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# Pathophysiological Basis of Human Papillomavirus in Penile Cancer: Key to Prevention and Delivery of More Effective Therapies

Philippe E. Spiess, MD, MS, FRCS(C)<sup>1</sup>; Jasreman Dhillon, MD<sup>2</sup>; Adam S. Baumgarten, MD<sup>3</sup>; Peter A. Johnstone, MD, FACR<sup>4</sup>; Anna R. Giuliano, PhD<sup>5</sup>

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<sup>1</sup>Associate Member, Department of Genitourinary Oncology, Moffitt Cancer Center, Tampa, FL; <sup>2</sup>Assistant Member, Department of Anatomical Pathology, Moffitt Cancer Center, Tampa, FL; <sup>3</sup>Urology Resident Physician, Department of Genitourinary Oncology, Moffitt Cancer Center, Tampa, FL; <sup>4</sup>Senior Member, Department of Radiation Oncology, Moffitt Cancer Center, Tampa, FL; <sup>5</sup>Senior Member, Department of Infection and Cancer, Moffitt Cancer Center, Tampa, FL.

**Corresponding author:** Philippe E. Spiess, MD, MS, FRCS(C), Department of Genitourinary Oncology, Moffitt Cancer Center, 12902 Magnolia Drive, Office 12538, Tampa, FL 33612; philippe.spiess@moffitt.org

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**ABSTRACT:** Squamous cell carcinoma (SCC) of the penis is a rare malignancy in the United States, with a significantly higher incidence—up to 20 to 30 times greater—in areas of Africa and South America. This can be explained in part by the significantly greater prevalence of sexually transmitted diseases among high-risk males often having unprotected sex with multiple sexual partners. Human papillomavirus (HPV) has been implicated as the infectious pathway by which several these penile neoplasms originate from precursor lesions. In this regard, a fundamental understanding of HPV in penile carcinogenesis can have meaningful implications in understanding 1) the diagnosis of HPV-related precursor penile lesions, 2) targeting HPV-specific molecular pathways, and 3) cancer prevention. Using vaccination programs not only may improve patient outcomes but also may minimize the need for highly aggressive and often debilitating surgical resection. *CA Cancer J Clin* 2016;66:481–495. © 2016 American Cancer Society.

**Keywords:** diagnosis, human papillomavirus, penile cancer, prevention, review, treatment, vaccination

## Practical Implications for Continuing Education

- > A significant proportion of penile cancers are related to HPV.
- > Effective prevention of penile cancer among high-risk populations should entail the adoption of HPV vaccination programs.
- > Novel therapeutic agents, including immune checkpoint inhibitors, offer great promise in the management of advanced penile cancer.

## Introduction

Penile cancer is a rare malignancy, accounting for 0.24% of all neoplasms among men in the United States.<sup>1</sup> Squamous cell carcinoma (SCC) is the most frequently reported pathology of penile tumors, and over 90% have this histology.<sup>2</sup> The diagnosis and management of penile cancer have been plagued by disappointing outcomes because of a paucity of knowledge on the molecular pathways implicated in the development and progression of such tumors; the rarity of cases treated at individual centers, resulting in limited expertise; and the heterogeneous therapeutic approaches offered at most nontertiary care referral centers. There is no question that the implementation of national (National Comprehensive Care Network [NCCN]) and international (European Urological Association [EUA]) treatment guidelines have been pivotal not only in establishing standards of care but in providing diagnostic and treatment benchmarks that health care professionals can adopt in clinical practice using a sound, evidence-based approach.<sup>3,4</sup> One of the most meaningful advances made in our fundamental understanding of penile cancer pertains to recognizing that there are 2 molecularly divergent pathways for

penile carcinogenesis: human papillomavirus (HPV)-induced and non-HPV-induced pathways.<sup>5</sup> It is estimated that between 50% and 80% of penile neoplasms may be HPV-induced, making this an essential mechanism by which the majority of such tumors arise.<sup>6</sup> Our recognition that HPV mediates the carcinogenesis of most penile tumors offers a unique opportunity to potentially prevent the disease using vaccination programs in specific high-risk patient populations or to diagnose lesions in precancerous or early stage/grade disease. Finally, treatment options specifically tailored to HPV status using local (surgery, radiotherapy) and systemic therapies have been proposed and are actively being investigated.<sup>7</sup>

The aims of this review article are to provide a comprehensive review of the molecular and pathophysiological (HPV and non-HPV) pathways in penile cancer, to highlight potential opportunities for the prevention of penile cancer and its incipient precursor lesions using targeted HPV vaccination programs, to provide clinical updates in the current diagnosis and management of penile cancer, and to discuss future horizons in penile cancer and HPV research that will likely further refine our treatment armamentarium.

### Molecular and Pathophysiological Pathways in Penile Cancer

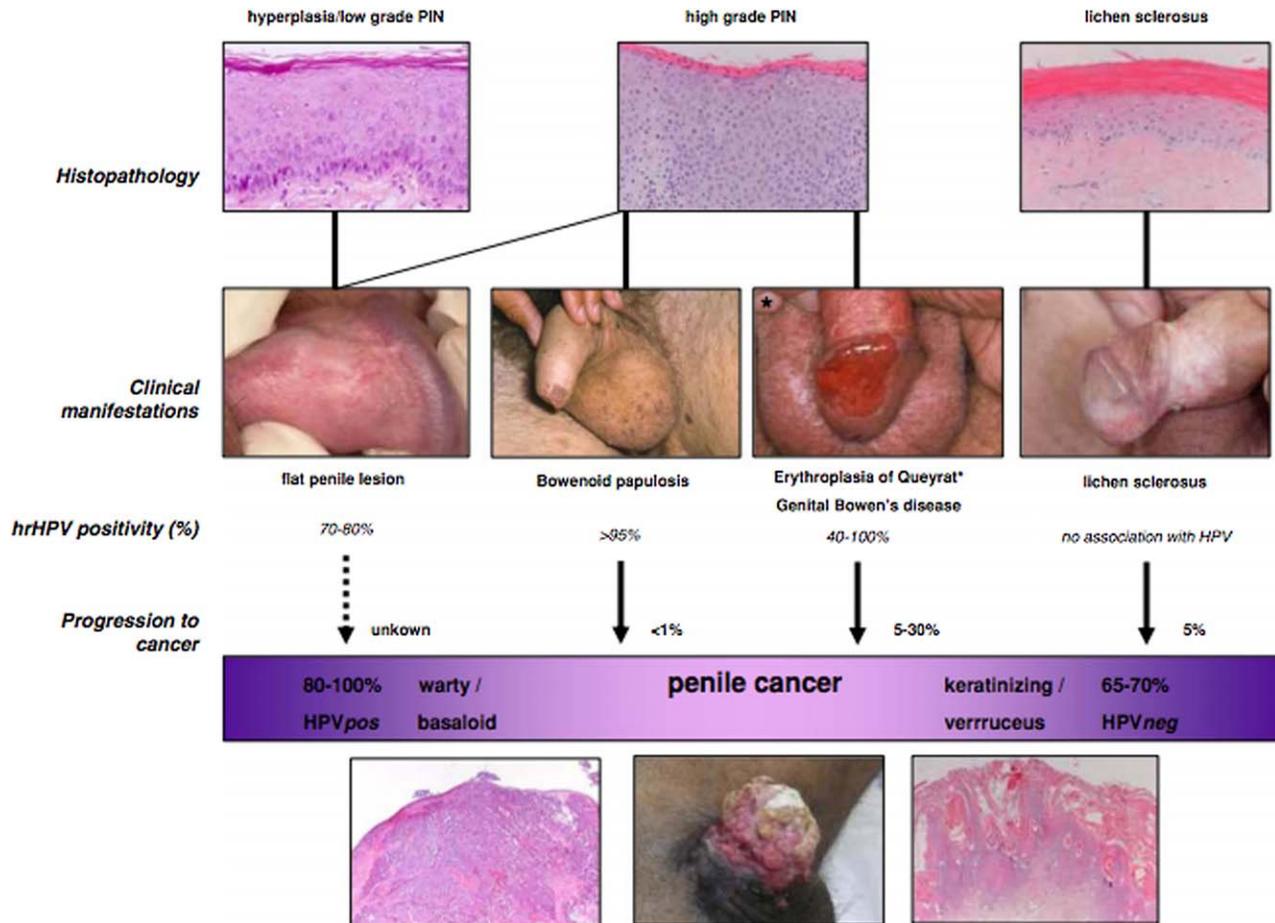
Risk factors associated with penile cancer are high-risk HPV infection, genital warts/condylomas, inflammation, lichen sclerosis, phimosis, poor hygiene, lack of circumcision during childhood, exposure to chemicals, cigarette smoking, genetic background, and smegma retention.<sup>8</sup> Penile intraepithelial neoplasia (PeIN) is defined by the World Health Organization as an alteration of the penile squamous epithelium characterized by dysplastic changes with an intact basement membrane. PeIN is said to be the precursor lesion of invasive SCC and, just like penile carcinoma, can be classified as HPV-related (undifferentiated PeIN, such as warty, basaloid, and mixed warty-basaloid) or non-HPV-related (differentiated PeIN). Differentiated PeIN is usually associated with lichen sclerosis and chronic inflammation (Fig. 1).<sup>9</sup>

HPV is a DNA virus. Currently, there are more than 100 different known types of HPV viruses, of which 20 are known to infect the genital tract.<sup>10</sup> The rate of HPV infection in penile cancers varies from 20% up to greater than 75%.<sup>11</sup> The frequency of HPV DNA in carcinomas of the penis varies, depending on the virus detection method used and the geographical region studied. HPV types 16, 18, 31, 33, 45, 56, and 65 are examples of high-risk HPV viruses that are frequently associated with penile cancer. Types 6 and 11 are examples of low-risk viruses that are detected frequently in benign lesions like condyloma acuminatum

and less commonly in carcinomas. Coinfection with more than one HPV type is common in patients with HPV.

The squamous epithelium is affected by the virus essentially in 2 ways: either as viral infection or as viral-associated precancer. Viral infection is responsible for lesions such as condyloma and mild dysplasia. These represent largely transient HPV infections in which the squamous epithelium supports virion production and produces a morphologic low-grade lesion; whereas, in precancerous lesions (HPV-associated PeINs), the viral genome integrates into the host genome, and viral oncogene overexpression drives cell proliferation to produce a clonal expansion of undifferentiated cells that carry a risk of malignant transformation. HPVs have circular, double-stranded DNA genomes that encode 8 genes, of which E6 and E7 have transforming properties. The viral E6 and E7 oncoproteins are necessary for malignant transformation of the host cell. Viral E6 and E7 get integrated into the host genome. E6 protein has oncogenic activities that are both dependent and independent of *p53*,<sup>12</sup> which plays an important role in controlling cell proliferation and growth arrest after DNA damage by ionizing radiation.<sup>13</sup> E6 associates with the tumor-suppressor gene product *p53*, whereby it stimulates the degradation of *p53*, promoting cell proliferation. The E6-promoted degradation of *p53* is adenosine triphosphate-dependent and involves the ubiquitin-dependent protease system.<sup>12</sup> *P53* mutations are not seen in HPV-related tumors such as cervical cancers.<sup>14</sup> In contrast, in HPV-negative tumors, *p53* is mutated and may be independently associated with lymph node metastases (Fig. 2).<sup>15,16</sup>

The E7 proteins encoded by high-risk HPVs bind with the tumor-suppressor retinoblastoma (*Rb*) gene product with much higher affinity compared with those encoded by low-risk HPVs, such as HPV6 and HPV11. One of the major biochemical functions of *Rb* is to bind E2F-family transcription factors and repress the expression of replication enzyme genes.<sup>13</sup> The ability to repress the expression of replication enzyme genes correlates with the tumor-suppression function of *Rb*. E7 disrupts the interaction between *Rb* and E2F, resulting in the release of E2F factors in their transcriptionally active forms.<sup>17</sup> These complexes lead to autonomous cell proliferation without G1 cell-cycle stops. This allows nuclear accumulation of the cyclin-dependent kinase inhibitor p16ink4a, which inhibits G1 cyclin-dependent kinase 4 (CDKN4), CDKN6, and cyclin D-dependent kinases, initiating phosphorylation of the *Rb* tumor-suppressor protein. The immunohistochemical demonstration of p16ink4a overexpression serves as a surrogate marker for a transcriptionally active (transforming), high-risk HPV infection.<sup>18</sup> Low-risk HPV infections do not lead to p16ink4a overexpression.<sup>19</sup>



**FIGURE 1.** Correlations Between Histology, Human Papillomavirus Presence, Clinical Manifestation, and Putative Transformation of Penile Precursor Lesions Into Penile Cancer. hrHPV indicates high-risk human papillomavirus; neg, negative; PIN, penile intraepithelial neoplasia; pos, positive. Reprinted with explicit permission from: Bleeker MC, Heideman DA, Snijders PJ, Horenblas S, Diliner J, Meijer CJ. Penile cancer: epidemiology, pathogenesis and prevention. *World J Urol.* 2009;23:141-150.<sup>9</sup>

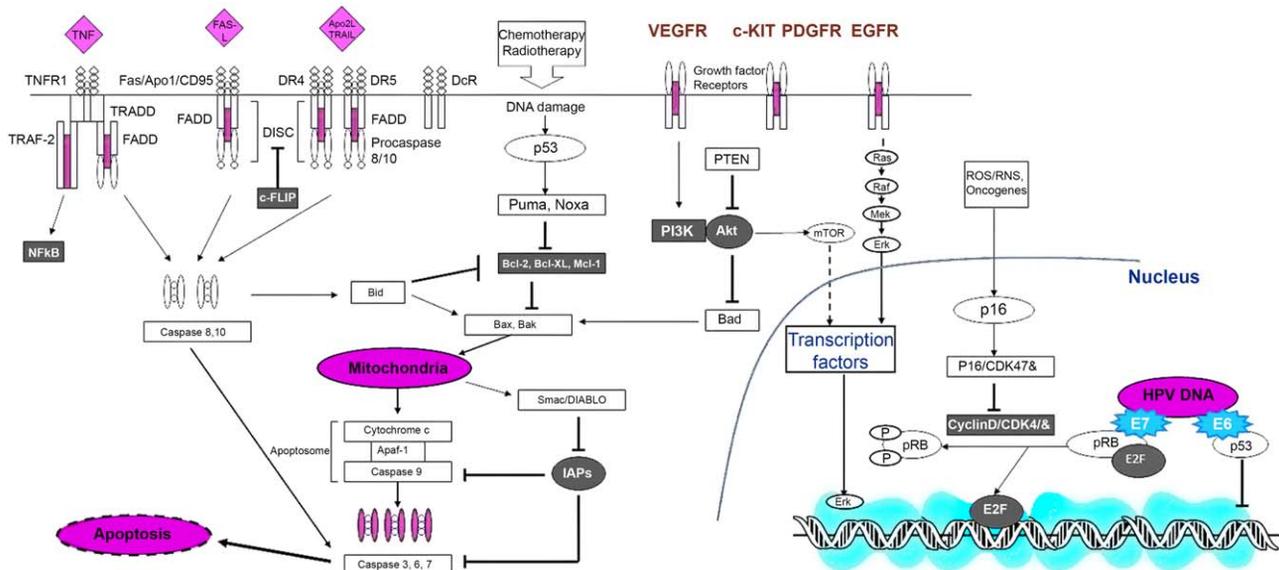
P16 immunohistochemistry measures the protein product of the tumor-suppressor gene *CDKN2A*, which is lost in the vast majority of HPV-negative tumors but is universally wild type and expressed in HPV-associated tumors. In HPV-associated tumors, E7 viral oncoproteins degrade *RB1* and enhance p16 expression. *RB1* loss can occur in HPV-negative tumors as well via mutations, resulting in p16 expression. Hence, p16 expression is not specific to HPV-associated cancers and also can occur in HPV-negative cancers.<sup>20</sup>

HPV-negative penile carcinogenesis is less well understood but has been linked to *p53* mutations.<sup>21</sup> These cancers are associated with lichen sclerosus and lichen planus and are believed to arise from precursor lesions identified as differentiated PeIN,<sup>22,23</sup> which are considered aggressive with rapid progression to invasive cancer. Differentiated intraepithelial neoplasia lacks p16ink4a overexpression but typically shows nuclear *p53* expression in atypical basal keratinocytes.<sup>24</sup> Various studies have demonstrated that *p53* expression in tumor cells predicts a poor prognosis.<sup>25-27</sup> *P53* expression represents an independent, adverse prognostic parameter. *P21* is a cyclin-dependent kinase

inhibitor that is induced by *p53*. It is a tumor-suppressor gene whose induction leads to cell cycle arrest. In a study by Gunia et al, *p21* and cyclin *D1* were not significantly associated with disease-specific mortality in multivariate analysis.<sup>26</sup> The major pathways and mediators involved in the development of penile preneoplastic lesions and neoplasms are listed in Table 1.<sup>16</sup>

*Ki-67* is a nonhistone nuclear matrix protein that is expressed in all phases of the cell cycle except *G0*.<sup>28</sup> A high *Ki-67* labeling index is associated with more aggressive behavior. However, it reportedly does not have any prognostic value for cancer-specific survival or overall survival.<sup>29,30</sup> In a study by Kayes et al, *Ki-67* expression determined by immunohistochemistry had a significant prognostic impact on overall survival in bivariate analysis. Higher levels of *Ki-67* expression were associated with poorer clinical outcomes. However, it had no independent prognostic value in a multivariable model.<sup>31</sup>

In addition to *Ki-67*, other proliferation markers that have been studied in patients with penile carcinoma are minichromosome maintenance 2 (*MCM2*) protein and Geminin. Studies to date analyzing the role of *MCM2* and



**FIGURE 2.** Schematic Diagram Illustrating Molecular Pathways Implicated in Human Papillomavirus (HPV)-Associated and Non-HPV-Associated Penile Cancer. Akt indicates protein kinase B; Apaf-1, apoptotic peptidase activating factor 1; Apo1, APO protein 1; Bad, B-cell lymphoma 2 (BCL2)-associated agonist of cell death; Bak, BCL2 antagonist/killer 1; Bax, BCL2-associated X protein; Bcl-2, B-cell lymphoma 2; Bcl-XL, B-cell lymphoma 2, extra large; Bid, BH3-interacting domain death agonist; CDK4/7, cyclin-dependent kinase 4/7; c-FLIP, cellular FADD-like interleukin-1 $\beta$ -inhibitory protein; DcR, decoy receptor; DISC, death-inducing signaling complex; DR4/DR5, death receptors 4 and 5; E2F, gene group that codifies a family of transcription factors in higher eukaryotes; E6/E7, E6 and E7 oncoproteins; EGFR, epidermal growth factor receptor; Erk, extracellular signal-regulated kinase; FADD, tumor necrosis factor receptor superfamily 6 (Fas)-associated with death domain; Fas, tumor necrosis factor receptor super family 6; FAS-L, Fas ligand; HPV, human papillomavirus; IAPs, inhibitor of apoptosis proteins; Mcl-1, myeloid cell leukemia 1; Mek, mitogen activated protein kinase kinase; mTOR, mammalian target of rapamycin; NF- $\kappa$ B, nuclear factor  $\kappa$ B; Noxa, phorbol-12-myristate-13-acetate-induced protein 1; P, protein; p16, cyclin-dependent kinase inhibitor 2A; p53, tumor protein 53; PDGFR, platelet-derived growth factor receptor; pRB, retinoblastoma protein; PTEN, phosphatase and tensin homolog; Puma, p53 up-regulated modular of apoptosis; Raf, v-raf murine leukemia viral oncogene homolog; Ras, rat sarcoma (a family of proteins); RNS, reactive nitrogen species; ROS, reactive oxygen species; Smac/DIABLO, second mitochondria-derived activator of caspase/direct inhibitor of apoptosis-binding protein with low isoelectric point; TNF, tumor necrosis factor; TNFR1, TNF receptor 1; TRADD, TNF receptor superfamily, member 1A-associated with death domain; TRAF-2, TNF receptor-associated factor 2; TRAIL, TNF-related apoptosis-inducing ligand; VEGFR, vascular endothelial growth factor receptor. Reprinted with explicit permission from: Protzel C, Spiess PE. Molecular research in penile cancer—lessons learned from the past and bright horizons for the future? *Int J Mol Sci.* 2013;14:19494-19505.<sup>16</sup>

Geminin in penile cancer have produced somewhat conflicting data. A study by May et al demonstrated that MCM2 and Geminin labeling indices were prognostic indicators and predictors of locoregional metastasis. However, they failed to have a significant, independent prognostic impact on cancer-specific survival.<sup>30</sup> Kayes et al found a significant prognostic impact of MCM2 on overall survival in univariate analysis. However, both MCM2 and Geminin failed to demonstrate any significant independent prognostic value in multivariate analysis.<sup>31</sup>

The epidermal growth factor receptor (EGFR)/human epidermal growth factor receptor (HER)/phosphoinositide 3-kinase (PI3K)/phosphatase and tensin homolog (PTEN)/ protein kinase B (Akt)/mammalian target of rapamycin (mTOR)/glycogen synthase kinase 3(GSK-3) (EGFR-HER-PI3K-PTEN-Akt-mTOR-GSK-3) pathway plays a prominent role in regulating the cell cycle. The PI3K-Akt-mTOR pathway is an intracellular signaling pathway important in regulating the cell cycle, including cell differentiation, migration, proliferation, and survival. The human epidermal growth factor receptor family is composed of EGFR, HER2, HER3, and HER4 transmembrane tyrosine kinase receptors. Extracellular ligand

binding to HER receptors leads to tyrosine phosphorylation and activation.<sup>32</sup> Overexpression of HER family proteins has been linked to a worse prognosis in several cancers. Stankiewicz et al have suggested a greater role of EGFR in HPV-independent penile carcinogenesis. Those authors postulate that, for HPV-positive penile cancers, EGFR activation plays a role in its early stage; and, after HPV integration, it sustains cell proliferation that is independent of EGFR through disruption of the RB/p16 pathway by E6/E7 oncoproteins, as previously discussed.<sup>32</sup> EGFR activation by overexpression is an early event in the history of penile cancer and generally is considered to have a negative impact on prognosis. In a recent study by McDaniel et al, genomic profiling was performed on penile cancer specimens, and EGFR amplifications were identified in 9% of cases.<sup>33</sup> However, in a study by Gou et al, no correlation was observed between EGFR expression and tumor grade, stage, or lymph node metastases.<sup>34</sup>

Penile cancers are known to express HER3 and HER4 but not HER2.<sup>32</sup> It has been suggested that, in penile cancer, HPV may up-regulate HER3 protein expression, possibly through its viral E6 and/or E7 oncoproteins, as it does with HER2 protein in human cervical keratinocytes.<sup>35</sup>

**TABLE 1. Molecular Changes Reported for Penile Carcinomas**

CARCINOGENESIS	PROLIFERATION/INVASION	METASTASES
<b>Inflammation</b>	<b>Growth factors/receptors</b>	<b>Metastases suppressor genes</b>
COX-2	EGFR	<i>KA11</i>
PGE-2	HER-3/HER-4	<i>Nm23H1</i>
	VEGF	
<b>Tumor suppressor genes</b>	PI3K/PTEN/AKT	
<i>p53</i>		
<i>p16</i>	EMT	
<i>PTEN</i>	MMP2/MMP9	
	E-cadherin	
<b>Oncogenes</b>	Tenascin C	
<i>HPV E6/E7</i>	Annexins	
<i>MYC</i>	Glut1	
<b>Apoptosis/cell death</b>		
DR4/DR5		
Bcl-2/BAX		
<i>p53</i>		
Telomerases		

AKT, protein kinase B; BAX, B-cell lymphoma 2-associated X protein; bcl-2, B-cell lymphoma 2; COX-2, cyclooxygenase-2; DR4/DR5, death receptors 4 and 5; EGFR, epidermal growth factor receptor; EMT, epithelial-mesenchymal transition; Glut1, glucose transporter 1; HER-3/HER-4, human epidermal growth factor receptors 3 and 4; *HPV E6/E7*, human papillomavirus E6 and E7 oncoproteins; *KA11*, type I keratin KA11; MMP2/MMP9, matrix metalloproteinases 2 and 9; *MYC*, v-Myc avian myelocytomatosis viral oncogene homolog; *Nm23H1*, NME/NM23 nucleoside diphosphate kinase 1; *p16*, cyclin-dependent kinase inhibitor 2A; *p53*, tumor protein 53; PGE-2, prostaglandin E2; PI3K, phosphoinositide 3-kinase; *PTEN*, phosphatase and tensin homolog; VEGF, vascular endothelial growth factor. Reprinted with explicit permission from: Protzel C, Spiess PE. Molecular research in penile cancer—lessons learned from the past and bright horizons for the future? *Int J Mol Sci*. 2013;14:19494-19505.<sup>16</sup>

Activation of HER receptors by various growth factors stimulates intracellular signaling pathways, including the PI3K/Akt and rat sarcoma proto-oncogene-RAF proto-oncogene serine/threonine-protein kinase-mitogen-activated protein kinase kinase-extracellular signal-regulated kinase (Ras-Raf-MEK-ERK) pathways. Akt targets include B-cell lymphoma 2 (Bcl-2) family proteins; cell-cycle regulators like p53, p21, and p27; and Fas ligand and forkhead transcription factors (FOXO).<sup>36</sup> There are 3 isoforms of Akt in mammals: Akt1, Akt2, and Akt3. Various tumors overexpress different Akt isoforms.<sup>37,38</sup> In penile cancer, Akt1 has been positively associated, along with HER3 and HER4, with tumor grade and progression.<sup>32</sup>

The PI3K/Akt signaling pathway is antagonized by *PTEN*.<sup>39</sup> Loss of *PTEN* expression in penile cancer is not known to affect phosphorylated Akt protein expression, suggesting that HER3 and HER4 proteins may have a greater

impact than *PTEN* on increased activation of the PI3K/Akt pathway.<sup>32</sup> mTOR signaling is altered in penile carcinomas. In a study by Ferrandiz-Pulido et al, phosphorylated eukaryotic initiation factor 4E (peIF4E) and phosphorylated mTOR (pmTOR) overexpression were correlated with aggressive behavior in penile cancer, and p53 and pmTOR were overexpressed particularly in HPV-negative tumors.<sup>40</sup>

The EGFR-RAS-RAF signaling pathway plays an important role in the regulation of tumor cell survival and proliferation. There are 3 different human *RAS* genes: Kirsten rat sarcoma viral oncogene homolog (*KRAS*), Harvey rat sarcoma viral oncogene homolog (*HRAS*), and neuroblastoma rat sarcoma viral oncogene homolog (*NRAS*). RAS proteins are small guanosine triphosphate-hydrolyzing enzymes (GTPases) downstream of *EGFR* that are central mediators for cell proliferation, survival, and differentiation. *RAS* can activate several downstream effectors, including the PI3K-AKT-mTOR pathway, which is involved in cell survival, and the RAS-RAF-MEK-ERK pathway, which is involved in cell proliferation. *KRAS* mutations are mostly found in codons 12 and 13 (exon 2) and occasionally in codon 61 (exon 3) when studied in different tumor types.<sup>41,42</sup> Only rare cases of penile cancers with mutations involving *KRAS* have been reported.<sup>34,43</sup> Although *EGFR* is detected immunohistochemically in a large subset of penile cancers, it is not known whether its expression is associated with the presence of an *EGFR* gene mutation.<sup>44</sup> Because the *KRAS*/v-Raf murine sarcoma viral oncogene homolog B (*BRAF*) pathway is a major EGFR-dependent signaling pathway, *KRAS* mutation may lead to anti-EGFR treatment failure. However, because of high *EGFR* expression and rare *KRAS* mutations in penile cancer, anti-EGFR therapy may represent an effective treatment option for this disease.<sup>34,45,46</sup> Currently, there are ongoing phase 2 trials with irreversible EGFR and Her2 inhibitors, afatinib and dacomitinib, for advanced/metastatic SCC of the penis.

The *BRAF* gene is a component of the EGFR-RAS-RAF signaling pathway. It encodes a RAS-regulated kinase that mediates cell growth, differentiation, apoptosis, and malignant transformation. *BRAF* mutations have not been reported in penile cancer to date.<sup>34</sup> RAS-association domain family 1A (*RASSF1A*) is expressed in all nonmalignant epithelial cells and exerts its tumor-suppressor activity via RAS-mediated apoptosis.<sup>47,48</sup> In a study by Gou et al, loss of *RASSF1A* protein expression was common and was observed in 96.67% of the 150 penile carcinomas analyzed, whereas *KRAS* mutation was rare and was detected in only 1 of 94 carcinomas analyzed, suggesting that *RASSF1A* inactivation may exclude the necessity of *KRAS* activation to alter RAS signaling in carcinogenesis.<sup>34</sup>

Mutually exclusive mutations have been identified in the PI3K and RAS pathways, indicating that either pathway is sufficient for the development of penile cancer.<sup>16</sup>

V-myc avian myelocytomatosis viral oncogene homolog (*MYC*) is a proto-oncogene that regulates cellular proliferation, differentiation, and apoptosis and many times is up-regulated in some forms of cancer. In penile cancer, *MYC* gains progressively increased during tumor progression and were identified as an independent factor for poor prognosis.<sup>49</sup> Expression of c-myc was increased in HPV-positive tumors in that study, indicating direct activation of *MYC* by the virus.

E-cadherin is a cell-to-cell adhesion molecule, low levels of which are associated with an increased risk of metastases of tumor cells. Low levels of E-cadherin expression have been reported to increase the risk of lymph node metastases in penile cancer.<sup>50</sup> Matrix metalloproteinase 2 (MMP-2) and MMP-9 are part of a group of enzymes that degrade type IV collagen in the basement membrane and are involved in the invasion mechanism. In the same study, the authors did not find any correlation of MMP-2 and MMP-9 immunoreactivity with the risk of lymph node metastases.<sup>50</sup>

HPV infection induces an immune reaction in an immunocompetent host, which leads to the generation of HPV-specific memory T lymphocytes. Lohneis et al have suggested that the tumor microenvironment in HPV-positive carcinomas is different from that in HPV-negative carcinomas.<sup>51</sup> Although additional studies are required to confirm this, one can hypothesize that the penile tumors with intense immune cell infiltrate are HPV-positive and may respond to antiprogrammed cell death protein 1 (PD-1) drugs. These drugs are currently being researched in other HPV-mediated cancers.

Cyclooxygenase-2 (COX-2) and prostaglandin E2 (PGE2) are key mediators in inflammation-induced carcinogenesis. Cyclooxygenase catalyzes the synthesis of prostaglandin H2 (PGH2), which is converted by microsomal prostaglandin E synthase (mPGES-1) into PGE2. COX-2 and mPGES-1 are overexpressed in penile cancer. Golijanin et al observed high levels of COX-2 and mPGES-1 in PeIN, invasive SCC, and lymph node metastases. Increased levels of COX-2 were detected in penile SCC arising in an HPV16 transgenic mouse, suggesting that a selective COX-2 inhibitor may inhibit the formation or growth of HPV-related SCCs.<sup>52</sup> However, more studies are required to confirm this hypothesis.

So far, large numbers of biomarkers have been analyzed in cases of penile cancer, many of which have not been discussed in this review, eg, KAI1 (kangai 1), CD147 (cluster of differentiation 147 [basigin]), annexins, and the monoclonal antibody D2-40. The biomarkers have been tested in a few retrospective studies with small case numbers.

Additional studies with larger case numbers are needed to clearly establish their prognostic impact and the role of biomarker inhibitors in this relatively rare malignancy.

## Prevention of Penile Cancer and Preneoplastic Lesions

Although penile cancer incidence is low, several studies among men have shown that the presence of external genitalia HPV of any HPV type can be up to 71-73%, with the incidence of new genital HPV infection being exceedingly high similar to the incidence rates reported for HPV-positive cervical tumors among women.<sup>53</sup> These observations have led to studies investigating the factors associated with genital HPV infection, the progression of infection to carcinogenesis, and the prevention of infections with HPV vaccination.

Among the first male HPV studies were those examining HPV seroprevalence in men compared with women.<sup>54</sup> In every study conducted, lower HPV seroprevalence was observed in men compared with women.<sup>55</sup> This low prevalence of serum antibodies to HPV in men has recently been explained by a low rate of seroconversion after HPV infection in men.<sup>56</sup> For example, approximately 60% of women will develop antibodies to HPV16 within 24 months of initial infection. In contrast, only 10% of men develop HPV antibodies after natural infection.<sup>57</sup> Unlike women, in whom antibodies in response to natural HPV infection confer partial protection against new infections with the same HPV type, among the men who seroconvert after natural HPV infection, no protection against subsequent infection is observed.<sup>58</sup> In fact, in prospective studies, subsequent recurrences of the same genital HPV genotypes were observed among men throughout the lifespan.<sup>59</sup> Related to the lack of immunity conferred from past HPV infection in men, a higher transmission of HPV from women to men than from men to women has been observed.<sup>60,61</sup> Together, these findings indicate that men remain susceptible to genital HPV infection throughout their lifespan, a conclusion supported by epidemiologic studies showing sustained HPV prevalence and incidence throughout the lifespan of men.<sup>62</sup>

Numerous modifiable and nonmodifiable factors have been associated with genital HPV burden among men. Among the modifiable factors, infrequent condom use,<sup>63,64</sup> current tobacco use,<sup>65,66</sup> alcohol consumption,<sup>67</sup> and herpes simplex virus 2 (HSV2) and chlamydia infections<sup>68</sup> have been associated with higher genital HPV seroprevalence and incidence in men. Infant as well as adult medical male circumcision provides partial protection against HPV (with protection varying by HPV genotype).<sup>69-73</sup> Consistent with the lower penile cancer incidence among men of Asian descent, a significantly lower burden of genital HPV

infection has been observed in this population compared with that in other racial/ethnic groups.<sup>74,75</sup>

The rate of progression from genital HPV infection to disease varies by HPV genotype.<sup>76,77</sup> In one study, 26% of men with a genital HPV6 infection progressed to an HPV6-positive condyloma, and 24% of men with a genital HPV11 infection progressed to an HPV11-positive condyloma, with rapid rates of progression to disease after initial genital infection (ie, a median of 7.7 months). In contrast, despite the high prevalence of genital HPV16 infection observed in men (approximately 6%), progression of HPV16 infection to PeIN was rare, with only 2% progressing within a 24-month period. Progression of HPV16 infection was relatively slow, with 50% of infections requiring more than 19 months for PeIN to be detected. However, it is important to note that, in prospective studies, all diagnosed PeIN lesions were HPV-positive, and the majority were positive for HPV type 16, 6, or 11,<sup>77,78</sup> genotypes that patients are protected against by Gardasil (Merck & Company, Kenilworth, NJ) vaccination.<sup>79</sup>

As discussed above, infection with HPV rarely results in the development of antibodies in men; and, if antibodies do develop, then these are not protective against subsequent infection or neoplastic progression.<sup>58</sup> In contrast, 100% of young adult males vaccinated with Gardasil produce a type-specific antibody at levels log-fold higher than the levels observed after natural HPV infection.<sup>80</sup> In the only international phase 3 trial of the quadrivalent HPV vaccine Gardasil, the vaccine was efficacious in preventing HPV type 6, 11, 16, and 18-related external genital lesions (EGLs) in men ages 16 to 26 years (Table 2).<sup>79</sup> Vaccine efficacy against these HPV-related EGLs in the intent-to-treat population was high (65.5%; 95% confidence interval [CI], 45.8%-78.6%), as was its efficacy against the development of any EGL, regardless of HPV genotypes (60.2%; 95% CI, 40.8%-73.8%). In the per protocol efficacy (PPE) population, Gardasil reduced the incidence of HPV type 6, 11, 16, and 18-related EGLs by 90.4% (95% CI, 69.2%-98.1%). Efficacy against condyloma in the PPE population was 89.4% (95% CI, 65.5%-97.9%). In addition, Gardasil was efficacious against HPV type 6, 11, 16, and 18-related persistent infection and HPV DNA detection. The only cases of PeIN (grades I-III) that were diagnosed in that trial were among the placebo control group. Because only 3 cases were observed in the PPE population, efficacy (presumed to be 100%) was not reported to the US Food and Drug Administration (FDA); hence, an indication for the prevention of penile cancer is not part of the vaccine label. On the basis of the condyloma data, the FDA licensed Gardasil for use in males ages 9 to 26 years for the prevention of genital warts (condyloma) in November 2009. Altogether, these results are encouraging and hold promise for

an ultimate reduction in genital HPV infection and its related lesions among men, most notably if the vaccine is successfully disseminated among a large proportion of the male population. To this end, in 2011, the Advisory Committee on Immunization Practice of the US Centers for Disease Control and Prevention recommended routine HPV vaccination of males as well as females at the target age of 11 or 12 years and up to age 21 years for males. Since this recommendation, approximately 22% of US adolescent males between ages of 13 and 17 years have received all 3 doses of Gardasil.<sup>81</sup> Clearly more work is needed to increase vaccine dissemination to males in the United States and other countries. To date, very few countries have gender-neutral national HPV vaccination policies, including the United States, Israel, Australia, and Austria. More recently, the immunogenicity and safety of Gardasil 9, which protects against HPV types 6, 11, 16, 18, 31, 33, 45, 52, and 58, has been demonstrated in adolescent and young adult males.<sup>82,83</sup> Licensure of Gardasil 9 for adolescent males ages 9 to 15 years occurred in 2014, with the expectation that FDA licensure for young adult males ages 16 to 26 years will occur in the near future. To maintain consistent vaccine recommendations, the Advisory Committee on Immunization Practice has extended its male vaccination recommendation (males ages 9-21 years) to Gardasil 9 in 2015 with an increase in the upper age range to 26 years for high-risk and immunocompromised males.

## Clinical Updates in Penile Cancer

The diagnosis and management of penile cancer has undergone a significant paradigm shift in recent years, with the fundamental understanding that patients and health care professionals alike have been hesitant to recommend aggressive surgical resection attributable to the life-altering change and poor quality of life faced by patients when undergoing such potentially debilitating treatment.<sup>84</sup> As a consequence, patients with favorable primary penile malignancies (in situ, Ta, and select T1 tumors of lower grade) may be suitable candidates to undergo penile-sparing treatment approaches, including topical therapy, wide local excision with primary reapproximation or reconstruction, and penile brachytherapy (at centers with expertise in this area).<sup>85-88</sup> Prior studies have similarly refuted the previously held belief that 2-cm surgical margins are required to ensure tumor eradication in favor of less than 5-mm margins. The smaller margin is adequate without compromising oncological outcomes and has corroborated the merits of penile sparing surgery in many cases.<sup>89</sup> Selective adoption of such treatment modalities in select patients now offers the ability to maintain sexual function and minimally disturb quality of life—most importantly, not at the expense of a worse oncological outcome. As a result, the

TABLE 2. Efficacy of Quadrivalent Vaccine Against the Development of External Genital Lesions in the Intention-to-Treat Population<sup>a</sup>

VARIABLE	QUADRIVALENT HPV VACCINE			PLACEBO			OBSERVED EFFICACY (95% CI), %
	CASES OF EGL, NO.	PERSON-YEARS AT RISK	RATE: NO./100 PERSON-YEARS AT RISK	CASES OF EGL, NO.	PERSON-YEARS AT RISK	RATE: NO./100 PERSON-YEARS AT RISK	
HPV type							
Any type	36	4612.6	0.80	89	4538.6	2.00	60.2 (40.8 to 73.8)
Type 6, 11, 16, or 18	27	4625.7	0.58	77	4556.5	1.69	65.5 (45.8 to 78.6)
Type 6	21	4635.8	0.45	51	4576.0	1.11	59.4 (31.2 to 76.8)
Type 11	6	4663.7	0.13	25	4606.6	0.54	76.3 (40.8 to 92.0)
Type 16	3	4663.1	0.06	10	4621.9	0.22	70.3 (−15.5 to 94.7)
Type 18	2	4670.0	0.04	3	4627.9	0.06	33.9 (−476.7 to 94.5)
Sexual orientation <sup>b</sup>							
Heterosexual males	21	4153.9	0.51	57	4087.5	1.39	63.7 (39.3 to 79.1)
Males who had sex with male partners	6	471.8	1.27	20	469.0	4.26	70.2 (23.0 to 90.2)
Lesion type <sup>c</sup>							
Condyloma acuminatum	24	4635.4	0.52	72	4558.8	1.58	67.2 (47.3 to 80.3)
All PIN lesions	6	4658.7	0.13	5	4628.2	0.11	−19.2 (−393.8 to 69.7)
PIN grade 1	3	4666.1	0.06	4	4629.7	0.09	25.6 (−339.9 to 89.1)
PIN grade 2 or 4	3	4663.1	0.06	2	4628.6	0.04	−48.9 (−1682.6 to 82.9)
Penile, perianal, or perineal cancer	0	4670.6	0	0	4630.5	0.00	−

95% CI indicates 95% confidence interval; EGL, external genital lesions external genital lesions with diagnosis of condyloma acuminatum; HPV, human papillomavirus; PIN, penile, perianal, or perineal intraepithelial neoplasia. <sup>a</sup>Data shown are for patients who had at least one follow-up visit after day 1. Patients were counted once in each applicable category. A patient may have been included in more than one category. <sup>b</sup>There were 1653 heterosexual males and 290 males who had sex with male partners. <sup>c</sup>There were 115 cases of condylomata acuminata associated with any HPV type in the intention-to-treat population (32 in the vaccine group and 83 in the placebo group). Of these 115 cases, 20 involved patients with biopsy specimens that tested positive for more than 1 of the 14 HPV types tested (2 in the vaccine group and 18 in the placebo group). Reprinted with explicit permission from the Massachusetts Medical Society: Giuliano AR, Palefsky JM, Goldstone S, et al. Efficacy of quadrivalent HPV vaccine against HPV infection and disease in males. *N Engl J Med*. 2011;364:401-411.<sup>79</sup> ©2011 the Massachusetts Medical Society.

suitable recommendation of penile-sparing treatment approaches has been integrated into NCCN and EUA guidelines.<sup>3,4</sup> However, it is important to emphasize that treatment-specific outcomes depend on appropriate clinical staging, which sometimes may require magnetic resonance imaging and/or penile ultrasound to rule out a more locally advanced, primary penile tumor (T2-T4).<sup>90,91</sup> Similarly, very rigorous follow-up after treatment cannot be overemphasized. With most recurrences occurring within the first 12 months, surveillance every 3 months over that period is recommended, with the unequivocal performance of a biopsy of any suspected local recurrence.<sup>92</sup>

The involvement of inguinal lymph nodes in patients with penile cancer remains the single most important prognostic factor, and the benefits of early versus delayed inguinal lymph node dissection have been established.<sup>93,94</sup> Similarly, the indication for conducting an inguinal lymph node dissection (ILND) in the absence of palpable inguinal

lymphadenopathy has been strongly correlated with pathological findings of the primary penile tumor. Patients with pathologic T1 (pT1) tumors that are high grade or have the presence of lymphovascular invasion and patients with pT2 to pT4 tumors currently are recommended for ILND.<sup>95</sup> Recently however, the consistency in primary tumor grade assignment has been called into question, with prior single blinded studies among genitourinary pathologists demonstrating a high degree of inconsistency in uniformly assigning a given grade.<sup>96,97</sup> Consequently, one may question the accuracy of using the present primary tumor characteristics in deciding which patients who have penile cancer without palpable inguinal lymphadenopathy should undergo an ILND. The diagnostic and therapeutic benefits of ILND are unquestionable, particularly when conducted in the setting of low-volume clinical lymph node (cN1) metastasis; however, there has been some reticence in the more widespread recommendation for ILND, in large part because of

the high risk of perioperative complications.<sup>98</sup> Prior retrospective studies have documented that, despite the many advances in surgical technique and clinical care pathways, the incidence of such complications remains disappointingly high. Most complications pertain to wound-related complications; and many of these can be predicted based on patient characteristics, postoperative pathology, and surgery-specific details.<sup>99,100</sup> In an effort to reduce the morbidity of evaluating inguinal lymph nodes in patients with penile cancer, a group from the Netherlands Cancer Institute has pioneered the approach of dynamic sentinel lymph node biopsy using a combination of radiotracer and blue dye, with quite favorable outcomes (sensitivity,  $\geq 88\%$ ); however, few sites have the required volume or expertise with such techniques, making this treatment available only at certain centers of excellence worldwide.<sup>101</sup>

A similar effort to surgically resect and evaluate inguinal lymph nodes with a minimally invasive technique using pure laparoscopic or robotic-assisted techniques has been reported with promising results, although the findings are limited by a relatively short-term follow-up.<sup>102,103</sup> This technique adheres to the anatomic boundaries of surgical dissection established in open surgery but avoids many wound-related complications because of the limited size of the necessary laparoscopic sites (typically 12–15 mm each). More widespread adoption of this technique is cautioned, particularly in the setting of bulky inguinal adenopathy (cN2/cN3) or after previous neoadjuvant chemotherapy, radiation, or both.

The potential role of positron emission tomography-computed tomography imaging using the nuclear radiotracer <sup>18</sup>F-fluorodeoxyglucose in the evaluation of inguinal lymph nodes among patients with penile cancer has been actively pursued in recent years and shows great promise. Currently, this modality is best used in the setting of patients with palpable inguinal adenopathy in deciphering the potential occult metastatic nature of a given lymph node(s). Its utility in patients who have penile cancer without palpable inguinal lymph nodes has been disappointing, with little to no clinical yield when used in this setting.<sup>104,105</sup>

One of the clinical conundrums in the management of penile cancer involves which patients should undergo pelvic lymph node dissection. Previous retrospective studies have indicated that the size of inguinal lymph nodes ( $>3$  cm), the presence of 3 more involved inguinal lymph nodes with metastases identified on ILND, and the presence of extranodal extension within the resected inguinal lymph node as useful criteria for making this clinical decision.<sup>106,107</sup> In addition, a bilateral versus unilateral pelvic lymph node dissection should be contemplated if 4 or more positive inguinal lymph nodes (cumulatively, on both sides) are identified at the time of ILND.<sup>108</sup> Subsequent studies report improved overall survival in patients who have undergone a more extensive pelvic

lymph node dissection,<sup>109</sup> especially those who have positive pelvic lymph nodes with extranodal extension who are followed with adjuvant, systemic chemotherapy.<sup>110</sup>

The management of inguinal recurrences after a prior ILND has been associated with poor overall survival (typically less than 1 year). Salvage radiotherapy has provided a limited survival benefit.<sup>111</sup> Results from a recent multicenter trial suggest that, in the absence of other sites of metastatic disease, inguinal recurrences are surgically managed best by salvage ILND after neoadjuvant systemic chemotherapy, appreciating that such salvage surgery has an exceedingly high risk (over 50%) of perioperative complications because of wound-related complications.<sup>112</sup> Patients who have penile cancer with bulky inguinal lymph nodes (cN2/cN3 at presentation) are best approached in a multimodal approach consisting of neoadjuvant, systemic chemotherapy (typically using a platinum-based regimen) followed by aggressive surgical resection in appropriate responders.<sup>113</sup> The landmark phase 2 study by Pagliaro et al nicely depicted the merit of such a treatment paradigm, with a 50% objective response reported. Subsequent consolidative ILND surgery revealed that 10% of these patients had no viable tumor on final pathology.<sup>114</sup>

Despite these great strides in our understanding and uniform approach to diagnosing and managing penile cancer, a recent study disappointingly highlighted that the overall prognosis of patients who have penile cancer with positive inguinal lymph nodes has not improved over recent years.<sup>115</sup> Novel emerging therapies, such as the application of targeted therapies and EGFR monoclonal antibodies, have produced promising preliminary results when applied to select patients with advanced penile cancer exhibiting chemorefractory disease and may be a therapeutic consideration in select patients at this time.<sup>43,116</sup> Nevertheless, the most promising avenue is the development of a more personalized and refined approach to advanced penile cancer, taking into account the HPV status of the lesions and the specific targetable molecular pathways in penile carcinogenesis, which are discussed below.

## Future Horizons in Penile Cancer and HPV Research

Advances and refinements in the care of patients with penile cancer hold increasing promise thanks to meaningful progress in our fundamental understanding of the disease, with a plethora of novel systemic therapies presently being investigated in preclinical and early clinical trials.<sup>117</sup>

The present and future advances in the management of penile cancer are particularly promising in the area of HPV-directed prevention and treatment. This is available in large part because of significant advances in our appreciation of the interplay between HPV and host immunity of SCC in other organ sites, such as head and neck cancer.<sup>118–120</sup> Focusing our attention on penile cancer prevention, the

initial approval by the FDA in 2009 of the quadrivalent HPV vaccine and, most recently, of the 9-valent HPV vaccine for use in females ages 9 to 26 years and in males ages 9 to 15 years, with the primary indication of HPV prevention, in all likelihood will have a meaningful impact on the incidence and natural history of penile cancer.<sup>121,122</sup> The pivotal decision taken by the FDA to approve HPV vaccination in an effort to positively impact the incidence and natural history of HPV-related infections and malignancies was primarily based on research advances in the area of HPV-related cervical cancer.<sup>123</sup> One such randomized screening trial (the ARTISTIC trial) was conducted in the United Kingdom. That trial effectively demonstrated that HPV testing was a more effective way of cervical cancer screening than cervical cytology, and the investigators proposed that a substantial decrease in high-grade cervical cytology can be expected as a consequence of the institution of a primary HPV vaccination program.<sup>124</sup> The merits of adopting an HPV vaccination program is multifold, in that it can help prevent the progression of high-risk preneoplastic lesions with the appropriate implementation of primary screening within high-risk young male and female patient subsets.<sup>125</sup> The appreciation of the impact of HPV vaccination in its downstream prevention of HPV-related malignancies has fostered some very novel drug-delivery systems, like plasmid and nanoparticle novel gene systems, which are anticipated to significantly improve the effectiveness and adoption of HPV therapeutic vaccines in the years to come.<sup>126,127</sup>

A recent systematic review evaluated which factors most accurately could predict the adoption of an HPV vaccination program.<sup>128</sup> Of the 28 studies reviewed, vaccination adoption was highest when 3 criteria were met: 1) patients believed the vaccine was effective, 2) treating physicians recommended it, and 3) HPV infection was likely. Hindrances to compliance with HPV vaccination included cost and concerns of some parents that this would promote adolescent sexual behavior. Clearly, these are all important topics that must be touched upon by parents and providers when discussing the merits of including young adolescent males and females in an HPV vaccination program.

In summary, great strides have been made in our appreciation of the positive impact that HPV vaccination can play in minimizing such infections and downstream infection-related cancers. This is a great area of promise that all health care providers must not only actively discuss with patients but similarly should promote ongoing research initiatives while breaking down current barriers to its more widespread adoption.

The therapeutic applicability of HPV status to the diagnosis and management of penile cancer is multifold. A study by Fujita et al suggests that HPV-positive and HPV-negative tumors in fact may exhibit unique radiographic features on contrast-enhanced computed tomography imaging that can be exploited in our approach to such tumors.<sup>129</sup> Although most

of our efforts pertaining to devising treatment approaches based on HPV-seropositivity status have been developing novel systemic therapies, several studies have emphasized that local therapies should take HPV status into consideration in ongoing treatment refinements. In a recent review, Mirghani et al highlight their findings that HPV-positive head and neck SCC is in fact more radiosensitive than non-HPV-related lesions.<sup>130</sup> In addition, a recent phase 2/3 trial highlighted that the combination of surgery and adjuvant radiotherapy could be tailored based on the HPV status of tumors.<sup>131</sup> Clearly, there is still much to learn about how our locoregional therapies can be tailored based on HPV status. This has far-reaching implications not only for improving the efficacy of our treatment approaches but also for decreasing the morbidity of therapy.

Our fundamental understanding about how the HPV status of a given SCC tumor can impact the local immune milieu has truly been instrumental.<sup>132</sup> It has been appreciated for the past decade or so that patients with HPV-positive head and neck tumors have a better clinical outcome than those with HPV-negative tumors, and similar subsequent conclusions have been made in penile SCC.<sup>100</sup> For some time, this clinical observation has been poorly understood, and no translational research studies or observations have corroborated these clinical findings. However, recently, it has been demonstrated that HPV-positive tumors have significantly higher numbers of infiltrating interferon/CD8-positive T lymphocytes, interleukin-17/CD8-positive T lymphocytes, myeloid dendritic cells, and proinflammatory chemokines.<sup>133</sup> In addition, HPV-positive tumors exhibited significantly lower Cox-2 messenger RNA (mRNA) and higher PD-1 mRNA levels compared with HPV-negative tumors. These very meaningful findings may significantly help decipher the improved prognosis attributed to HPV-positive SCC tumors. A recent study by Stevanovic et al provided some proof of concept by treating patients with metastatic cervical cancer who had previously received platinum-based chemotherapy or chemoradiotherapy in a prospective clinical trial.<sup>134</sup> Patients were treated with a single infusion of tumor-infiltrating T cells (TILs), which were selected preferably for HPV E6 and E7 reactivity. This cell infusion had been preceded by lymphocyte-depleting chemotherapy and was followed by aldesleukin. Three treatment responses (33%) were observed, 2 of which were complete responses at 15 and 22 months posttherapy. The HPV reactivity of T cells was strongly correlated with clinical response, providing a glimpse of the great promise of such directed therapy based on HPV status in SCC tumors. A prior study by Badoual et al similarly demonstrated that PD-1-expressing TILs are a favorable prognostic biomarker in patients with HPV-seropositive head and neck tumors.<sup>135</sup> In that study, using a mouse model, administration of an HPV vaccine

increased PD-1 expression on T cells with subsequent tumor regression. In this regard, the potential imparted to PD-1 blockade synergized with HPV vaccination in displaying antitumor activity was shown and clearly offers similar great promise in our future therapeutic approach to penile cancer. Recent translational studies similarly suggest that the PD-1 and PD-L1 pathways maybe instrumental in explaining the immune resistance of HPV related tumors, hence targeting them constitutes a new therapeutic approach to chemo-refractory tumors which have until now constituted a treatment conundrum.<sup>136,137</sup> This paradigm shift in all likelihood may result in such patients (who, until now, typically were offered palliative/supportive treatment) now embarking on a new treatment paradigm specifically targeting the PD-1/PD-ligand 1 axis either as monomodal or multimodal therapy. In this regard, the combination of dual-blockade PD-1 and CTLA-4 (cytotoxic T-lymphocyte-associated protein 4) has been proposed and maybe one of the many avenues we use in a multifold mechanistic approach to improve therapeutic outcomes for our patients with advanced HPV-seropositive tumors.<sup>138</sup>

## Conclusion

Over the past decade, we have made some instrumental advances in our understanding of the molecular pathways implicated in penile carcinogenesis. In this regard, HPV infection is responsible for a majority of penile cancer cases seen worldwide. Although one may consider this malignancy of inconsequential importance compared with more common cancers, one must consider: 1) the significantly higher incidence and mortality rates in certain areas of South America and Africa; 2) the debilitating and adverse prognosis attributable to advanced disease, often requiring mutilating surgery for locoregional control; 3) the heterogeneous and often inconsistent patterns of diagnosis and care at most centers because of the paucity of cases; and 4) the lack of effective systemic agents for patients with metastatic disease. The creation and implementation of

evidence-based treatment guidelines for penile cancer both in North America and Europe (NCCN and EAU, respectively) have been instrumental in standardizing the diagnostic and therapeutic approach to this malignancy. In addition, an appreciation that penile-sparing treatment can be adapted to primary tumors of appropriate stage and grade and that multimodal approaches of systemic chemotherapy followed by consolidative surgery in favorable responders can be used in patients with bulky inguinal metastases (cN2/N3) are just 2 examples of how advances have been made in our evolving treatment paradigm. The greatest area of promise as it pertains to penile cancer results from the fundamental role played by HPV in the majority of penile tumors. This can be exploited to develop vaccination programs in high-risk male populations to decrease the incidence of penile cancer and similarly tailoring our local and systemic therapies based on the molecular pathways and immune-modulating environment disrupted by individual tumors. The future of penile cancer diagnosis and management without question will further refine HPV-targeted approaches in part using novel drug-delivery systems, such as nanoparticle HPV vaccination and emerging systemic therapies with HPV-directed TILs and PD-1/PD-L1 inhibitors, either as monotherapies or in combination with other novel agents. We have finally reached the era of personalized therapy in penile cancer and are exploiting HPV status to refine our treatment armamentarium. ■

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