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Prevalence, genotyping and phylogenetic analysis of HPV infecting Palestinian women

Ibrahim Salhi[1], Zaidoun Salah[2*] and Mohammad Qadi[3*]

Abstract

Background Human Papillomavirus (HPV) is a significant global public health concern due to its association with cervical, other anogenital, and oropharyngeal cancers. This study aimed to evaluate the prevalence and the phylogenetic relationships of HPV among Palestinian in order to inform public health strategies.

Methods A cross-sectional study was conducted between September 2023 and April 2024 involving 379 Palestinian women over the age of 18 from 11 governorates in the West Bank. Cervical swabs were collected and analyzed using nested PCR and Sanger sequencing methods to detect and genotype HPV. The study also included phylogenetic analysis to understand the genetic relationships between HPV strains.

Results The overall HPV prevalence was 14.5%. The highest prevalence was observed in the 20–29 age group (19.6%), the Middle region of the West Bank (19.0%), and lower educational attainment. Genotyping revealed a diverse distribution of HPV types, with HPV 11 and HPV 6 being the most common low-risk types, while HPV 16 was the most common high-risk type. About 21.8% of the detected strains were high-risk strains. Phylogenetic analysis indicated significant regional clustering of HPV strains.

Conclusion The study highlights the need for targeted public health interventions, including vaccination and regular screening, particularly for younger women and those with lower educational attainment. Continued surveillance and research are essential to reduce the burden of HPV-related diseases in the West Bank, Palestine.

Keywords HPV genotypes and phylogenetic, HPV prevalence, Human cervical cancer, Sexually transmitted infections, Women's sexual health

Introduction

Human Papillomavirus (HPV) is the most prevalent viral infection of the reproductive tract and a major global public health concern [1]. It affects a significant proportion of sexually active individuals at some point in their lives [2]. HPV is particularly known for its role in causing cervical cancer, the fourth most common cancer in women worldwide, as well as other anogenital and oropharyngeal cancers [3]. With over 200 identified genotypes, HPV is divided into high-risk and low-risk types based on their potential to cause cancer [4]. High-risk types such as HPV-16 and HPV-18 are responsible for approximately 70% of cervical cancer cases globally [3].

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Despite the introduction of prophylactic vaccines, HPV remains a significant public health challenge, especially in regions with limited access to screening and vaccination programs [5]. Globally, cervical cancer is responsible for approximately 350,000 deaths annually, with the highest mortality rates observed in low- and middle-income countries [6].

In Palestine, cervical cancer is the third most common gynecological cancer, with an age-standardized incidence rate of 2.5 per 100,000 females [7]. The 5-year prevalence of cervical cancer in Palestine is reported to be 6.05 per 100,000 female population [8]. Also, cervical cancer has a higher age-standardized mortality rate in Palestine compared to other countries in the region, reflecting significant healthcare challenges [9]. These statistics highlight the significant burden of cervical cancer in the region, underscoring the need for enhanced screening and vaccination efforts. Awareness and knowledge about cervical cancer risk factors among Palestinian women remain relatively low, which further complicates efforts to reduce the incidence and mortality associated with this disease [7].

The West Bank, with its unique demographic and socio-political context, provides a distinct setting for studying HPV prevalence and distribution [2]. Previous research in this region has provided valuable insights but has often been limited in scope and methodology [2]. This study was conducted to expand on this body of work by conducting a comprehensive analysis of HPV prevalence using the nested PCR method, which is highly sensitive and capable of detecting even low viral loads [9]. The study was designed to enhance our understanding of HPV epidemiology through genotyping and phylogenetic analysis. Such data is essential for developing effective public health policies and targeted interventions [10]. Furthermore, the study aimed to identify the most common high-risk HPV strains, which will aid in selecting appropriate vaccine types for the local population [4]. By assessing demographic variables such as age and geographic distribution, the study provides a deeper understanding of HPV dynamics in the region, informing both clinical practice and community health initiatives [11].

In summary, this study provided a detailed epidemiological overview of HPV in the West Bank, Palestine, and addressed a critical gap in regional healthcare research related to the topic [10]. By doing so, we provided for the first time a comprehensive study about HPV that can inform the medical community and prompt public health stakeholders to take informed actions in HPV screening, vaccination, and education programs, contributing to the global effort to reduce the burden of HPV-related diseases.

Methods

Study population and design

This cross-sectional study was conducted from September 2023 to April 2024 to evaluate the prevalence and HPV genotypes in the West Bank, Palestine. The study population consisted of Palestinian women over 19 years old visiting gynecologist clinics for routine checkups. Participants were recruited from 11 governorates, including Jenin, Ramallah, Hebron, Nablus, Tulkarem, Qalqilya, Jerusalem, Bethlehem, Jericho, Tubas, and Salfit.

Study size and calculation

The sample size for this study was determined based on HPV prevalence in neighboring countries, which ranges from 4 to 30% [12]. Using a 95% confidence level and a 5% margin of error, we calculated that at least 314 participants were needed. This calculation was performed using the online tool available at Raosoft Sample Size Calculator [13]. To account for potential non-response or exclusion, we aimed to recruit at least 350 participants from gynecological clinics across the West Bank. Ultimately, we collected 379 samples, exceeding our target and further strengthening the reliability of our findings on HPV prevalence and genotypic distribution.

Sampling technique

A convenience sampling strategy was employed to recruit women who met the inclusion criteria of residing in the West Bank and attending participating clinics for routine gyenocological checkup, and being over 19 years of age. Participants with prior cervical cancer treatment or medical conditions such as hysterectomy or chemotherapy were excluded to avoid confounding results. A total of 379 samples were collected and categorized into three groups based on their residency over the past ten years in either the North, South, or Middle areas of the West Bank. Gynecologists collected cervical swabs using cotton swabs and transported them in viral transport media to maintain specimen integrity.

DNA extraction

From each of the collected cervical swabs, 200 µL was used for DNA extraction by the ZYMO Quick-DNA/RNA™ Viral MagBead kit (Catalog Nos. R2140 & R2141) following the manufacturer's instructions. The extracted DNA was stored at -20 °C until further use.

PCR amplification and analysis

Nested PCR was used to amplify HPV DNA. DNA was amplified in a 20 µL reaction mix. The mix contained 10 µL of Q5 High-Fidelity X2 PCR Master Mix (Catalog #: M0492L), 5 µL of extracted DNA, 0.5 µM of each forward and reverse primer, and 4 µL of nuclease-free water. The MY09 (5'-CGTCCCAAAGGAAACTGAGC-3') / MY11

(5'-GCMCAGGGWCATAAYAATGG-3') primer pair was used in the outer PCR reaction, and the GP5+ (5'-TTTGTTACTGTGGTAGATACTAC-3') / GP6+ (5'-GAAAAATAAACTGTAAATCATATTC-3') primer set was used for the inner PCR reaction [14, 15]. PCR reactions were performed on an Applied Biosystems Veriti 96-Well Thermal Cycler using the following cycling programs; for the MY09/MY11 primer pair, an initial denaturation step at 98 °C was followed by 35 cycles of denaturation at 98 °C for 20 s, annealing at 55 °C for 25 s and extension at 72 °C for 20 s, the final extension was at 72 °C for 2 min. For the GP5+/GP6+primer set, an initial denaturation step at 98 C was followed by 35 cycles of denaturation at 98 C for 15 s, annealing at 48 °C for 4 s, 38 °C for 30 s, 42 °C for 5 s, 66 °C 5 s and extension at 72 °C for 20 s, a final extension was at 72 °C for 2 min. PCR products were run on a 2% agarose gel and visualized using a UVITEC gel documentation system (Cambridge).

Sanger sequencing

HPV-positive PCR products were cleaned using the EPPIC Fast ultra-rapid enzymatic purification kit (A&A biotechnology). Briefly, 1 µL of EPPIC Fast enzymatic solution was added to 5 µL of PCR product and incubated in a thermal cycler at 37 °C for 5 min, followed by 1 min at 80 °C. PCR targeted the L1 gene with the outer primers MY09/MY11 amplifying a 468 to 550 bp region and the inner primers GP5+/GP6+generating a 196 to 220 bp fragment. The purified products were cycled for sequencing using the ProDye™ Terminator Sequencing system kit (Promega) according to the manufacturer's instructions. PCR cycling products were cleaned using the Wizard® MagneSil® Sequencing Reaction Clean-Up System. Sequencing was performed using the Spectrum Compact analyzer (Promega), and results were analyzed using Proview Software (Promega).

Phylogenetic analysis of HPV

Sequencing results for each patient were collected and aligned using MEGA11 software (version 11.0.13). Genotyping was performed through phylogenetic analysis, comparing the sequences to reference sequences in the NCBI GenBank database. Phylogenetic trees were constructed using the maximum likelihood method (ML) and the Kimura two-parameter substitution model, incorporating 1000 bootstrap replicates to ensure the robustness and reliability of the inferred relationships.

Human ethics and consent to participate declarations

Ethical approval was obtained from the Institutional Review Board (IRB) at An-Najah National University (Ref: MAS. OCT. 2023/6). Written informed consent was obtained from all participants before their inclusion in this study. All patients' samples and data were coded and access was restricted to the research staff.

Statistical analysis

All data were analyzed using SPSS Version 26 (SPSS Chicago, IL, USA). Descriptive variables were statistically evaluated using the Chi-square non-parametric test, with a significance threshold set at $P<0.05$.

Results

Demographic analysis of the study sample

The study included 379 Palestinian women from the West Bank categorized into various groups based on different demographic and health-related variables. The age distribution showed that the majority of participants were between 30 and 39 years old (36.94%), followed by those aged 40–49 (26.91%) and 20–29 (24.27%). The participants were predominantly from cities (61%), with a significant portion from villages (36.94%) and a small number from refugee camps (2.11%). Educationally, most women had a bachelor's degree (56.46%), followed by those with school-level education (38.26%) and a minority with master's or PhD degrees (5.28%). Economically, nearly half of the participants were from high-income families (48.02%), with the rest distributed between middle (31.66%) and low-income (19.79%) groups, as shown in Table 1.

Health-related data revealed that a significant majority of participants had no history of HPV infection (96.57%) or tumors and warts (95.51%). However, only 26.12% had undergone a Pap smear. HPV vaccination was notably low, with only 0.5% of participants vaccinated. Smoking was relatively uncommon, with 84.70% of women being non-smokers. Additionally, 90.50% had no history of abnormal gynecological visits, and 92.88% had no history of surgery or biopsy. The frequency of routine gynecological visits varied, with 46.97% undergoing check every three years, while 28.50% had visits less frequently than every three years. Table 1 describes the results, including demographics, age groups, exposure history, and some risk factors, underscoring the need for increased awareness and access to HPV screening and vaccination programs in the West Bank, Palestine.

To assess the relationship between demographic variables and HPV screening results, we conducted Chi-square analyses for locality, age group, and education level. The results of these tests are presented in Table 2.

The Chi-square test results are summarized in Table 2. No statistically significant relationships were found between HPV screening results and the variables of **locality** ($\chi^2(2)=4.233$, $p=0.120$), **age group** ($\chi^2(6)=8.472$, $p=0.206$), or **education level** ($\chi^2(2)=0.974$, $p=0.615$).

Table 1 Demographic and health-related characteristics of the study population

VARIABLE	CATEGORY	FREQUENCY	PERCENT	CUMULATIVE PERCENT
AGE GROUPS	20–29	92	24.27%	24.27%
	30–39	140	36.94%	61.21%
	40–49	102	26.91%	88.13%
	50–59	31	8.18%	96.31%
	60–69	11	2.90%	99.21%
	70–79	3	0.79%	100.00%
MARITAL STATUS	Yes	379	100.00%	100.00%
RESIDENTIAL AREA	Village	140	36.94%	36.94%
	City	231	60.95%	97.89%
	Refugee Camp	8	2.11%	100.00%
EDUCATION LEVEL	School	145	38.26%	38.26%
	Bachelor	214	56.46%	94.72%
	Master and PhD	20	5.28%	100.00%
FAMILY ECONOMIC STATUS	Low Income	75	19.79%	19.79%
	Middle Income	120	31.66%	51.45%
	High Income	184	48.55%	100%
PAP SMEAR HISTORY	No	280	73.88%	73.88%
	Yes	99	26.12%	100.00%
HPV INFECTION HISTORY	No	366	96.57%	96.57%
	Yes	13	3.43%	100.00%
TUMORS AND WARTS HISTORY	No	362	95.51%	95.51%
	Yes	17	4.49%	100.00%
HPV VACCINATION HISTORY	No	377	99.47%	99.47%
	Yes	2	0.53%	100.00%
SMOKING STATUS	No	321	84.70%	84.70%
	Yes	58	15.30%	100.00%
HISTORY OF ABNORMAL GYNECOLOGICAL EXAMINATIONS	No	343	90.50%	90.50%
	Yes	36	9.50%	100.00%
SURGERY OR BIOPSY HISTORY	No	354	93.%	92.88%
	Yes	25	6.60%	100%
FREQUENCY OF ROUTINE GYNECOLOGICAL EXAMINATIONS	Never	23	6.07%	6.07%
	More than 3 years	108	28.50%	34.56%
	Every 3 years	178	46.97%	81.53%
	Every 2 years	45	11.87%	93.40%
	Annually	25	6.60%	100.00%

• "Percent represents the proportion of the total sample."

• "Cumulative percent shows the running total."

Table 2 Chi-square test results for HPV screening variables

Variable	Chi-square Value (χ^2)	Degrees of Freedom (df)	*p*-value	Interpretation
Locality	4.233	2	0.12	Not significant
Age Group	8.472	6	0.206	Not significant
Education	0.974	2	0.615	Not significant

Table 3 Distribution of HPV-positive samples among different residency areas in the West Bank

Locality	Total	Negative	Positive	Prevalence
Middle	137	111	26	19.00%
North	97	83	14	14.40%
South	145	130	15	10.30%
Total	379	324	55	14.50%

Table 4 Correlation between HPV prevalence and women's age groups

Age Group	Total	Negative	Positive	Prevalence
20–29	**92**	**74**	**18**	**19.60%**
30–39	**140**	**117**	**23**	**16.40%**
40–49	**102**	**95**	**7**	**6.90%**
50–59	**31**	**27**	**4**	**12.90%**
> 60	**14**	**11**	**3**	**21.43%**

Prevalence of HPV in Palestinian women residing in the West Bank

The study assessed the prevalence of HPV genotypes in a cohort of 379 samples, revealing an overall prevalence rate of 14.5%. The participants were recruited from various regions of the West Bank and were categorized into three distinct groups based on their residency over the past ten years. Those from the Northern region accounted for 25.6% of the samples, participants from the Southern region comprised 38.3%, and individuals from the Middle cities made up 36.1%, as shown in Table 3.

The age range of the participants varied from 20 to 70 years. Notably, most of the study population, comprising 334 individuals (88.1%), fell within the age group of 20 to 49 years. In contrast, 45 participants (11.9%) were aged over 49 years. A closer examination of HPV prevalence across different age groups revealed significant variations. The prevalence was highest at 21.4% among participants aged > 60 years, followed by 19.6%, 16.4% and 12.9% in the 20–29, 30–39, and 50–59 age groups respectively, and decreased to 6.9% among those aged 40–49 years (Table 3). These findings underscore the importance of age and geographic residency in understanding the epidemiology of HPV in the Palestinian population, as shown in Table 4.

In this study, we also examined the correlation between the prevalence of Human Papillomavirus (HPV) among Palestinian women and their education level. When analyzed by educational attainment, the results indicated that women with only a school education had the highest

prevalence at 16.6%, with 24 out of 145 testing positive for the virus. In contrast, among those with a bachelor's degree, the prevalence was slightly lower at 13.6%, with 29 positive cases out of 214 participants. The group with master's and PhD degrees exhibited the lowest prevalence at 10.0%, with only 2 out of 20 women testing positive, as shown in Table 5. These findings suggest a potential link between educational level and HPV prevalence, highlighting the importance of education in influencing awareness and risk factors associated with HPV infection among women in this region.

Table 5 Correlation between HPV prevalence and women's education level

Level	Total	Not detected	Positive	Prevalence
School	145	121	24	16.60%
Bachelor	214	185	29	13.60%
Master and PhD	20	18	2	10.00%
Total	379	324	55	14.50%

Table 6 Distribution of LR and HR HPV genotypes in the studied population

Genotype	Frequency	Percent	LR / HR
HPV 11	10	18.20%	LR
HPV 6	10	18.20%	LR
HPV 1	6	10.90%	NC
HPV 16	6	10.90%	HR
Failed samples	5	9.10%	NA
HPV 53	4	7.30%	NC
HPV 31	2	3.60%	HR
HPV 66	2	3.60%	NC
HPV 11/16	1	1.80%	HR
HPV 13	1	1.80%	NC
HPV 18	1	1.80%	HR
HPV 34	1	1.80%	NC
HPV 39	1	1.80%	HR
HPV 42	1	1.80%	LR
HPV 52	1	1.80%	HR
HPV 54	1	1.80%	LR
HPV 84	1	1.80%	NC
HPV 89	1	1.80%	NC
Total	55	100.00%	

• LR: Low-risk, HR: High-risk, NC: Not classified

• HPV genotypes were classified according to the guidelines of the International Agency for Research on Cancer (IARC)

Diversity of HPV genotypes among infected Palestinian women

In order to study the HPV genotypes circulating among infected Palestinian women, we performed Sanger sequencing of the PCR products obtained from the positive samples. A total of 55 HPV positive samples were successfully genotyped while 5 samples could not be genotyped due to technical issues. Sequence analysis of HPV genotypes detected in our studied population revealed a diverse distribution of both low-risk (LR) and high-risk (HR) HPV types. The percentage of samples that expressed LR HPV was 58.2%, while the percentage of samples that contained HR HPV was 32.7%. Additionally, 9.1% of the samples consisted of strains that were not classified.

Among the most frequently detected genotypes were HPV 11 and HPV 6, each accounting for 18.2% of the total cases, as shown in Table 6. Both genotypes are classified as low-risk and are primarily associated with benign lesions such as genital warts, indicating a lower potential for progression to malignancy. Additionally, HPV 1 was detected in 10.9% of cases. Although HPV 1 is not classified as either low- or high-risk, its presence may be associated with benign lesions but has no established link to cervical cancer. Other unclassified genotypes detected included HPV 13, 34, 66, 84, and 89, each with a prevalence of 1.8%, except for HPV 53, which had a prevalence of 7.3%.

For high-risk HPV genotypes, HPV 16 is the most prevalent, with a 10.9% prevalence rate. HPV16 is one of the most well-known high-risk HPV types. This genotype is strongly associated with the development of cervical cancer and other anogenital malignancies, emphasizing the importance of monitoring and managing infections caused by this strain. Among other high-risk types, HPV 31 was detected in 3.6% of the cases; is another high-risk type and recognized for its association with cervical dysplasia and cancer. Other high-risk genotypes identified in our study included HPV 18, 39 and 52, all with 1.8% prevalence. Among these, HPV 18 is notable as a high-risk type associated with cervical cancer. In one case, HPV 11 and HPV 16 were co-detected, illustrating the complexity of HPV infections and the potential for co-infections that may influence disease progression.

For the first time in Palestine, we were able to show a significant prevalence of both low-risk and high-risk HPV genotypes, with HPV 11 and HPV 6 being the most prevalent LR genotypes and HPV 16, HPV 53, and HPV 31 as the most common genotypes, as shown in Table 6. This emphasizes the need for ongoing surveillance and preventive measures, including vaccination and regular screening, to reduce the risks associated with HPV-related diseases. Overall, our findings contribute valuable insights into the epidemiology of HPV and its associated risks within the Palestinian population.

Phylogenetic analysis of HPV genotypes

To study the diversity of HPV genotypes and understand the relationship between the identified genotypes, and since this is important for choosing the appropriate interventions, we conducted a phylogenetic analysis for the genotypes found in our population. In this phylogenetic analysis (Fig. 1), the HPV strains from patients

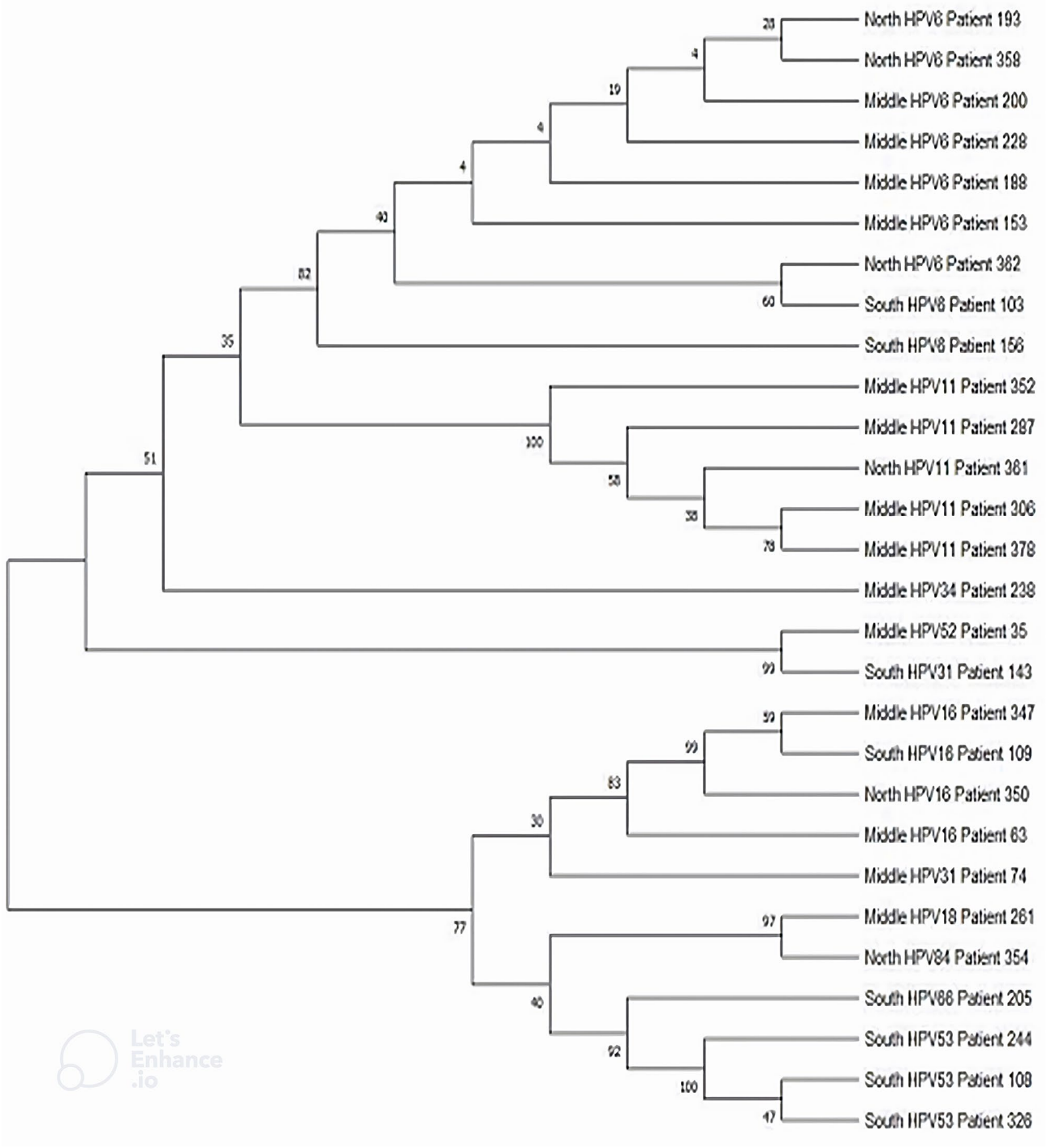

Fig. 1 Phylogenetic analysis. Phylogenetic analysis showing the relationship between the identified HPV genotypes

across different regions are illustrated with a high level of detail, supported by a bootstrap value set to 1000, ensuring the robustness and reliability of the inferred relationships. The phylogenetic tree reveals clear clustering patterns that highlight significant regional variations in the prevalence and spread of specific HPV types. For instance, HPV6 strains from the Northern and Middle regions exhibit close genetic proximity, suggesting a shared evolutionary history or recent transmission events restricted within these areas. Similarly, the tight clustering of HPV11 strains predominantly from the Middle region points towards a localized outbreak or a common infection source, indicating that the virus's spread may be

geographically constrained due to factors such as limited inter-regional movement or specific social behaviors.

The phylogenetic tree was constructed using the maximum likelihood method with the Kimura two-parameter substitution model, incorporating 1000 bootstrap replicates to ensure robustness.

Discussion

Based on a cohort of 379 samples collected from gynecological clinics this study reveals a human papillomavirus (HPV) prevalence rate of 14.5% among women in the West Bank, Palestine. This prevalence highlights significant demographic factors, including age, geographic region, and educational attainment, which serve as key predictors of infection rates. The distribution of samples from various regions of the West Bank, 25.6% from the Northern region, 38.3% from the Southern region, and 36.1% from the Middle cities demonstrates a diverse demographic representation crucial for understanding regional variations in HPV prevalence.

When comparing these findings to neighboring Arab countries, the HPV prevalence in Palestine is moderate. For example, Kuwait reported a much lower prevalence of 2.4% in 2007, while Bahrain reported a rate of 9.8% in studies conducted between 2011 and 2014 [16–18]. Jordan showed a comparable prevalence of approximately 14.8%, particularly among younger women, indicating that regional healthcare access and awareness variations may significantly influence these rates [19]. Studies from Egypt documented HPV prevalence ranging from 15 to 25%, especially in urban areas, where factors like increased sexual activity and lower vaccination rates contribute to higher infection rates [20]. Lebanon's HPV prevalence of about 15.7% underscores the importance of socioeconomic factors and access to healthcare in shaping infection rates across the region [21].

The Chi-square analyses, as summarized in Table 2, revealed no statistically significant associations between HPV status and demographic variables such as locality, age group, and education level. While the results were not significant, observed trends may still suggest areas for targeted public health interventions. The lack of significance could reflect limited statistical power due to sample size, rather than an absence of real associations. Future research with larger, more representative samples may help uncover meaningful correlations and guide region-specific health strategies.

Globally, the estimated HPV prevalence is 11.7%, with significant regional variations [22]. The prevalence in sub-Saharan Africa was as high as 24% [2]. In Nigeria, studies have reported HPV prevalence rates ranging from 32%, with higher rates observed in urban areas due to increased sexual activity and lower vaccination coverage [23]. In Ethiopia, the prevalence of HPV among women attending gynecological clinics was found to be around 19.9%, highlighting the need for improved screening and vaccination programs [24]. In Uganda, a study reported an HPV prevalence of approximately 21%, emphasizing the impact of socioeconomic factors and healthcare access on infection rates [25]. Furthermore, research in Brazil indicated an HPV prevalence of about 25.41%, with significant variations across different regions and populations [26]. These comparative insights underscore the need for targeted public health interventions, such as enhanced screening and vaccination programs, to effectively address HPV-related health risks in Palestine and its neighboring regions. Public health efforts, including vaccination campaigns and educational programs, have been shown to significantly reduce HPV prevalence and associated cancer risks [22]. The World Health Organization (WHO) recommends vaccination for girls before the age of 15 and regular screening for pre-cancerous lesions to prevent cervical cancer [27]. Implementing these strategies in Palestine and neighboring regions could help mitigate the burden of HPV and improve overall public health outcomes.

The relatively high prevalence observed in the West Bank compared to the global average and some other Arab countries is concerning and indicates the need for targeted public health interventions. Variations may influence these differences in prevalence in healthcare access, cultural practices, and public health initiatives. Understanding these regional differences is essential for designing effective public health strategies tailored to the specific needs of each population. Enhanced educational campaigns focused on younger women, improved access to HPV vaccination, and more widespread screening programs could contribute to better health outcomes for women in the West Bank and the broader region.

A closer examination of the screening results reveals that the Middle region had the highest prevalence at 19.0%, the Northern region at 14.4%, and the Southern region at 10.3%. These findings suggest that geographic factors may play a role in the distribution of HPV infections, potentially influenced by differences in healthcare access, awareness, and cultural practices among the regions. The age distribution of participants also highlights significant trends; the majority of the study population (88.1%) fell within the reproductive age group of 20 to 49 years. Notably, the highest prevalence of HPV was observed in the >60 years group. Although older age is a factor that lowers the immune system function and thus more susceptibility to different infections, the small number of participants in this group may be a bias factor in this age group, and therefore, a bigger sample number might be needed in the future studies related to this age group. The second most affected age group is the 20–29 age group (19.6%), indicating that younger women in this

cohort are at a greater risk for HPV infection. This trend aligns with global patterns where HPV prevalence is typically highest among younger sexually active populations, underscoring the need for targeted prevention strategies, including vaccination and education [28].

Educational attainment emerged as another critical factor influencing HPV prevalence. Women with only a school education exhibited the highest prevalence at 16.6%, while those with a bachelor's degree showed a slightly lower prevalence of 13.6%. The lowest prevalence was observed among women with master's and PhD degrees at 10.0%. These findings suggest a potential link between education and HPV awareness, where higher educational levels may correlate with better knowledge of HPV and its associated risks. This aligns with previous research indicating that education plays a vital role in health literacy and the uptake of preventive measures [29].

The analysis of HPV genotypes detected in the population revealed a diverse distribution of both low-risk (LR) and high-risk (HR) HPV types. The most frequently detected genotypes were HPV 11 and HPV 6, each accounting for 18.2% of the total cases. These LR types are primarily associated with benign lesions, indicating a lower potential for progression to malignancy. In contrast, HPV 16, an HR type strongly linked to cervical cancer, was detected in 10.9% of the cases, emphasizing the importance of monitoring and managing infections caused by this strain. The presence of HPV 31, a high-risk type, further underscores the need for ongoing surveillance, along with the detection of other genotypes such as HPV 53, which, although not classified, may require monitoring for potential clinical relevance [30].

Globally, HPV 16 and HPV 18 are the most prevalent HR types, responsible for approximately 70% of cervical cancer cases [4]. In a study conducted in China, HPV 52 and HPV 58 were also found to be prevalent, particularly in cases of cervical intraepithelial neoplasia [11]. In sub-Saharan Africa, HPV 16, 18, and 45 are the most common HR types [31]. In Latin America, HPV 16, 18, and 31 are frequently detected [30]. These variations in genotype distribution highlight the importance of regional studies to adapt public health interventions effectively.

Using 1000 bootstrap replicates provides strong statistical support for the observed clustering patterns, with many branches exhibiting high bootstrap values confirming the accuracy of the phylogenetic relationships shown [32]. The relatively short branches within specific clusters, such as those for HPV11 in the Middle region, imply recent divergence, potentially due to rapid spread within a confined population [10]. In contrast, the longer branches that separate clusters from different regions suggest older transmission events or more significant genetic drift over time [33]. This detailed phylogenetic structure not only maps the genetic diversity of HPV strains across the population but also offers insights into the dynamics of viral transmission, potentially driven by regional connectivity, population movement, or localized health interventions [30].

The West Bank shows distinct patterns of HPV type distribution, with HR types like HPV16 and HPV18 clustering tightly in the Middle region. This localized clustering could necessitate targeted vaccination or screening programs to prevent the spread of these oncogenic types [4, 30]. Additionally, the genetic diversity observed in HPV6 across the North and Middle regions may require broader surveillance to understand the transmission dynamics and implement effective control measures [4, 30].

These findings are crucial for informing targeted public health strategies to effectively manage and mitigate the spread of HPV within and between these regions [34] by designing more effective vaccination programs, improving screening protocols, and implementing region-specific health interventions to control the spread of HPV and reduce the incidence of HPV-related diseases [35].

Conclusion

This study reveals a relatively high HPV prevalence (14.5%) among women in Palestine with significant variations based on age, region, and education. Younger women (20–29 years) showed the highest prevalence, highlighting their vulnerability. Geographic disparities, particularly in the Middle region, suggest local factors influence HPV transmission. Lower educational attainment correlated with higher infection rates, emphasizing the need for targeted educational interventions.

The analysis identified diverse HPV genotypes, with HPV 11 and HPV 6 as the most prevalent low-risk types, and HPV 16 as a significant high-risk type. The presence of multiple high-risk types underscores the importance of ongoing surveillance, vaccination, and regular screening.

In summary, public health initiatives focusing on education, vaccination, and screening are crucial to reduce HPV infections and their complications in the West Bank, Palestine. Continued research is essential to improve detection methods and understand HPV dynamics, informing effective prevention and treatment strategies.

Limitations

This study has several limitations that should be considered. The sample size, although sufficient for analysis, limits the ability to generalize findings to the broader population. Some women may have been hesitant to participate due to shyness or discomfort in discussing personal health information. The reliance on self-reported data may have introduced recall bias, and not all

gynecologists responded as expected, reducing the diversity of the sample. Future studies should address these challenges with larger, more representative samples.

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Author contributions
IS conceptualized and designed the study, conducted the literature search, performed lab work, and wrote the manuscript. MQ and ZS conceptualized and designed the study, conducted the literature search, supervised the lab work, and revised and wrote the manuscript. All authors discussed the results and contributed to the final manuscript.

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Data availability
The data used to support the findings of this study are included in the manuscript.

Declarations

Consent for publication
Every participant was clearly informed about the purpose of the study before participating, and their consent was obtained with their signature on the form.

Competing interests
The authors declare no competing interests.

Conflict of interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical approval
was obtained from the Institutional Review Board (IRB) at An-Najah National University (Ref: MAS. OCT. 2023/6). Written informed consent was obtained from all participants before their inclusion in this study. All patients' samples and data were coded and access was restricted to the research staff.

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