Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/20706
DOI URL: http://dx.doi.org/10.21474/IJAR01/20706

RESEARCH ARTICLE

A REVIEW ON HUMAN PAPILLOMAVIRUS: EPIDEMIOLOGY, PATHOGENESIS, ADVANCES IN PREVENTION AND TREATMENT

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Manuscript Info

Manuscript History
Received: 07 February 2025
Final Accepted: 10 March 2025
Published: April 2025

Key words:-
Human Papillomavirus (HPV), Low-Risk and High-Risk Types, HPV Infection, Therapeutic Intervention

Abstract

Human papillomavirus (HPV), among the most common viruses, can be classified into more than 200 genotypes as low-risk and high-risk types according to oncogenicity. HPV-6 and HPV-11, for instance, are low-risk types that lead to benign lesion manifestations like genital warts; while types like HPV-16 and HPV-18 are highly associated with many cancers in females, particularly the cervix, oropharynx, as well as other anogenital regions. Direct skin contact including sexual transmission and, in most cases, vertical from mother to child is the way that HPV is transmitted. Persistent HPV infection is a major cause of cervical cancer, so prevention through vaccination and early detection is important. Advancements in HPV research implemented in the development of different diagnostic procedures; including Polymerase Chain Reaction (PCR), Hybrid Capture II, and p16 immunohistochemistry which further enhance early detection. Preventive vaccines, like Gardasil and Cervarix, have shown a marked efficacy in preventing infections by HPV and related neoplasia, but with little therapeutic intervention on that emerging horizon such as immunotherapy, therapeutic vaccines, or CRISPR-Cas genome editing. With today's advancements, inequalities and hindrances have existed in the future resolution of HPV disease prevalence and inequality in HPV vaccine availability. Countries in the high-income range have put up strong HPV vaccination and screening programs and have markedly reduced the disease burden brought by HPV. Barriers include cost, awareness, and cultural hesitance among other factors that must contend with low-resource settings. Holistic public health initiatives would include improved and even increased vaccine coverage and comprehensive delivery of state-of-the-art diagnostic and therapeutic measures.

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Introduction:-

Human Papillomavirus (HPV) has over 40 types that are capable of infecting the anogenital and oral mucosa, which is the most diverse group of more than 200 related viruses. Based on their potential to cause diseases it is classified into 2 main types low-risk & high-risk [1]. HPV-6 & HPV-11 which are low-risk types lead to benign conditions like genital warts and recurrent respiratory papillomatosis, whereas HPV-16 & HPV-18 which are high-risk types are strongly associated with cervical, oropharyngeal and anal cancers. The primary transmission of HPV is through direct skin-to-skin contact during sexual activity, including oral, vaginal, and anal sex [2]. There are also such cases of nonsexual transmission from mother to child during childbirth which has been reported. HPV infections are asymptomatic and clear on their own in most cases, but persistent infections with high-risk types can lead to precancerous lesions and malignancies [3].

HPV related diseases make prevention and early detection essential, which pose a significant public health burden. Vaccination is the most preventive measure against HPV and current vaccines majorly focus on high-risk types [4]. To reduce the risk of cancer development regular cervical cancer screenings such as Pap tests and HPV DNA test help to detect early cellular changes. The inactivation of tumor suppressor proteins and promotion of abnormal cell growth is due to the virus's potential to elude immune responses, basically due to E6 and E7 oncogenes [5]. To eradicate the existent infections, the research is mainly focused on the development of therapeutic vaccines and also the development of second-generation vaccines which provide a broader spectrum. Public awareness, expanding global access to vaccines and improving screening programs remain critical in reducing the burden of HPV associated diseases [6].

Due to its strong association with cervical cancer and other malignancies, Human Papillomavirus (HPV) is a major global health concern. As HPV is also associated with oropharyngeal and anogenital cancer which makes it a critical target for prevention and treatment strategies [7].

Structure of Human Papillomavirus (HPV)

Human Papillomavirus (HPV) belongs to the Papillomaviridae family, a small and non-enveloped virus. It is primarily made up of the major structural protein L1 with the minor protein L2 which is present in smaller amounts with a defined icosahedral capsid composed of 72 pentameric capsomers [8]. The capsid is 60 nm in diameter enclosing a circular double-stranded DNA genome which ranges from 7.1 to 8.0 kilobases. For host cell manipulation, capsid formation and viral replication the genome encodes early (E1-E7) and late (L1-L2) proteins which are essential[9]. Detailed insights into three-dimensional structure have been provided by cryoelectron microscopy that reveals the capsomers have a star-shaped morphology and include cylindrical channels of about 2.8 nm which may be involved in host interactions (Figure 1) [10].

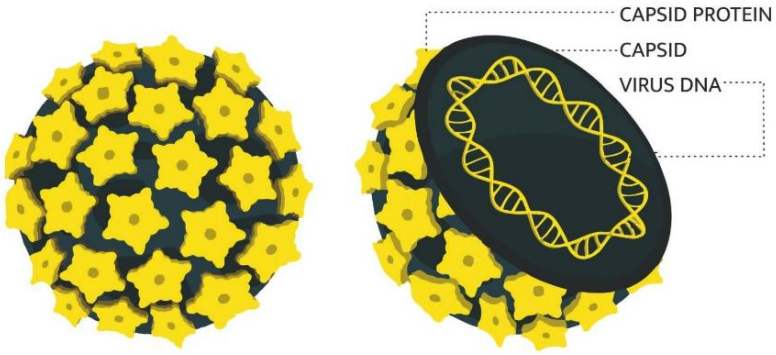

Figure 1:- Three-dimensional structure of Human Papillomavirus (HPV).

The viral DNA is implicated with histone protein inside the capsid forming a nucleohistone core that aids in genome packaging. The traditional structural studies such as X-ray crystallography have been limited due to challenges in propagating HPV in-vitro [11]. In vaccine development, advancements in virus like particles have facilitated the study of antigenic properties. It is essential to understand HPV's structural component to design effective therapeutic and preventive strategies against HPV-related diseases [12].

Classification and types of HPV

Based on their potential to cause cancer and other diseases Human Papillomavirus (HPV) is classified into high-risk (HR) and low-risk (LR) types (Table 1). The different diagnostic methods such as Hybrid Capture II (HCII) and Polymerase Chain Reaction (PCR) with genotyping assays are used to identify HR-HPV types that play an important role in cervical cancer progression. HR-HPV types such as 16,18,31,33,35,39,45,51,52,56,58,59,68 are strongly associated with cervical cancer [13].

Table 1:- Classification and types of HPVand its diagnostic relevance.

HPV Group	HPV Types	Diagnostic Relevance
Low Risk	6,11,42,44	Genital warts or benign lesions, not cervical cancer
High Risk	16,18,31,33,35,39,45,51,52,56,58,59,68	All types isolated in cervical cancer

However, LR HPV types such as HPV 6,11,42,44 are relevant to benign conditions such as genital warts and have a lower risk of leading to malignancies. Scientific studies confirm that LR-HPV are observed in low-grade cytological abnormalities and their occurrence decreases with increasing lesion severity[14]. To understand the combined impact on cervical pathology co-infections with HR and LR types have also been examined. For early detection and prevention in reducing HPV associated diseases, it is essential to classify HPV into HR and LR types for screening, diagnosis and vaccination strategies [15].

Global Prevalence and Distribution

Human Papillomavirus (HPV) infection among men is estimated at 31% approximately with high-risk HPV prevalence at 21% globally. Sub-Saharan Africa has the highest rates at 37%, followed by Europe and North America at 36% are the significant regional variations in HPV (Figure 2). The countries that have high incomes have a slightly higher prevalence of HPV compared to low-income regions. The occurrence of HPV is highest among young adults between the ages of 25 and 29 [16]. The studies also highlight the geographical disparities in HPV prevalence, with Sub-Saharan Africa exhibiting the highest occurrence of HPV and cervical cancer associated HPV types, especially HPV16. For both, high-risk as well as low-risk Europe shows the lowest rate. Asia is observed with variability in occurrence with different rates across countries. Additionally, research suggests that the burden of HPV is significant in older women, particularly in regions of Africa and Central/South America [17].

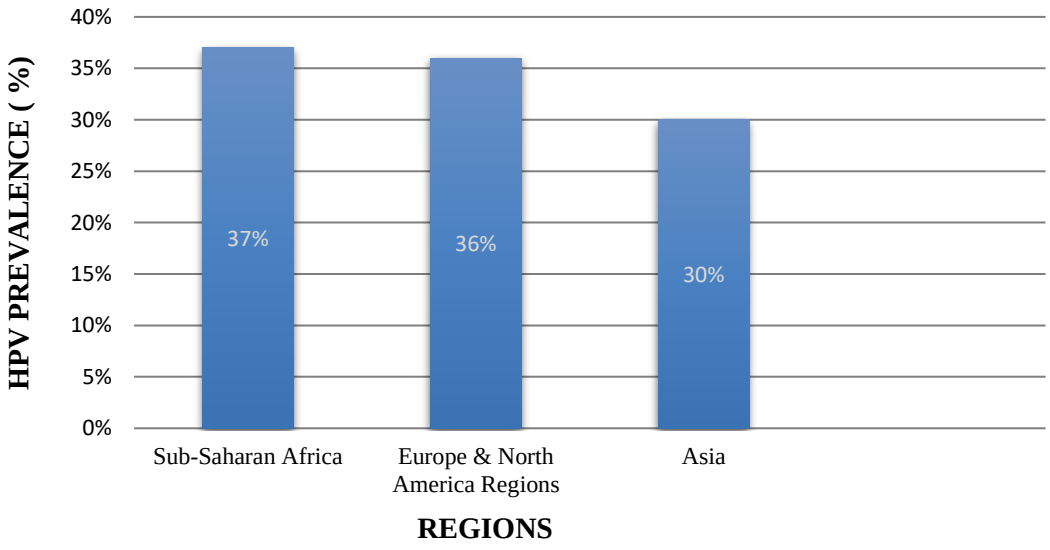

Figure 2:- Global prevalence and distribution of Human Papillomavirus (HPV).

Risk factors associated with infection

Human Papillomavirus infection is influenced by several demographic, behavioral and clinical factors, especially among women living with HIV. Studies indicate that women under 30 years old are at a higher risk, with 74.6% of women in this age group testing positive for HPV compared to 59.7% in older women. Race also plays an important role, with black women indicating the highest occurrence of HPV at 76.4% followed by First Nations/Asian Women at 66.7% and white women at 62.7% [18]. Different behavioural factors such as inconsistent condom use and multiple sexual partners further increase the risk of HPV infection. However, lower CD4 counts (below 0.20 × 10^9/L) and a history of sexually transmitted diseases (STDs) contribute to higher risk, likely due to compromised immune system.

Mechanism of HPV infection and replication

Binding to heparan sulfate, attached to the cell surface, initiates host cell entry by human papillomaviruses (HPVs), after which they undergo endocytosis through clathrin- or caveolae-mediated pathways. In this way, the virus can infect basal epithelial cells, within which the viral genome is established and maintained as an episome, with replication at low copy numbers [21]. As infected cells begin differentiation, the virus switches to a differentiated and productive replication phase, amplifying its genome in the upper epithelial layers. Importantly, some viral proteins such as E6 and E7 hijack normal cell cycle regulations for the inactivation of pRb and degradation of p53, thus allowing continuous cell proliferation and avoidance of apoptosis. Such modifications are necessary for viral replication and persistence [22].

When HPV replicas enter into host DNA with the replication, their genome usually gets integrated into that of the host due to the DNA-erasing damage suffered, leading to the loss of the E2 gene and overload expression of E6 and E7 oncoproteins. Thus, this mechanism leads to genomic instability and neoplastic lesion development that could advance to cervical cancer [23]. The virus also avoids immune detection since it ensures high levels of expression from its genes are only in the upper layers of epithelium, minimizing the effect of immune surveillance. At the final stages, new virions are produced inside differentiated cells and, as these cells slough off, they release the virions, making them available for transmission from such cell death to another host [24]. as these cells slough off, they release the virions, making them available for transmission from such cell death to another host [24].

Role of E6 and E7 proteins in carcinogenesis

In the carcinogenesis process, the E6 and E7 proteins of high-risk human papillomavirus play an important role, particularly in cervical cancer. This is a key event in the early stages of tumor formation and also leads to cellular proliferation. E6 targets the tumor suppressor protein p53 which causes its degradation through a complex with E6 associated protein [25].

A Hallmark of Cancer which is genomic instability is caused by the combined action of E6 and E7 proteins. The E6 protein not only degrades p53 but also activates telomerase which contributes to cellular immortalization. The E7 protein induces centrosome abnormalities and promotes cell cycle progression [26]. Both these proteins regulate apoptosis and enhance cellular proliferation which further develops tumors. E6 and E7 cooperation is essential for maintaining the transformed phenotype in tumor cells and there and during expression is necessary for tumor progression. For treating HP with induced cancer these oncoproteins are considered promising targets for therapeutic interventions with strategies like RNA interference [27].

Associated cancers

In developing countries where screening resources are limited cervical cancer which is primarily caused by HPV types 16 and 18 remains the second most common cause of cancer death among women globally. As compared to traditional cytology, HPV DNA testing is a more sensitive screening method. HPV vaccination and regular screening are the key strategies for prevention [28]. In the U.S. and Western Europe, oropharyngeal cancer (OPC) which is associated with HPV has been on a significant rise, now accounting for 70-80% of oropharyngeal cases. Traditional risk factor like tobacco use also causes oropharyngeal cancer. HPV-positive OPC has a better diagnosis as it is more responsive to treatment. While ongoing research aims to improve early detection and therapeutic strategies, HPV vaccination and targeted public health initiatives are crucial to prevent both HPV and oropharyngeal cancer [29].

Symptoms and diseases caused by HPV

Cancer and genital warts are the health issues which are caused by human papillomavirus. For the development of cervical cancer persistent infection with higher-risk HPV types is necessary, but other factors like smoking and long-

term contraceptive use can increase the risk of cervical cancer. HPV can cause cervical intraepithelial neoplasia (CIN), which is a precancerous lesion, which may progress to cancer if untreated. HPV is associated with cancers in the vagina, penis, vulva anus, and oropharynx (throat) [30].Low-risk types 6 and 11 cause genital warts which is another common manifestation of HPV. This wart requires treatment while they are benign and can be uncomfortable. The warts grow in the respiratory tract which causes breathing difficulties, a condition in HPV that is also linked to recurrent respiratory papillomatosis [31]. Many HPV infections do not show any symptoms and may resolve on their own but in some scenarios, the virus can lead to long-term health issues and therefore it is essential for screening and vaccinations for prevention. To reduce HPV-related risk HPV vaccines are effective in reducing the risk of HPV-related diseases such as cancer, genital warts, and respiratory issues which highlights the importance of vaccination programs in controlling the spread of the virus [32].

Variability in disease progression

Asymptomatic patients with aortic stenosis experience disease progression without any symptoms. It requires close monitoring as valve calcification increases, and the risk of symptom onset rises. On the other hand, symptomatic patients with more advanced stages and worse outcomes with increased jet velocity and higher calcification levels lead to a need for intervention like valve replacement [33].

Asymptomatic individuals show a tightly regulated immune response and avoid the inflammatory pathway that causes symptoms of influenza A whereas in symptomatic patients there is an increase in cytokines 36 hours before symptoms manifest and patients exhibit strong inflammatory response. For the development of symptoms, the inflammatory response plays a critical role [34]. Many individuals remain asymptomatic despite having tears, gradually as tear size increases it shows significant symptoms development in rotator cuff tears. The symptomatic rotator cuff disease rises with age, as age is also another critical factor. For appropriate management and timely intervention across all these conditions understanding these differences is essential [35].

Methods for HPV detection

Different molecular methods are used for this purpose with specific strengths. For amplifying HPV DNA to detectable levels several methods are widely used in which the most common method is Polymerase Chain Reaction. To detect multiple HPV genotypes PCR can be type specific or consensus primers can be used. PCR can be known for its high sensitivity and specificity which makes it suitable for detecting even low amounts of viral DNA [36]. To detect multiple HPV types simultaneously another widely used method is signal amplification in which techniques like reverse hybridization assays and HPV DNA microarrays are performed. For genotyping and identifying high-risk strains of HPV these methods are particularly used [37].

HPV-related proteins such as p16 are detected by other methods like Immunohistochemistry (IHC) whereas HPV DNA in tissue samples is identified by the In Situ hybridization (ISH) method. Additionally, several tests like HC2, Cervista, Aptima, and Cobas 4800 are frequently used in cervical cancer screening and are combined with cytology for enhanced diagnostic accuracy [38]. Due to their high sensitivity PCR and signal amplification assays are considered the standard for detecting HPV while other methods like ISH and ISC are particularly important for protein expression or tissue localization which are valuable in specific clinical settings. For early detection and prevention of HPV-related cancer, these methods continue to improve in terms of speed, cost-effectiveness, and reliability as there is advancement in technology [39].

Molecular techniques

For the detection and management of Human Papillomavirus molecular techniques play a crucial role. Polymerase chain reaction (PCR) and reverse transcription PCR (RT-PCR) are the primary methods that amplify HPV DNA or RNA to detect the virus with high sensitivity [40]. To enable type-specific detection hybridization techniques such as reverse hybridization and Southern blotting are used whereas to detect high-risk oncogenic HPV types Hybrid Capture 2, an FDA-approved test is used for nucleic acid hybridization with signal amplification. In situ hybridization (ISH) and branch DNA (bDNA) assays are direct probe methods that provide a histopathological context for HPV presence but may have lower specificity [41].

In head and neck squamous cell carcinomas (HNSCCs) advanced techniques like p16 immunohistochemistry (p16-IHC) serve as surrogate markers for HPV-related malignancies. For more reliable results, highly sensitive p-16 IHC lacks specificity and is combined with consensus PCR HPV-DNA and ISH [42]. Methylation-specific PCR and DNA microarrays are emerging technologies that are explored to analyze viral integration and genetic variation

which improve the accuracy of HPV detection. It enhances diagnostic precision enabling better patient management and treatment strategies by assimilation of these methods [43].

Cytological screening

In Human Papillomavirus, to detect cervical abnormalities at an early stage it is essential to undergo cytological screening, also known as Pap smear. In the development of cervical intraepithelial neoplasia (CIN) and cervical cancer, the major factors in development are high-risk types like HPV 16 and 18. To reduce cervical cancer cases Pap smear has been instrumental and it has limitations in sensitivity, missing up to 35% of high-grade CIN cases [44]. HPV DNA testing has been integrated into screening programs to enhance detection in conjunction with cytology or primary test. In women with borderline or mild dyskaryosis, the combination of Pap smear and HPV testing improves the identification of high-grade lesions which allows for better management and monitoring of at-risk individuals [45].

At age 21 or within 3 years of initiating sexual activity women must undergo Pap testing, continue with every 3 years until 65 or 70. For increasing sensitivity and extending screening intervals, women over 30 should co-test with HPV DNA. Organizations like the American Cancer Society and ASCCP advocate its use for improving cervical cancer prevention despite some controversy regarding HPV testing guidelines. To ensure better detection rates while minimizing unnecessary procedures for low-risk individuals ongoing research aims to refine screening strategies [46].

Advances in diagnostic tools

In low-resource settings, recent awards in HPV with Diagnostic have significantly improved sensitivity, specificity, and accessibility. The accuracy of HPV detection has been enhanced by traditional nucleic acid amplification techniques including polymerase chain reaction (PCR), reverse transcription-PCR (RT-PCR), and loop-mediated isothermal amplification (LAMP) [47]. To make it useful in urgent clinical settings the integration of isothermal amplification technology has reduced diagnostic time. By analyzing HPV-specific molecular changes emerging techniques such as Fourier transform Infrared Spectroscopy (FTIR), Raman spectroscopy, and mass spectrometry offer non-invasive high-precision detection [48].

By an application of ultrasensitive detection through nucleic acid hybridization and antibody-antigen interactions biosensing platforms incorporate nanotechnology and micro fluids that have transformed HPV diagnostics. In detecting HPV-associated oncogenes CRISPR-Cas Technology is also being explored for its specificity. By offering superior predictive value for cervical cancer risk, E6/E7 mRNA testing has merged as a reliable marker for active HPV infections [49]. While ensuring cost-effectiveness, rapid processing, and compliance with international regulatory standards, future research aims to refine these tools for broader clinical applications. For better management of HPV-related diseases worldwide these advancements collectively contribute to improving HPV screening early diagnosis [50].

Prognostic and Clinical Implications of HPV DNA Copy Number

HPV DNA copy number is a useful biomarker relating to prognosis, risk stratification, and patient management in HPV-associated cancers, especially cervical cancer and head and neck cancers. Quantifying DNA is important to identify high-risk individuals, as higher levels correlate with persistent infections and faster disease progression [51]. Outcome assessment through viral load will enable clinicians to stratify patients according to the risk of severe disease, thus activating timely interventions, such as increased monitoring or early treatment [52].

Furthermore, not only for prognostic purposes, the HPV copy number acts as a critical denominator in making treatment decisions and monitoring after treatment. On the one hand, lower viral loads might only justify the active surveillance of patients [53]. Those with higher viral loads will probably require more aggressive treatment strategies. In addition, the follow-up of HPV DNA levels after a treatment procedure has been proven useful for predicting recurrence and consequently enables better proactive management with timely adjustments of treatment plans. This personalized approach to patients dramatically improves outcomes as it connects early detection with effective clinical intervention for precision in cancer management [54].

Overview of available vaccines

For preventing HPV infections and related diseases including cervical cancer, HPV vaccines are essential. Gardasil and Cervarix are the two primary vaccines with different compositions, efficacy, and cross-protection. Additionally, offering border protection against genital warts, Gardasil is available in quadrivalent (HPV-6, 11, 16, 18) and nine-

valent (HPV-6, 11, 16, 18, 31, 33, 45, 52, 58) versions [55]. The two most oncogenic strains with strong cross-protection against HPV-31, 33, and 45 are Cervarix, a bivalent vaccine targeting HPV-16 and 18. In preventing HPV infections and pre-cancerous lesions, both vaccines have demonstrated high efficacy with Cervarix showing long-term immunogenicity for over 9 years [56].

For there, adjuvants and production methods, Gardasil and Cervarix differ with Gardasil uses yeast-derived L1 proteins and an aluminum salt adjuvant whereas Cervarix uses baculovirus-infected insect cells and the AS04 adjuvant to enhance immune response. With potential immunogenicity benefits for HIV-infected individuals, studies have shown that both vaccines induce cross-neutralizing antibodies [57]. Reinforcing their role in global cervical cancer prevention strategies, their incorporation into immunization programs has led to significant reductions in HPV prevalence and associated cancer. In low-resource settings, research is needed to improve vaccine coverage and accessibility [58].

Impact on HPV-related diseases

Health-related quality of life and psychosocial well-being are significantly impacted by HPV-related diseases which include cervical cancer, genital warts, and precancer lesions. Emotional distress, self-image concerns, and impaired sexual function are the conditions women experience who are diagnosed in younger adults with genital warts [59].

HPV infections are more persistent and severe in HIV-positive individuals which leads to a higher prevalence of squamous intraepithelial lesions, and invasive cervical and anal cancers. By triggering chronic inflammation and cytokine production (IL-6, TNF-**α**, IL-1**β**), HPV may accelerate HIV progression which creates a favorable environment for HIV replication [60]. Especially in women, HPV-related cervical lesions also contribute to higher HIV transmission risks. Comprehensive patient management and integrating HPV prevention, screening, and treatment strategies in HIV care programs are the complex HPV-HIV interplay that highlights the need [61].

Importance of regular screening in reducing HPV-associated cancers.

For preventing and reducing HPV-associated cancers, regular screening is a crucial strategy, especially for cervical cancer. Pap test and HPV DNA testing are the screening methods that help to detect precancerous lesions (CIN2+) which enables timely treatment before they progress into invasive cancer [62]. HPV vaccinations lower the risk of infection significantly but it does not cover all HPV types which makes screening an essential complementary method. Oropharyngeal and anal cancers are the non-cervical HPV-associated cancers that are on the rise but the screening programs for this remain limited. To ensure maximum protection against HPV-related malignancies integrating screening with vaccinations plays a major role [63].

For early detection of cervical cancer, there are benefits to regular screening. High-risk groups are targeted for monitoring, which ensures that high-grade lesions receive prompt treatment whereas the individuals with low-grade lesions are observed over time. High-grade cervical dysplasia has been reduced in countries with national vaccination programs that highlight the combined impact of vaccination and screening [64]. Cervical cancer incidence can be reduced by 90% by combining vaccination and screening which is an important Public Health measure as per the studies related to cost-effectiveness. To reduce the burden of HPV-related diseases worldwide, regular screening provides an opportunity for health education, increasing awareness about HPV, its risks, and preventive strategies [65].

Strategies to promote vaccine uptake and safe practices

Presenting the vaccines as a routine part of adolescent care plays a key role by providing strong endorsements and using a presumptive communication style. Parental safety concerns, Training healthcare providers to address vaccine hesitancy can further enhance acceptance. For the completion of the vaccination series and to ensure timely vaccine administration, reminder systems for both providers and patients are beneficial [66].

Public health strategies must equally work toward community mobilization and misinformation counteractions. Social media as well as advocacy networks have the power to change anti-vaccination narratives; yet, one strategy with solid evidence for increasing coverage rates is school-based vaccination programs [67].

Current therapeutic approaches

Due to the correlation of Human Papillomavirus with cervical cancer and other lesions, it is a major public health concern including oral and genital warts. For managing HPV infections current therapeutic approaches include

Cryotherapy, surgical excision, laser therapy, chemotherapy, radiation therapy, immunotherapy, therapeutic vaccines, and emerging genome-editing techniques [68]. Freezing abnormal tissue with liquid nitrogen is involved in cryotherapy where precancerous lesions are effectively destroyed minimally in an invasive manner. For larger or more severe lesions that allow histopathological examination, a surgical excision, including loop electrosurgical excision procedure (LEEP) and conization is used. With minimal thermal damage laser therapy provides precise removal of abnormal tissue where more research is needed to evaluate its effectiveness in HPV-related oral lesions [69].

For advanced cases of invasive cervical cancer, chemotherapy, and radiation therapy are standard treatments. To stimulate immune clearance of infected cells, therapeutic vaccines target viral oncogenes E6 and E7 and undergo clinical investigation. By preventing tumor progression, genome editing tools show promise in targeting and disrupting the HPV genome. To improve treatment outcomes, the combination of these therapies enhances the patient's condition [70].

Advances in antiviral and immunotherapeutic research

To contribute to cervical, anogenital, and oropharyngeal cancer Human papillomavirus remains a major Public Health Challenge. Both prevention and treatment of antiviral and immunotherapeutic research have led to promising strategies in the recent advancement. Gardasil and Cervarix are the Prophylactic vaccines, that have successfully reduced HPV infection rates by targeting the L1 capsid protein [71]. For HPV-related tumor survival, therapeutic vaccines are being developed to eliminate existing infections by stimulating cytotoxic T lymphocytes that respond against the E6 and E7 oncoproteins. To enhance vaccine efficacy and stability nanoparticle-based vaccines and genetic engineering approaches are also being explored in the current research studies [72].

In enhancing immune responses against HPV-related malignancies immunotherapy is gaining traction with checkpoint inhibitors like Pembrolizumab and Nivolumab. Some other approaches like oncolytic viruses selectively destroy HPV-infected cells and cytokine-based therapies that improve immune system activation [73]. Plant-derived compounds and topical microbicides such as carrageenan are being explored as preventive measures. By directly targeting HPV DNA with infected cells the integration of genome editing tools like CRISPR/Cas9 offers future potential. In improving HPV treatment and prevention this research progresses toward an approach that ultimately reduces the Global burden of HPV-associated diseases [74].

Conclusion:-

It is a significant concern for public health, due to the associations of Human Papillomavirus with cancers of the cervix, oropharynx, and anogenital sites. While most HPV infections resolve spontaneously, persistent infections by high-risk types may lead to malignancies. Vaccination programs have been very successful in decreasing both HPV prevalence and disease, yet global disparities in their access live on. Regular cervical cancer screenings such as Pap tests and HPV DNA testing are important for early detection and prevention. New diagnostic methods are also improved by the use of molecular techniques and biomarker-based screening for the rich detection of HPV. Advances in therapy such as immunotherapy and genome editing will be beneficial in treating HPV-associated cancers. Reducing the global burden of HPV will involve removing barriers to the uptake of vaccination, increasing public awareness, and improving access to health care. Long-term reduction of disease and improved patient outcomes will be achieved by an emphasis on understanding novel prevention strategies, developing new treatments, and comprising HPV control within national health programs through continued research and public health efforts.

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