Role of HPV in Head and Neck Cancer

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ABSTRACT: The evidence is that infection with high-risk human papillomavirus (HRHPV), particularly HPV 16, is the cause of the increase in incidence over the past 2–3 decades, in economically developed countries, of oropharyngeal squamous cell carcinoma (OPSCC), a subset of head and neck squamous cell carcinomas (HNSCC). HRHPV DNA sequences are detected in HNSCC with tonsil and base of tongue, the sites with the highest prevalence of HPV+ve carcinomas. HRHPV E6/E7 mRNA oncogene expression and p16^{INK4A} overexpression (a marker of HRHPVE7 overexpression) are detected in 50–80% of OPSCC depending on geographical locale. Evidence from in vitro studies with oral keratinocyte cell lines and E6/E7 transgenic mice shows that E6/E7 oncogene expression is required for initiation and maintenance of the malignant phenotype. Case–control and cohort studies show that risk for OPSCC is associated with HPV exposure prior to cancer diagnosis. The experimental and epidemiological data provide robust evidence for a causal role in OPSCC, but the evidence for association of HPV with other HNSCC such as oral cavity or larynx is weak.

KEYWORDS: head and neck cancer, oropharngeal squamous cell cancer, HPV, causality, epidemiology molecular markers

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Introduction

Human papillomaviruses (HPVs) are a large family of small, double-stranded DNA viruses that infect the squamous epithelia of the skin and internal mucosal surfaces of the anogenital and upper respiratory tracts. HPVs are classified as genotypes as determined by the sequence of the gene encoding the major capsid protein L1 and numbered in the order in which they were isolated: HPV 1, HPV 2, etc. About 30–40 HPV types regularly or sporadically infect the squamous mucosal surfaces of the anogenital tract and these mucosatropic types can be classified into two groups:

1. Low-risk viruses that cause genital warts or Condyloma acuminata, the most prevalent types are HPV 6 and 11.
2. High-risk or oncogenic viruses associated with malignant disease. Thirteen of these types are recognized as oncogenic.

Infection with an oncogenic HPV type is the cause of cervical cancer in women.[1] Globally, HPV 16 is the most commonly detected type (55% of cases) followed by HPV 18 (15% of cases). Other oncogenic types, 31, 33, 35, 45, 52, and 58, comprise a further 18% of cases. In addition, squamous cell cancers of the anus, vulva, vagina, penis, and head and neck have an HPV attributable fraction.[2] HPV 16 is the most prevalently detected type in these other sites. Defining the contribution of HPV to the etiology of head and neck cancer is complicated by the fact that in comparison to the cervix and anogenital sites, at which HPV has been shown to play a role,[2] the head and neck is anatomically and histologically complex including the oral cavity, oropharynx, hypopharynx, nasopharynx, nasal sinuses, larynx, and trachea (Fig. 1). At all these sites, squamous cell carcinomas (SCCs) amount to more than 90% of malignancies and there is a strong and synergistic association with tobacco smoking and alcohol abuse in their development.[3,4]

However, recent trends in incidence differ for these sites. In England, over the period 1990–2006, the incidence of SCC of the oral cavity, the naso pharynx, hypopharynx, and larynx either increased slightly or stabilized, possibly as a consequence of the decline in the smoking habit.[5] In contrast,
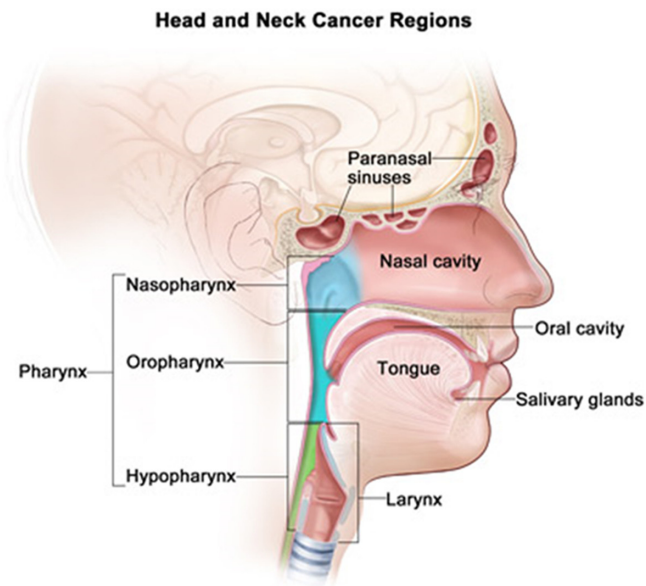
Head and Neck Cancer Regions

Figure 1. Cancers of the head and neck are classified according to the area of the head or neck from which they arise. The majority begins in the squamous cells that line the moist, mucosal surfaces inside the head and neck, and these are referred to as HNSCC.

the incidence of oropharyngeal squamous cell carcinoma (OPSCC) more than doubled over this period. OPSCC shows a greater increase in incidence than any other head and neck cancer over the previous decade in England and this situation is mirrored in most developed countries.[6] The evidence that is accruing, strongly implicates infection with HPV as the primary causative factor in a subset of oropharyngeal carcinomas[6,7] with perhaps a minor attributable fraction at other sites in the head and neck.[8]

HPV Infection and HNSCC—Causality or Coincidence

Establishing causality for an infectious agent in cancer is not straightforward. Cancer is a chronic disease, a multistage phenomenon with usually an interval of decades between exposure to the infectious agent and the eventual emergence of clinical disease. However, molecular and experimental evidence[9] and epidemiological criteria as articulated by Hill[10] (strength, consistency, specificity, temporality, biological plausibility, and coherence) can, in combination, provide robust evidence for an etiological association.

Molecular and Experimental Studies

HPV DNA is detected in a subset of HNSCC. HPV cannot be grown efficiently in in-vitro culture and HPV infection is determined usually by detection of HPV DNA in swabs or scrapes or biopsies using sensitive molecular hybridization methods.[11] Amplification of target DNA sequences by polymerase chain reaction (PCR) followed by hybridization with type-specific probes is the most widely

used method.[12] Using such methods, HPV DNA has been detected in HNSCC arising at several sites in the head and neck (reviewed in Ref.[13]). These studies show that prevalence is higher in OPSCC (35%) compared with SCC of the oral cavity (25%) or larynx (24%). Levels of HPV DNA prevalence in OPSCC as detected by PCR have varied considerably with levels up to 90% in some studies,[14] although they are on average 50–60%.[15,16] Among HPV+ve OPSCC, HPV 16 is the most prevalent accounting for 90% or more of cases.[17] The extreme sensitivity of PCR-based DNA detection methods that are capable of detecting less than one genome copy per cell raises the question of the relevance of detecting such low viral loads—when very low genome copies are detected is HPV really causal? The virus could be a passenger or a contaminant and have nothing to do with the oncogenic process. However, in studies in which PCR has been combined with in situ hybridization, a less-sensitive but cell-specific methodology, HPV DNA is present as diffuse staining both in malignant cells throughout the lesion[18,19] and also in intraepithelial lesions adjacent to the invasive cancer[19] arguing against contamination in these cases. Furthermore, as in cervical cancer, HPV genomes are integrated into the host genome, in many tonsillar cancer cases,[19–21] implying clonality.

High-risk HPV oncogene expression and initiation and maintenance of the malignant phenotype. The detection of viral DNA in the malignant cells however is not unequivocal proof of causality. The question is whether there is viral gene expression and whether that viral gene expression is necessary for the initiation and maintenance of the tumor phenotype. The E6/E7 genes of the high-risk HPVs (HRHPVs) are potent oncogenes. E6 binds to TP53 targeting it for ubiquination, E7 binds to unphosphorylated pRB thereby disabling the G1/S cell cycle checkpoint, and the combined action of E6/E7 leads to loss of cell cycle control, inhibition of apoptosis, and chromosomal instability. The deregulation and consistent expression of HRHPV E6/E7 is required for the initiation and maintenance of the malignant phenotype in cervical carcinogenesis.[22] There is evidence that this applies also to HPV+ve HNSCC. In vitro studies have shown that oropharyngeal and tonsillar keratinocytes are immortalized by full-length HPV 16 DNA and/or E6/E7 and that the E6/E7 genes are expressed.[23–25] Knockdown experiments show that inhibition of E6/E7 in HPV+ve oropharyngeal cancer cells results in apoptosis and restoration of the P53 and RB pathways that are the target for E6 and E7.[26,27] Mice transgenic for HPV 16 E6/E7 under the control of tissue-specific promoters exhibit abnormal epithelial proliferations in the oral cavity and oropharynx that progress, after exposure to low doses of the chemical carcinogen 4NQO, to HNSCC.[28] These tumors are HPV 16 DNA+ve, show HPV 16 E6/E7 expression and overexpression of P16^{INK4A} triggered by the deregulation of E7 expression, and induction of the histone demethylase KDM6B.[29]

Expression of HPV E6/E7 mRNA, the gold standard for HPV infection, is less common in HNSCC than PCR-based DNA detection[30,31] with about 14–50%[32–34] of HPV DNA+ve tumors negative for HPV E6/E7 expression. HPV E6/E7+ve tumors show other markers associated with HPV viral gene expression and HPV-mediated carcinogenesis. Thus, HNSCC displaying E6/E7 expression is positive for $P16^{INK4A}$ immunostaining[35] and there is a strong correlation between $P16^{INK4A}$ overexpression and HPV status in OPSCC, although it is not absolute. E6/E7+ve HNSCC show chromosomal abnormalities in common with cervical carcinogenesis[36] with imbalances at 3p, 9p and 7p.[30,37] In contrast to E6/E7 mRNA–ve HNSCC, E6/E7+ve tumors have wtTP53.[18,37–39] Furthermore, E6/E7+ve tumors are characterized by distinct microarray gene expression profiles,[40–42] fewer somatic mutations,[43] and distinct small microRNA patterns.[44]

Epidemiology

Case–control and cohort studies have evaluated the association between the risk for HNSCC and several measures of HPV infection or exposure including serology, sexual behavior, and the detection of HPV DNA in oral cells.

HPV 16 L1 seropositivity and risk for HNSCC. Seroconversion following HPV infection in the anogenital tract is not always observed with an average of 40–70% women[45] and 4–36% men[46] developing antibody to the major capsid protein L1. However, these antibodies persist over many years and large seroepidemiological studies suggest that the L1 seropositivity is a surrogate for the lifetime cumulative exposure to HPV infection.[47] HPV 16 is the most frequently detected HPV genotype in HNSCC tumors and most studies have evaluated HPV 16 seroreactivity and HNSCC risk either overall and/or for SCCs at one or more anatomical subsites.[15,48–56] Odds Ratio's (OR's) for HNSCC and HPV 16 L1 seropositivity vary from 1.7 to 7.5 but almost without exception when different cancer subsites in the head and neck and HPV L1 serology are evaluated, much stronger associations with OPSCC, particularly tonsillar and base of tongue cancer, are reported than that for oral or laryngeal cancers (for review see Ref.[57]). In a nested case–control studies in the Nordic countries,[58] serum samples were prospectively collected from 292 individuals who subsequently developed HNSCC and from 1568 age- and sex-matched controls. For HNSCC, overall, HPV 16 seropositive subjects had an OR > 2, for OPSCC > 14, for tongue cancer > 3, for laryngeal cancer > 2. This study was adjusted for tobacco use by measuring serum cotinine levels. Crucially, since increased risk occurred up to 15 years before cancer diagnosis, it can be inferred that HPV infection preceded cancer development.

HPV 16 E6/E7 serology and risk for HNSCC. Serum antibodies to the early proteins E6 and E7 of the HRHPVs are rarely detected in subjects with cervical intraepithelial neoplasia of any grade but can be detected in a proportion of subjects with invasive cervical cancer.[59] Recent studies suggest that HPV 16 E6 seropositivity in particular is associated with a subset of HNSCC, particularly OPSCC and that this seroreactivity precedes the diagnosis.[60] HPV 16 antibodies are present in a significant proportion of patients, 35%, with OPSCC many years before disease but are rare in controls 0.6%. These data are comparable with those from other large studies.[56,61] The most recent of these involved 1425 controls, 0.8% of which were E6 seropositive, and 324 patients, 30% of whom were E6 seropositive.[61]

HPV DNA in exfoliated oral epithelial cells. Most studies have found an association between the detection of HRHPV DNA in exfoliated oral epithelial cells and HNSCC risk.[62] Associations are much higher for OPSCC than oral cavity and other sites.[55,63] There are methodological and classification issues for these studies. A variety of sampling techniques have been used to collect cells; oral rinses, swabbing, or scraping the oral cavity and oropharynx with cotton tip buds or toothbrushes potentially resulting in variability in the samples. The DNA detection methods also vary in sensitivity and specificity, and misclassification of cancers according to subsite cannot be excluded. Overall case–control studies show a consistent association between HPV infection (as determined by DNA detection) and OPSCC but the association with other subsites remains to be defined.[62]

Sexual behavior associations. The strongest environmental associations for HNSCC are tobacco use, high alcohol intake, and poor dentition.[64] High-risk mucosatrophic HPV infection is sexually transmitted in the genital tract[1] and the consensus view is that this is true also for oral HPV infection. Measures of sexual behavior should therefore be a surrogate for oral HPV infection, and a number of case–control studies have evaluated sexual behaviors as a risk for HNSCC (for review see Ref.[57]). The sexual behaviors most consistently associated are increasing number of lifetime sex partners and number of oral sex partners.[65] The cancer risk sites in the head and neck most strongly associated with sexual behavior are in the oropharynx specifically tonsil and base of tongue and these are the sites with the highest prevalence of HPV DNA detected in the tumors and evidence of HPV gene expression.[65]

Trends in the Incidence of HNSCC

The evidence from both molecular experimental and epidemiological studies strongly supports a causal association between OPSCC, mainly tonsil and base of tongue, and HRHPV[7,18] particularly HPV 16, but the role of HPV in other HNSCC sites such as the oral cavity cancer (OCC) is not proven.[66] Cancers of the oral cavity and of the oropharynx are the sixth commonest cancers worldwide with an estimated 400,000 cases per annum and 230,000 deaths.[67] Heavy tobacco and alcohol use and poor dentition are strong risk factors for both OCC and OPSCC.[68] The incidence of OCC has declined or stabilized in many parts of the world in the recent past and this coincides with the decline in tobacco

use in those localities.[64] In contrast, OPSCC incidence has increased in several countries predominantly in developed countries[69–71] such as Northern Europe, Australia, and the USA. In those countries for which molecular data are available, that is Australia,[70] Sweden,[72] and the USA,[73] these increases correlate strongly with increase in the proportion of HPV+ve OPSCC over the period from 1980 onward. The rise is greater, two- to threefold, in men than women and in contrast to HPV–ve cancers, HPV+ve OPSCC occur in younger age groups <60 years and are not associated strongly with tobacco or alcohol use.[54] A comprehensive analysis of worldwide trends in incidence of OPSCC and OCC has been published recently.[6] To attempt to discriminate between tobacco use and HPV in causality, trends in SCC of the lung were evaluated in addition to oral cavity and oropharynx. These studies show that in developed countries such as the UK and the USA, HPV infection contributed to the dramatic rise in OPSCC over the period 1983–2002, particularly in men. However, the incidence of lung SCC in men declined over this time, supporting a role for factors other than smoking in OPSCC, such as HPV. There is evidence that sexual behaviors have changed among the recent birth cohorts in developed countries consistent with the younger age of patients with HPV+ve OPSCC.[70,73] Furthermore, HPV prevalence in OPSCC differs between developed and developing countries. Thus, at present, 60–70% of OPSCC are associated with HPV infection in the USA,[73] 50–60% in the UK,[16] but less than 10% in poorer countries.[15]

HPV Vaccines and HNSCC

The evidence for a causal role for HPV in OPSCC is strong, meeting the most important criteria enunciated by Bradford Hill,[10] strength, consistence, and specificity but the most unequivocal evidence would be if prevention of HPV infection by vaccination prevented HPV+ve OPSCC. There are two licensed prophylactic HPV vaccines. These are Cervarix®, a bivalent HPV (bHPV) 16/18 product from GlaxoSmithKline Biologicals Rixensart, Belgium, and Gardasil® (also known as Silgard), a quadrivalent HPV (qHPV) 6, 11, 16, 18 product from MSD (Whitehouse Station, NJ, USA). These products are subunit protein vaccines comprising the HPV L1 coat protein assembled into virus-like particles. In randomized clinical trials (RCTs), both have shown efficacy >90% against vaccine HPV-type infection and benign and premalignant disease in the cervix, vagina, vulva, anus, and penis.[74] Since these systemically administered vaccines have reduced disease and infection at all the anogenital mucosal sites so far evaluated, it is likely that they will equally be effective against HPV-associated HNSCC. This speculation is supported by preliminary evidence from a population-based trial using the bHPV vaccine in Guancaste Province Costa Rica in which prevalence of HPV 16 and 18 infection was reduced by 93% 4 years after vaccination.[75]

Clinical Significance of HPV in HNSCC

OPSCC has two distinct etiologies, HPV infection or alcohol and tobacco use. Until recently, the significance of making this distinction with respect to the individual patient was not appreciated, but it is becoming evident that this is of clinical importance. HPV+ve OPSCC are associated with better response to chemotherapy, chemoradiotherapy, and radiotherapy than HPV–ve OPSCC and overall have a better prognosis.[17,76–78] Furthermore, better outcomes have been reported for HPV+ve OPSCC after surgery, suggesting that the improved responses are independent of the treatment received.[79,80]

Tissue Tropism, HPV, and HNSCC

The concensus view is that HPV is an established cause of OPSCC, predominantly of the tonsil and base of tongue, but that if it has a causal role at other anatomical sites in the head and neck, it is a minor one. Interestingly, the epithelia covering Waldeyers ring, the annular arrangement of lymphoid tissue in the pharynx do appear to be a target for viral carcinogenesis, with Epstein–Barr virus strongly associated with nasopharyngeal carcinoma and HPV with OPSCC (Fig. 2). Why should HPV target the squamous epithelia overlying the lingual and palatine tonsil but spare that of the oral cavity or the larynx? The other sites at which HPV is the most important etiological factor are the cervix (100% attributable cases) and the anus (>80% attributable cases).[2] Histologically, the cervix, anus, and lingual and palatine tonsil all display a squamocolumnar or squamomucosal junction, an abrupt switch from stratified squamous epithelial layer to a single layer of columnar epithelial cells. The cell and molecular biology of these junctional sites are poorly understood, but recent
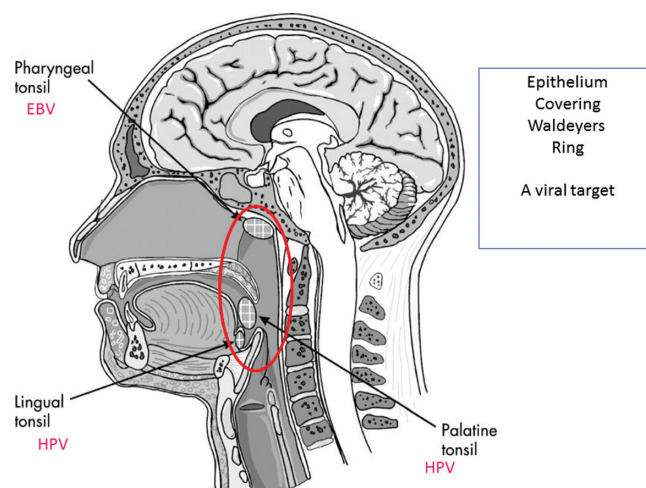

Figure 2. Waldeyers ring of lymphoid tissue circumscribes the naso and oropharynx with some of the tonsillar tissue located above and below the soft palate and to the back of the oral cavity. The epithelia overlying these sites appear to be susceptible to viral-mediated carcinogenesis with the oropharyngeal mucosa associated with HPV+ve cancers and the nasopharyngeal carcinoma associated with Epstein–Barr virus.

data from the cervix are relevant. Gene expression studies have revealed the presence at the cervical squamocolumnar junction of a subset of primitive embryonic cells defined by specific molecular markers.[81] This expression profile is consistently shown in the high-grade cervical precancers (cervical intraepithelial neoplasia grade 3) and invasive cervical cancers strongly suggesting that this primitive cell subset is the target for HPV-mediated cervical carcinogenesis. Primitive cell subsets have been detected in the anus[81] and at the esophageal gastric junction, and a major research question is whether a comparable subset of primitive cells exists in the tonsillar crypts, are the targets for HPV have an increased risk for the deregulation of HPV viral gene expression that drives the neoplastic process.[82] These are important questions since it is likely that the deregulation of E6/E7 gene expression with the subsequent disruption of the cell cycle, inhibition of apoptosis, and chromosomal instability are generic mechanisms for HPV-mediated carcinogenesis at all sites but that the cofactors that contribute to that process differ at each site and may represent different targets for intervention.

Author Contributions

Conceived the concept: MS. Wrote the first draft of the manuscript: MS. Made critical revisions: MS. The author reviewed and approved of the final manuscript.

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