin-1 receptor</td>
<td>Atrasentan, ZD-4054 (106)</td>
</tr>
<tr>
<td>Pyrophosphate</td>
<td>Zoledronic acid, samarium, strontium (100–102)</td>
</tr>
<tr>
<td>RANKL</td>
<td>Denosumab (103)</td>
</tr>
<tr>
<td>SRC</td>
<td>Dasatinib (104, 105)</td>
</tr>
<tr>
<td>VEGF</td>
<td>Bevacizumab, VEGF-TRAP (108, 112)</td>
</tr>
<tr>
<td>VEGFR</td>
<td>Sunitinib, vatalanib, sorafenib (109–112)</td>
</tr>
<tr>
<td>αvβ5 Integrin</td>
<td>Cilengitide (114)</td>
</tr>
<tr>
<td>Permeability</td>
<td>Dimethylxanthone (113)</td>
</tr>
<tr>
<td>Macrophages</td>
<td>CNT0888 (97)</td>
</tr>
<tr>
<td>T cells (CTLA-4)</td>
<td>MDX-010 (119)</td>
</tr>
<tr>
<td>Dendritic cells</td>
<td>Sipuleucel-T (117); GVAX (118)</td>
</tr>
<tr>
<td>Cell antigens</td>
<td>MUC-1 antibodies (120), PSMA (J591 conjugates) (121, 122)</td>
</tr>
</tbody>
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CTLA-4, CTL-associated antigen–4; Hsp, heat shock protein; mTOR, mammalian target of rapamycin; MUC-1, Mucin 1; RANKL, receptor activator of NF-κB ligand.
alternative pathways include: (a) amplification of the AR with associated hypersensitivity to lower levels of DHT; (b) broadening of the specificity of the AR to other hormone molecules (receptor promiscuity); (c) activation of the AR through phosphorylation by nonhormone kinases (outlaw pathways); (d) activation of growth through pathways that are independent of the AR (bypass pathways); and (e) repopulation of the tumor through androgen-independent stem/progenitor cells.

Amplification of the AR is common in androgen-dependent disease and is likely secondary to either gene amplification as a result of mutation or through selective pressure of the androgen-depleted environment, causing the death of cells with fewer ARs and the clonal expansion of cells with more ARs (58, 59). Potential methods to target continued activation of ARs include the development of better antiandrogens that competitively bind the AR, inhibiting AR dimerization by blocking the dissociation of AR from the heat shock protein Hsp90 using geldanamycin (17-AAG), altering proteasome degradation of AR, and inhibiting cofactor binding to the AR (Table 2 and Figure 4, pathways i and ii) (60–64).

The phosphorylation and subsequent outlaw activation of the AR by deregulated growth factors and their downstream signal transduction kinase pathways, including IGF, keratinocyte growth factor, PDGF, EGF, and IL-6, are being targeted in clinical trials using antibodies or small-molecule kinase inhibitors (Table 2 and Figure 4, pathway iii; refs. 65–71).

Androgen-independent prostate cancer cells have been demonstrated to frequently upregulate antiapoptotic molecules including Bcl-2, allowing them to bypass their need for androgens for cell growth and survival (Table 2 and Figure 4, pathway iv) (72–74). Anti–Bcl-2 agents include AT101, which binds to the BH3 domain of Bcl-2 (73). Inactivation of the tumor-suppressor gene PTEN with subsequent activation of Akt is also a frequent event in androgen-independent prostate cancer cells, and this is being targeted through the inhibition of mammalian target of rapamycin (75). The cytoprotective gene Clusterin has been silenced using antisense oligonucleotide OXG-011 and is the subject of ongoing phase II clinical trials (76).

Multiple agents are under clinical development for androgen-independent prostate cancer that inhibit cancer cell proliferation...
Antimicrotubule agents including ixabepilone and halichondrin are also under active study (79–81). Vitamin D acts as an immunostimulatory agent that interferes with DNA replication or mitosis. A phase III trial of satraplatin, an oral platinum that inhibits replication through the formation of DNA adducts, has demonstrated activity as a second line chemotherapy for patients with androgen-independent disease (77). The increased understanding of the relationship between DNA and chromatin structural proteins has led to the development of histone deacetylase inhibitors such as suberoylanilide hydroxamic acid (vorinostat), which interferes with chromatin unfolding and subsequent gene activation (78). Antimicrotubule agents including ixabepilone and halichondrin are also under active study (79–81). Vitamin D acts as an antiproliferative agent through a variety of poorly characterized mechanisms, and high-dose calcitriol, DN-101, has demonstrated activity in androgen-independent disease and is the subject of ongoing clinical trials (82).

Another potential mechanism for survival in the androgen-depleted environment is the presence of prostate cancer stem cells that continually regenerate a heterogeneous tumor cell population that is observed in androgen-independent patients despite therapy (Figure 4, pathway v) (14). A small population of cells that are CD44⁺αvβ3⁺CD133⁺ and do not express AR has been identified within prostate tumors and is thought to be composed of prostate cancer stem or progenitor cells (14). Although prostate-specific agents have not been identified, multiple therapeutics are being developed for clinical investigation, including inhibitors of Hedgehog, Notch, and Bim1, developmental genes that have been identified as activated in multiple stem populations (83, 84).

**Targeting therapy to bone metastases**

Bone metastases are the major cause of morbidity, and ultimately mortality, for men with metastatic prostate cancer (85, 86). The interaction of prostate cancer cells with the bone microenvironment has been described as a vicious cycle in which prostate cancer cells interact with both osteoclasts and osteoblasts in a complex interplay resulting in osteoblastic metastases (Figure 5) (85–87). Prior to the establishment of this vicious cycle, data suggest that the presence of the primary tumor can have positive and negative effects on the successful migration and growth of cancer cells at distant sites. Primary tumors appear to act in an endocrine fashion to alter the marrow environment and prime it for the arrival of metastatic cells by creating a premetastatic niche (88). Factors such as hypoxia and inflammation promote the release of factors resulting in the mobilization of bone marrow–derived endothelial progenitor cells and hematopoietic progenitor cells that circulate to distant sites and dictate the localization of metastatic spread of the tumor cells (88–91). Alternatively, primary tumors can also produce growth-inhibitory cytokines such as angiostatin, which suppress the growth of metastases (92, 93).

Prostate cancer cells that successfully metastasize to bone marrow hijack several properties exhibited by normal host cells that traffic through the circulation and bone marrow. For example, prostate cancer cells mimic hematopoietic stem/progenitor cells by upregulating the expression of stromal-derived factor-1 (SDF-1), also known as CXC chemokine ligand 12 (CXCL12) receptor CXCR4. Both HSCs and prostate cancer cells use the cell surface protein annexin II (Anxa2) on both endothelial cells (not shown) and osteoblasts as a dock/lock mechanism into the bone microenvironment. Conceptually, prostate cancer cells act as parasites of the HSC niche by coopting HSC chemokines and attachment sites to initiate a cascade of events that result in the osteoblastic metastases observed in prostate cancer patients.

**Figure 6**

Prostate cancer mimicry of HSC/progenitor cell homing mechanisms. The metastatic process of prostate cancer cells (PCa cells) is functionally similar to the migrational, or homing, behavior of HSCs to the bone marrow. Numerous molecules have been implicated in regulating HSC homing, participating as both chemokine receptors and regulators of cell growth. Endothelial cell–derived factors such as CCL2 act as chemokine receptors and growth factors for HSCs, tumor-associated macrophages, and prostate cancer cells. Osteoblasts produce the chemokine SDF-1 (CXCL12), which further guides both HSCs and prostate cancer cells into the marrow through their expression of the CXCL12 receptor CXCR4. Both HSCs and prostate cancer cells use the cell surface protein annexin II (Anxa2) on both endothelial cells (not shown) and osteoblasts as a dock/lock mechanism into the bone microenvironment. Conceptually, prostate cancer cells act as parasites of the HSC niche by coopting HSC chemokines and attachment sites to initiate a cascade of events that result in the osteoblastic metastases observed in prostate cancer patients.
Even though prostate cancer bone metastases are osteoblastic, osteoclasts are active in bone remodeling and are critical targets for interruption of the vicious cycle. Zoledronate has been demonstrated to decrease skeletal-related events in men with androgen-independent prostate cancer (100). The radionuclides samarium and strontium also bind to pyrophosphate, releasing presumably lethal radiation to all of the cells in the bone microenvironment (101, 102). Treatment with these agents leads to significant pain control in the majority of patients with osseous metastases. Another approach under active investigation is the interruption of the osteoblast/osteoclast axis through inhibition of the osteoprotegerin receptor/receptor activator of NF-κB ligand axis by denosumab (103). Dasatinib is a tyrosine kinase inhibitor that targets the src pathway and acts as an osteoclast inhibitor with activity in prostate cancer (104, 105). Atrasentan and ZD-4054 are endothelin-1 inhibitors that interrupt osteoblast function and proliferation and are currently in clinical investigation (106).

Prostate cancer metastases, even those in the bone marrow microenvironment, require blood vessels for growth (107). Antiangiogenic strategies are being actively pursued using several different paradigms of inhibition, including a current phase III trial of the combination of docetaxel with the anti-VEGF antibody bevacizumab in men with advanced prostate cancer (108). The interaction of VEGF with its receptors can also be blocked with antibodies that bind to the VEGFRs or with kinase inhibitors (Table 2) (97). Sipuleucel-T (APC8015; Provenge) is an immunotherapy that exposes autologous dendritic cells to a recombinant fusion protein of prostate acid phosphatase. These activated cells are then reinfused into the patient (117). GVAX is an immunotherapy in phase III clinical trials that is comprised of 2 irradiated prostate cancer cell lines that have been genetically modified to secrete GM-CSF (118).

Blockade of the T cell–inhibitory receptor CTL-associated antigen-4 (CTLA-4) augments and prolongs T cell responses and is under active clinical investigation to elicit antitumor immunity (119). Antigens present on prostate cancer cells offer attractive targets for immune therapy. Antibodies targeted against Mucin 1 and other glycoproteins that are overexpressed on multiple epithelial cancers, including prostate, are the subject of multiple clinical trials (120). Prostate-specific membrane antigen (PSMA) is an antigen expressed on the surface of prostate cells as well as the neovascularature of multiple tumor types (121, 122). Radiolabeled anti-PSMA monoclonal antibody J591 trials using the radiometals yttrium-90 and lutetium-177 have demonstrated manageable toxicity, excellent targeting of soft tissue and bone metastases, and efficacy in multiple preliminary trials.

Continued therapeutic development based on an evolving understanding of the biology of prostate cancer

The advances in prostate cancer therapy have been based on known molecular targets and biologic rationale. Unfortunately, prostate cancer patients have the second leading cause of cancer death in American men (1). Better use of the PSA and PSA kinetics should increase the sensitivity of detection of clinically relevant cancers while decreasing the diagnostic rate of clinically insignificant cancers. In the realm of metastatic disease, multiple new therapeutic strategies are entering the clinic, directing therapy not only at the cancer cells themselves, but also at the microenvironment in which those cancer cells proliferate. This can serve as a paradigm for multiple other cancers in the future. Furthermore, the evolving understanding that early in metastasis, prostate cancer cells act as parasites of the HSC niche by coopting bone marrow chemokines and attachment sites to initiate osteoblastic lesions will drive future therapeutic development for advanced prostate cancer.

Acknowledgments

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