

Cloning and expression in *Escherichia coli* of the full-length and deletion variants of a human papillomavirus 18 L1 gene isolated from a Cuban patient

Clonación y expresión en *Escherichia coli* de un gen L1 completo del virus del papiloma humano 18 aislado de una paciente cubana y variantes delecionadas

Elsa Pimienta^{1*}

Sandra Rodríguez¹

Rafael Fando¹

Yunier Serrano¹

Darién Ortega²

Ariel Palenzuela²

Karen Marrero¹

¹Biological Products Research Unit, Direction of Research, Development & Innovation, National Center for Scientific Research. La Habana, Cuba.

²Laboratory of Infectious Disease, Immunoassay Center. La Habana, Cuba.

*Corresponding author: epimienta@infomed.sld.cu

ABSTRACT

Introduction: Human papillomavirus (HPV) vaccines are based on the L1 major capsid protein.

Objectives: To clone the HPV-18 L1 gene from a Cuban female HPV-18-infected patient and to express the full-length and deletion variants of the cloned HPV-18 L1 gene in *Escherichia coli*.

Methods: The full-length HPV-18 L1 gene was PCR-amplified from total DNA isolated from a Cuban patient, cloned and finally subcloned into the *E. coli* expression vector pET26b. Three deletion mutants were constructed, which encode truncated proteins lacking 30 amino acids at the C-terminus in combination with 5, 6 or none deleted residue at the N-

terminus. Production of L1 proteins in *E. coli* BL21(DE3) and *E. coli* SHuffle T7 was assessed by SDS-PAGE and Western blotting.

Results: The cloned HPV-18 L1 gene was 99.9 % similar to the African variant EF202152 and probably shares a common origin with the B lineage of genotype 18. The three truncated variants of HPV-18 L1 were produced at higher levels than the full-length HPV-18 L1 protein, attaining higher levels in *E. coli* BL21(DE3) and higher solubility in *E. coli* SHuffle. The C-terminus-only truncated variant, L1 Δ C30, was produced at similar levels to the HPV-18 L1s truncated at both termini. *E. coli* SHuffle produced about three times more amounts of L1 Δ C30 when grown under autoinduction conditions with respect to conventional induction and thus, amounts were comparable to those obtained in *E. coli* BL21(DE3) under conventional induction.

Conclusions: Truncation of thirty amino acid residues at the carboxy-terminus of the HPV-18 L1 made a major contribution to the production and solubility of this wild-type protein in *E. coli*. This is the first report about soluble production of HPV-18 L1 protein in an *E. coli* SHuffle strain. However, higher amounts of L1 are needed to scale-up its production for developing an HPV vaccine candidate.

Keywords: human papillomavirus; L1 major capsid protein; vaccine, *Escherichia coli*.

RESUMEN

Introducción: Las vacunas contra el virus del papiloma humano (VPH) se fundamentan en la proteína principal de la cápsida L1.

Objetivo: Clonar el gen L1 del VPH-18 a partir de una paciente cubana infectada con VPH-18 y expresar las variantes de longitud completa y delecionadas del gen L1 del VPH-18 en *Escherichia coli*.

Métodos: El gen L1 del VPH-18 de longitud completa se amplificó por PCR a partir de ADN total aislado de un paciente cubana, se clonó y finalmente se subclonó en el vector de expresión de *E. coli* pET26b. Se construyeron tres mutantes de deleción, que codifican para proteínas truncadas que carecen de 30 aminoácidos por el extremo carboxilo, en combinación con 5, 6 o ningún residuo delecionado por el extremo amino. La producción de las proteínas L1 en *E. coli* BL21(DE3) y *E. coli* SHuffle T7 se evaluó mediante SDS-PAGE y Western blot.

Resultados: El gen L1 del VPH-18 clonado fue 99.9 % similar a la variante africana EF202152 y probablemente comparte un origen común con el linaje B del genotipo 18. Las tres variantes truncadas de la proteína L1 del VPH-18 se produjeron a mayores niveles que la proteína L1 del VPH-18 de longitud completa, alcanzando mayores niveles en *E. coli* BL21(DE3) y mayor solubilidad en *E. coli* SHuffle. La variante truncada solo por el extremo carboxilo, L1 Δ C30, se produjo a niveles similares a las proteínas L1 del VPH-18 truncadas por ambos extremos. *E. coli* SHuffle produjo aproximadamente tres veces más cantidades de L1 Δ C30 cuando creció en condiciones de autoinducción, con respecto a la inducción convencional y, por ende, las cantidades fueron comparables a las obtenidas por *E. coli* BL21(DE3) bajo inducción convencional.

Conclusiones: La truncación de treinta residuos de aminoácidos por el extremo carboxilo de la proteína L1 del VPH-18 tuvo una importante contribución a la producción y solubilidad de la proteína L1 nativa en *E. coli*. Este es el primer informe sobre la producción soluble de la proteína L1 del VPH-18 en una cepa de *E. coli* SHuffle. Sin embargo, se necesitan mayores cantidades de la proteína L1 para escalar su producción para desarrollar un candidato vacunal contra el VPH.

Palabras clave: papiloma humano; proteína principal de la cápsida L1; vacuna; *Escherichia coli*.

Received: 01/12/2017.

Accepted: 05/11/2018.

INTRODUCTION

Human papillomaviruses (HPV) are the etiological agents of cervical and other anogenital malignancies.(1) HPV is a small double-stranded DNA virus with a circular genome of approximately 8 kb. The viral icosahedral capsid is formed by 72 pentameric capsomeres, which consist of L1 and L2 molecules. The L1 is the major capsid protein with molecular weight of 55 kDa.(2,3) Recombinant production of L1 using heterologous systems has resulted in the formation of virus-like particles (VLPs) that resemble the native virions in size and shape but lack the potentially oncogenic viral genome.(4,5) Assembled VLPs are

potent immunogens, as they can induce high titers of neutralizing antibodies for preventing HPV infections.^(4,6)

Currently there are three licensed preventive HPV vaccines available on the market: Gardasil, Gardasil-9, and Cervarix. The three HPV vaccines target HPV type 16 (HPV-16) and HPV type 18 (HPV-18),⁽⁷⁾ which are responsible for 69.4 % of cervical cancer cases.⁽⁸⁾ HPV-16 is the most common viral genotype detected in cervical cancers; however, the frequencies of HPV-18 in adenocarcinomas and adenosquamous carcinoma are known to be higher than those of HPV-16.^(9,10) Thus, HPV-18 is a representative of the high-risk viruses most often associated with genital carcinoma.⁽¹¹⁾ The HPV vaccines are based on L1 VLPs, obtained in eukaryotic hosts with high production costs, which have affected their availability in low-income countries, where cervical cancer results in high mortality. The quest for a cheaper, thermostable and broad spectrum vaccine has led to the development of new prophylactic vaccine candidates obtained from more economical alternative expression hosts such as *Escherichia coli* and methylotrophic yeasts.^(12,13)

Escherichia coli has been the most widely used bacterial system for the recombinant production and characterization of HPV L1 protein.^(14,15) Most of the studies of the HPV L1 gene expression in *E. coli* deal with the generation of HPV-16 and HPV-11 L1 proteins fused to N-terminal glutathione S-transferase (GST), which promotes correct folding and stability of recombinant L1 in *E. coli*.^(15,16,17) However, among the HPV L1 proteins targeted by the commercial vaccines, HPV-18 L1 has the highest amount of amino acids residues and cysteine residues along its sequence^(18,19) and its expression in *E. coli* has been less studied than the HPV-16 or HPV-11 L1 genes. Seo et al. obtained VLP from the purified full-length HPV-18 L1, which was expressed as a GST-18 L1 fusion,⁽²⁰⁾ while Gu et al. reported the production of the HPV-18 L1, truncated at the amino terminus, in the soluble fraction of *E. coli*. In this last work, a bivalent HPV vaccine candidate against genotypes 16 and 18 has been developed,⁽¹³⁾ which is currently undergoing a Phase 3 clinical study (ClinicalTrials.gov NCT01735006) and supports the potentiality of *E. coli* as a host for obtaining VLPs of HPV. In addition, previous results have shown a positive effect of the carboxy terminal truncation of the HPV-16 L1 protein on its production and solubility in *E. coli* and insect cells. Schädlich et al obtained an almost twofold increase in HPV-16 L1 protein yields in constructs with C-terminal deletions in *E. coli*,⁽²¹⁾ while Deschuyteneer et al reported that removal of the carboxy terminus of the HPV-16/18 L1 proteins might

minimize the risk of cellular nucleic acid encapsidation for obtaining the truncated proteins in insect cells as active ingredients of Cervarix[®].⁽²²⁾

In Cuba, several molecular epidemiologic studies of HPV infections have found the distribution of oncogenic HPV genotypes in women,^(23,24,25,26,27) in patients with colorectal cancer⁽²⁸⁾ and more recently, in HIV-seropositive men.⁽²⁹⁾ In women, the most recent study detected 30 different HPV genotypes in 519 participants aged between 15 and 59 years, where the most prevalent type was HPV-16 (41.0 %), followed by HPV-31 (11.6 %) and HPV-18 (10.2 %).⁽²⁷⁾ In patients with colorectal tumors, the infection frequency was 25 % and genotypes 16 and 33 were identified. Viral infection was associated with the presence of adenocarcinomas (41.7 %, $p = 0.009$)⁽²⁸⁾ In anogenital samples from 56 HIV-infected men, a high frequency of HPV infection, above 50 %, was detected. HPV- 16 genotype was the most common type (52 %), while HPV-18 was the most frequently detected genotype in men with high-grade squamous intraepithelial lesions.⁽²⁹⁾ Therefore, considering that HPV genotype 18 is a high-risk type with clinical relevance in Cuba, the aim of this work was to clone a HPV-18 L1 gene from a Cuban female patient and to express the full-length and deletion variants of the HPV-18 L1 gene in *E. coli*, for further vaccine candidate development.

METHODS

Clinical sample and total DNA extraction

To isolate the HPV-18 L1 gene, total DNA was purified from HPV-18-infected cervical cells, which were collected by cervical scrapings from a 59 year-old woman suffering from epidermoid carcinoma (La Habana, Cuba). The cell sample had been previously diagnosed as HPV-18 positive by the CLART[®] HPV2 assay (Genómica S.A.U., Spain).⁽³⁰⁾ Total DNA was isolated by the GFX Genomic Blood DNA Purification Kit (GE Healthcare, USA) using the Direct Method, according to the manufacturer's specifications.

Amplification and cloning of a full-length HPV 18 L1 gene

Total DNA was used to amplify by PCR a 1521 bp DNA fragment, comprising the full-length HPV-18 L1 gene, with the forward primer 5'-CATATGGCTTTGTGGCGGC-3' (18L1F), including the NdeI restriction enzyme site, and the reverse primer 5'-AGATCTATTACTTCCTGGCACGTACAC-3' (18L1R), containing the BglII site at the 3' terminal sequence (underlined sequences are the restriction enzyme sites). Both sites were

included to enable the subsequent cloning of the L1 amplified product. The NdeI restriction site was incorporated in the forward primer for introducing a translational start codon, coding for a consensus methionine required for efficient formation of VLP in recombinant expression systems.⁽¹⁹⁾ The primers were designed from the alignment of HPV-18 L1 gene sequences of the 10 HPV-18 representative genomes for viral variant sublineages.⁽³¹⁾

The PCR conditions included 35 cycles of 30 sec at 94 °C, 30 sec at 60 °C and 3.5 min at 72 °C on a Master Cycler (Eppendorf, Germany). The amplified product was purified with the Wizard® SV Gel and PCR Clean-Up System (Promega, USA) and was cloned into the pGEM-T Easy vector (Promega, USA) in *E. coli* Mach 1-T1, obtaining pGEM-T Easy-HPV-18L1 plasmid. The recombinant plasmid was sequenced using the Macrogen services (Korea) to determine the cloned HPV-18 L1 nucleotide sequence. The identity of the nucleotide sequence was established using the Blastn bioinformatic program (https://blast.ncbi.nlm.nih.gov/Blast.cgi?PROGRAM=blastn&PAGE_TYPE=BlastSearch&LINK_LOC=blasthome).

Construction of expression plasmids encoding the full-length and truncated variants of HPV-18 L1 proteins in *E. coli*

To evaluate the expression of the full-length HPV 18 L1 gene in *E. coli*, the 1530 bp NdeI - BglIII fragment was excised from pGEM-T Easy-HPV18L1 plasmid and subcloned into pET26b vector to generate pET26b-HPV-18 L1.

For evaluating the effect of N- and C-terminal truncations on the production and solubility of HPV-18 L1 protein, three deletion mutants were constructed by PCR using pET26b-HPV-18 L1 as template. A genetic construct encoding a carboxy-terminal-only truncated variant (L1ΔC30, missing aa 478-507) was obtained, which was generated by PCR amplification with the primer 18L1F and the reverse primer Δ30 (5'-AGATCTATTAGCGACGCAATCCAGCCTG-3'). The last primer hybridizes to the region previous to the last 30 codons of the HPV 18 L1 cloned gene.

N-terminal truncation of the HPV-18 L1 protein was also evaluated. To select the number of amino acids to be removed at the amino terminus of the HPV-18 L1 protein, we estimated the translation initiation rate (TIR) of the HPV-18 L1 gene, with 2, 3, 4, 5, 6, 7, 8 and 9 codons deleted at its 5' end, by using the RBS Calculator (<https://salislab.net/software/>)⁽³²⁾ and the UTR Designer (http://sbi.postech.ac.kr/utr_designer)⁽³³⁾ tools, in reverse-engineering mode. Based on the predictions of these tools, two other truncation mutants of HPV-18 L1 protein were generated. Thus, deletions of the coding region for the first 5 (ΔN5L1, aa 6-

477) and 6 (Δ N6L1, aa 7-477) amino acids, were combined with a C-terminal 30 amino acids deletion. PCR amplifications were carried out with oligonucleotide Δ 30, in combination with primers 5'-CATATGCCATCAGACAATACCGTATACCTTCC-3' or 5'-CATATGTCAGACAATACCGTATACCTTCCACCTC-3', for obtaining Δ N5L1 Δ C30 and Δ N6L1 Δ C30, respectively. NdeI and BglII recognition sites (underlined) were added to the primers to facilitate subcloning. The three PCR fragments were independently ligated into the pGEM-T Easy vector (Promega, USA) and their nucleotide sequences were verified. Then, the three NdeI/BglII fragments, containing the truncated sequences L1 Δ C30, Δ N5L1 Δ C30 and Δ N6L1 Δ C30 of the HPV18 L1 gene from the pGEM-T Easy derivatives, were independently ligated into NdeI/BglII digested pET26b vector to generate pETHPV18L1 Δ C30, pETHPV18 Δ N5L1 Δ C30 and pETHPV18 Δ N6L1 Δ C30, respectively. *E. coli* Mach 1-T1 was used for the cloning steps, while *E. coli* BL21(DE3) and *E. coli* SHuffle T7 were used as expression hosts. Ampicillin (100 μ g/mL) and kanamycin (100 μ g/mL) were used when necessary.

Plasmid pET28a-HPV-18L1-tag, encoding the HPV-18 L1 protein fused to the histidine tag and N terminal amino acids derived from the vector (Histag-HPV-18L1),⁽³⁴⁾ was also introduced in *E. coli* BL21 (DE3) and *E. coli* SHuffle T7 in order to compare the production of the Histag-HPV-18L1 and the three L1 truncated mutants, obtained above.

Evaluation of HPV-18 L1 protein production in *E. coli* BL21 (DE3) and *E. coli* SHuffle T7

Production of the HPV18 L1 protein variants was promoted by conventional induction with isopropyl-h-D-thiogalactopyranoside (IPTG). *E. coli* BL21 (DE3) and *E. coli* SHuffle T7 clones, harboring pET26b-HPV-18 L1, pETHPV18L1 Δ C30, pETHPV18 Δ N5L1 Δ C30, pETHPV18 Δ N6L1 Δ C30 or pET28a-HPV-18L1-tag⁽³⁴⁾ were grown overnight in terrific broth medium (TB) (35). Fifty microliters of pre-cultures were inoculated into 5 mL of TB medium and cells were incubated at 28 °C and 220 r.p.m. until reaching 0.6-0.8 units of optical density (at 600 nm, OD₆₀₀), moment in which IPTG (0.01; 0.1 or 1 mM as final concentration) was added to the culture broth for inducing recombinant protein expression. Then, cultures were incubated at 28 °C and 220 r.p.m. for 4 h and samples were withdrawn every 2 h. Lastly, cells were harvested and stored at -20 °C until further use.

For evaluating L1 protein production under auto-induction conditions, cells were cultured overnight under non-inducing conditions into modified TB medium.⁽³⁶⁾ Production cultures, composed by the abovementioned TB medium supplemented with 2 g/L lactose or IPTG (125, 60 or 30 μ M), were inoculated at an initial OD of 0.1 and allowed to grow for 14 h at 28 °C and 220 r.p.m. Cell samples were processed as mentioned before.

Evaluation of HPV18-L1 protein solubility in *E. coli* BL21 (DE3) and *E. coli* SHuffle T7

Samples were incubated 15 min at room temperature in a lysozyme solution at 20 mg/ml. Partially broken cells were freeze-thawed 3 times to promote cell lysis. After a centrifugation step at 12,000 \times g for 20 min, the soluble fractions were frozen and the insoluble fractions were washed and resuspended in equivalent amounts to the soluble fractions. All protein fractions were conserved at -20 °C for further SDS-PAGE and Western blot analysis.

SDS-PAGE and Western blot analysis

For estimation of molecular weight and determination of identity and solubility of HPV18 L1 proteins, 10 % (w/v) sodium dodecyl sulphate polyacrylamide gel electrophoresis (10 % SDS-PAGE) under reduced conditions,⁽³⁷⁾ followed by staining with Coomassie brilliant blue, was carried out. Cell samples were homogenized to 6.5 units of OD₆₀₀ with phosphate-buffered saline.⁽³⁸⁾ For Western blot analysis, the proteins resolved on the gels were transferred onto protran nitrocellulose membranes (Schleicher and Schuell Bioscience, Germany). The membranes were blocked with PBST solution⁽³⁸⁾ containing 5 % w/v nonfat dry milk and then reacted with mouse anti-HPV16 L1 antibody (clone CamVir-1, Merck, USA) diluted 1:15 000. Then, membranes were incubated with anti-mouse IgG-HRP (1:64 000, CIGB SS, Cuba). Immunoreactive protein bands were visualized using peroxidase substrate 3,3'-Diaminobenzidine (DAB, Sigma, USA). The densitometric analysis of protein bands on SDS-PAGE gels and Western blots scans were done with Gel Analyzer 2010 software.⁽³⁹⁾ All data represents mean values of at least three independent experiments.

Detection of inclusion bodies formation in *E. coli* SHuffle T7 [pET28a-HPV-18L1-tag] by transmission electron microscopy (TEM)

The cells expressing the full-length HPV-18 L1 gene fused to a His-Tag coding sequence were cultivated at 28 °C for 4 h upon 0.1 mM IPTG induction. Then the cells were harvested, fixed with 2 % glutaraldehyde and 1 % osmium tetroxide, both in 0,1 M sodium

phosphate buffer solution at pH 7.2. After graded-acetone serial dehydration steps, the cells were embedded in Spurr resin, ultrathin sectioned, stained with uranyl acetate and lead citrate solutions, and then observed with a Jeol JEM 1011 (JEOL, Japan) transmission electron microscope at 20 000 X.

Statistical analysis

Data are presented as means \pm SD from triplicate experiments. Statistical analyses were performed using an unpaired, two-tailed student's t test. $p < 0.05$ was considered statistically significant.

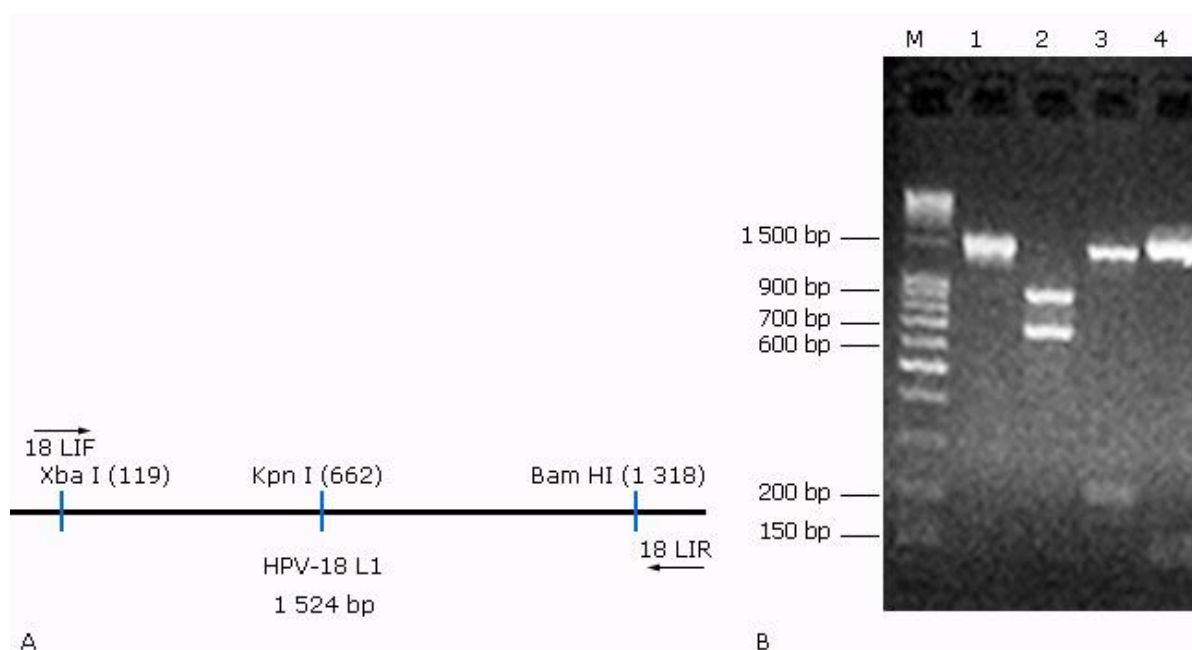
RESULTS

Amplification and cloning of the full-length HPV 18 L1 gene in

Escherichia coli

PCR amplification using total DNA isolated from a cervical exfoliated cell sample and the primer pairs 18L1F and 18L1R (Fig. 1, A) produced an amplicon of ~1.5 kb (Fig. 1, B, lane 1), size close to the expected value (1524 bp, Fig. 1, A). The identity of the PCR fragment was analysed by digestion with the restriction enzymes KpnI, BamHI and XbaI, which recognize conserved and unique sequences in the HPV18 L1 reference sequence (accession number NC_001357, Fig. 1, A). As expected, the Kpn I enzyme produced two bands of ~650 and ~800 bp (Fig. 1, B, lane 2), values close to the expected values (662 bp and 862 pb; Fig. 1, A). Digestion of the amplified fragment with BamHI enzyme also produced two bands (~200 bp and ~1300 pb; Fig. 1, B, line 3), close to the predicted values of 206 pb and 1318 bp (Fig. 1, A). Digestion with XbaI generated two bands of ~1 300 pb and < 150 pb (Fig. 1, B, line 4), close to the predicted sizes of 1 405 pb and 119 bp (Fig. 1, A), respectively. These results showed the conservation of three different restriction enzyme recognition sites in the amplified fragment and revealed the similarity with the reference HPV18 L1 gene at the nucleotide level. Then, the PCR product was cloned into the pGEM-T Easy vector, obtaining the plasmid pGEM-T Easy-HPV18L1, which was sequenced. The DNA sequence analysis revealed that the cloned HPV-18 L1 gene was 99.9 % similar to the African variant EF202152, representative for the HPV-18 sublineage B3. There was only one nucleotide difference between the EF202152 (A) and the cloned sequence (G) at position 1518, but without impact on the translated amino acid sequence. The complete

nucleotide sequence of the cloned HPV-18 L1 gene was deposited in GenBank under the accession number MK211166.



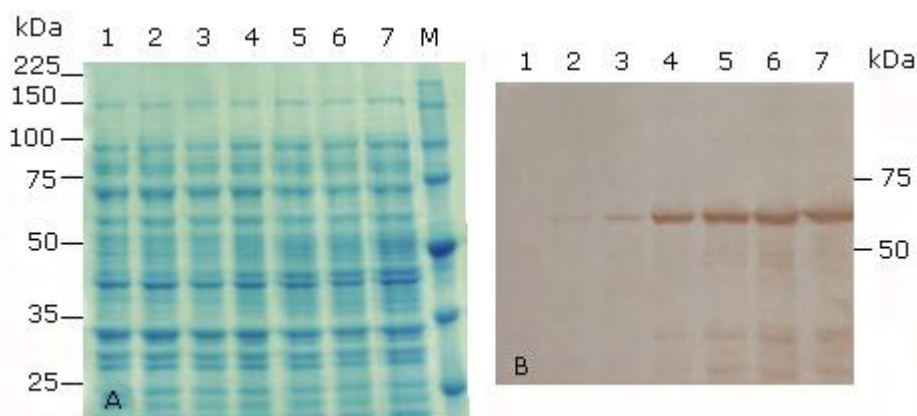
A: Schematic representation of HPV18 L1 reference sequence (accession number NC_001357) with the unique restriction sites Xba I, Kpn I and BamHI included. The primers 18L1F and 18L1R were also represented. B: Restriction analysis of the generated amplicon lane M: DNA molecular weight marker (SERVA DNA Standard 100 bp DNA Ladder extended); lane 1, PCR product; lanes 2-4, PCR product digested with KpnI, BamHI and XbaI, respectively.

Fig. 1 - Amplification of the full-length HPV-18 L1 gene using total DNA isolated from a cervical exfoliated cell sample.

Subcloning of the full-length HPV18 L1 gene and expression in *E. coli* BL21(DE3)

The cloned HPV-18 L1 gene was subcloned into pET26b vector and the recombinant plasmid pET26b-HPV-18 L1 was introduced initially into *E. coli* BL21(DE3), considering that this strain lacks OmpT outer membrane protease, which has been reported to degrade the carboxy terminus of HPV-16 L1 protein.⁽⁴⁰⁾ Expression of the HPV18L1 gene in response to increasing amounts of IPTG (0.01; 0.1 and 1.0 mM) in TB medium was analyzed by SDS-PAGE. Under these conditions, SDS-PAGE analysis did not show overexpression of HPV-18 L1 protein in IPTG-induced *E. coli* BL21(DE3) [pET26b-HPV-18 L1], since there were not differences observed between induced and non-induced *E. coli* cells (Fig. 2, A, lanes 1 vs. 2-7). However, an HPV-18 L1-specific immunoreactive band of about 57 kDa could be detected in whole cell lysates of the recombinant strain when IPTG was added to a final concentration of 1 or 0.1 mM, both for 2 and 4 h of induction (Fig. 2, B, lanes 4-7). Immunoreactive bands of lower molecular weights were also detected, which may be due to proteolytic degradation or early translation termination, as it has been

previously reported for HPV16 L1.^(16,40) HPV-18 L1 was faintly detected in whole cell lysates of *E. coli* BL21(DE3) [pET26b-HPV-18 L1] at the lowest inducer concentration used (0.01 mM) (Fig. 2, B, lanes 2 and 3). As expected, there was no detectable HPV-18 L1-specific immunoreactive bands in cell lysate of the non-induced control (Fig. 2, B, lane 1). The results revealed that *E. coli* BL21(DE3) was able to produce the native HPV18-L1 protein, although at low levels.



A: 10 % SDS-PAGE stained with Coomassie blue R-250, and B: Immunoblotting analysis using the HPV-16 L1 antibody CAMVIR-1. Lane 1, without IPTG (un-induced control); lane 2, 0.01 mM IPTG 2 h; lane 3, 0.01 mM IPTG 4h; lane 4, 0.1 mM IPTG 2 h; lane 5, 0.1 mM IPTG 4 h; lane 6, 1 mM IPTG 2h; lane 7, 1 mM IPTG 4 h; lane M, Broad-range protein molecular weight markers (Promega, USA).

Fig 2 - Production of the full-length HPV-18 L1 at different time of induction and concentrations of IPTG in *E. coli* BL21(DE3) [pET26b-HPV-18 L1].

Production of truncated variants of HPV-18 L1 in *E. coli* BL21(DE3)

We next evaluated the contribution of the deletion of the amino terminus of the native HPV-18 L1 protein on its production and solubility. For selecting the number of amino acid to be remove from the amino-terminus, translation initiation rates of L1 genes with deletions from one to nine codons was estimated by using the RBS Calculator and the UTR Designer. According to predictions of the two programs, the L1 truncated variants with higher TIR's values were those coding for the proteins lacking the first five and six amino acids (Δ N5L1 and Δ N6L1; table). Both DNA constructs had TIR higher than the values of the full-length HPV-18 L1 gene (table). Therefore, we decided to amplify by PCR the HPV-18 L1 gene with deletions of five and six codons at the 5' end of the cloned L1 gene. For both mutants, deletions of 30 codons at the 3' end of the wild-type HPV-18 L1 gene were generated. We also evaluated a construction with the last 30 codons deleted and the wild-type amino terminus (L1 Δ C30) to assess the contribution of the deletion of the carboxy terminus of the native L1 protein on its production and solubility.

We successfully amplified the PCR fragments corresponding to the three deletion variants of HPV-18 L1 gene, cloned them into the pGEM-T Easy Vector (Promega, EUA) and subcloned them into the expression vector pET26b. The resulting recombinant plasmids pETHPV18ΔN5L1ΔC30, pETHPV18ΔN6L1ΔC30 and pETHPV18L1ΔC30 were independently introduced in *E. coli* BL21(DE3). We also evaluated *E. coli* BL21(DE3) [pET28a-HPV-18L1-tag], a His-Tagged fusion derivative of the cloned HPV-18 L1 gene, which produced L1 protein (Histag-HPV-18L1) at detectable levels in SDS-PAGE,⁽³⁴⁾ in agreement with the higher TIRs values estimated by the two calculator, respect to the full-length L1 gene (table).

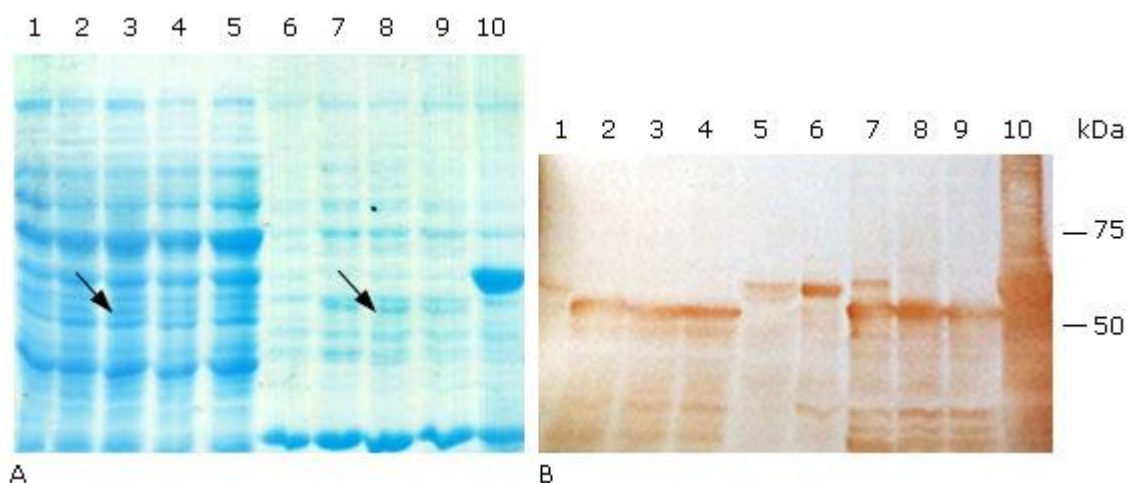
Table - Translation initiation rates (TIR) of constructs coding for N-terminal truncated and 6xHis-tagged (Histag-L1) variants of HPV-18 L1 protein, estimated by the RBS Calculator and the UTR Designer tools

HPV-18 L1 variant	TIR RBS Calculator	TIR UTR Designer
L1 full-length	449.4	48 691.2
ΔN2L1	1 105.6	78 327.9
ΔN3L1	1 323.6	364 664.9
ΔN4L1	2 819.0	843 811.2
ΔN5L1	15 038.6	2 808 550.6
ΔN6L1	3 726.5	1 518 068.1
ΔN7L1	365.4	443 515.9
ΔN8L1	3 794.2	693 793.1
ΔN9L1	843.9	126 003.4
Histag-L1	28 855.1	492 691.0

The ribosome binding site calculators were used in the reverse engineering mode and in agreement with the requirements of each tool.

The expression of the truncated- and Histag- HPV18 L1 variants was induced in the same medium and culture conditions than for *E. coli* BL21(DE3) [pET26b-HPV-18 L1], but IPTG was used at 0.1 mM. According to SDS-PAGE results, the three truncated HPV-18 L1 variants were produced as faint bands in *E. coli* BL21(DE3) and at similar levels (Fig. 3, A, lanes 2-4 & 7-9), which was confirmed by densitometric analysis of the immunoblots (Fig. 3, B, lanes 2-4 & 7-9). The fact that the carboxy-terminal-only truncated variant, L1ΔC30, was produced in *E. coli* BL21(DE3) at similar levels than the HPV-18 L1 protein truncated at both termini suggested that the carboxyl terminus truncation was the deletion that contributed to increase the HPV-18 L1 protein amounts. The densitometric analysis of blots also showed that the production of the three truncated forms of HPV-18 L1 had a fourfold

improvement in L1 levels, compared to the wild-type HPV-18 L1 protein (Fig. 3, B, lanes 1-4 & 6-9). From a solubility point of view, the three truncated variants of HPV-18 L1 had similar solubility, with at least a thirty-five percent of the L1 in the soluble fraction, compared to the wild-type HPV-18 L1 protein; which was mainly found in the insoluble fraction (92 % \pm 0.8) (Fig. 3, B, lane 6). In accordance with the predicted TIR results obtained by the RBS Calculator, the higher amount of HPV-18 L1 was obtained when the wild-type HPV-18 L1 gene was fused to the 5' end of the His-Tag coding sequence, carried by pET28a (Fig. 3, B, lanes 5 and 10). According to densitometric studies on Western blot, the production of Histag-HPV-18L1 resulted in about a tenfold increase in protein amount compared to the wild-type HPV-18 L1; although, the fusion protein was mostly found in the insoluble fraction (99 % \pm 0.4).



A: 10 % SDS-PAGE stained with Coomassie blue R-250, and B: Immunoblotting analysis using the HPV-16 L1 antibody CAMVIR-1. Lane 1, pET26b-HPV-18 L1 soluble fraction (sf); lane 2, pETHPV18L1 Δ C30 sf; lane 3, pETHPV18 Δ N6L1 Δ C30 sf; lane 4, pETHPV18 Δ N5L1 Δ C30 sf; lane 5, pET28a-HPV-18L1-tag sf; lane 6, pET26b-HPV-18 L1 insoluble fraction (if); lane 7, pETHPV18L1 Δ C30 if; lane 8, pETHPV18 Δ N6L1 Δ C30 if; lane 9, pETHPV18 Δ N5L1 Δ C30 if; lane 10, pET28a-HPV-18L1-tag if. The arrows in lanes 3 and 8 (3A) show the bands corresponding to an expected truncated variant (Δ N6L1 Δ C30).

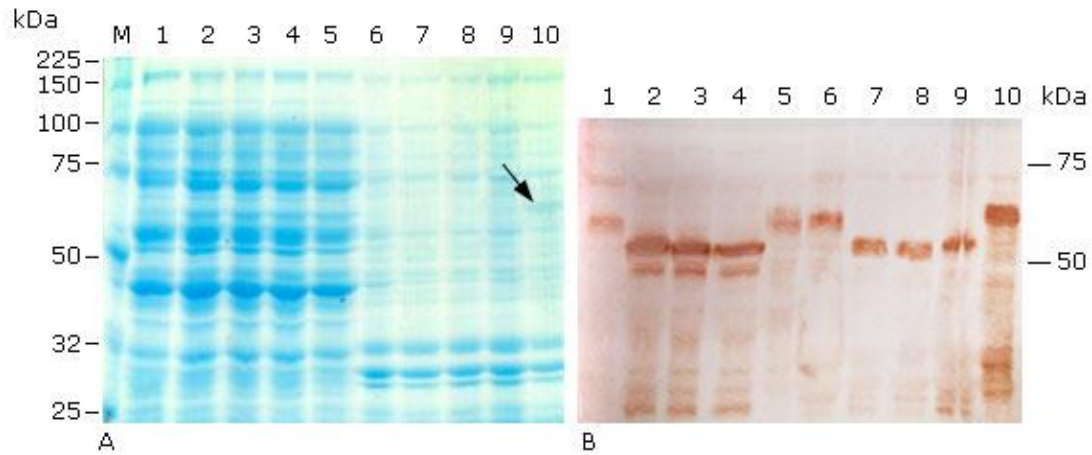
Fig. 3 - Soluble production of truncated and 6xHis-tagged variants of HPV-18 L1 in *E. coli* BL21(DE3).

Production of truncated and 6xHis-tagged variants of HPV-18 L1 in *E. coli* SHuffle T7

Considering that the three truncated HPV-18 L1 proteins were partially found in the soluble fraction of *E. coli* BL21(DE3), and HPV-18 L1 and its derived proteins contain 14 cysteine residues potentially involved in the formation of disulfide bridges,⁽¹⁸⁾ *E. coli* Shuffle T7 was selected as host to evaluate the production of L1 proteins in the soluble fraction. Therefore, plasmids pETHPV18 Δ N5L1 Δ C30, pETHPV18 Δ N6L1 Δ C30 and pETHPV18L1 Δ C30, as well pET28a-HPV-18 L1-tag were transformed in *E. coli* SHuffle T7. The induction of

protein expression was carried out in the same medium and culture conditions as for *E. coli* BL21(DE3).

In Coomassie stained polyacrilamide gels, the the three truncated proteins were not visually detected in cellular fractions of recombinant *E. coli* SHuffle T7 (Fig. 4, A, lanes 2-4 & 7-9), but the host protein background was high around the molecular weight of the truncated proteins in the soluble fractions (Fig. 4, A, lanes 1 & 5 vs. 2-4). This fact, combined with the finding that Histag-HPV-18L1 was detected as a faint band in the insoluble fraction of *E. coli* SHuffle T7 (Fig. 4, A, line 10) and as overexpressed band in *E. coli* BL21(DE3) [pET28a-HPV-18L1-tag] (Fig. 3, A, line 10), suggested that the truncated proteins were produced in smaller amounts in *E. coli* SHuffle T7 than in *E. coli* BL21(DE3), where the truncated proteins were detected by Coomassie staining (Fig. 3, A, lines 2-4). According to densitometric analysis on Western blot, the amounts of the L1 Δ C30, Δ N5L1 Δ C30 and Δ N6L1 Δ C30 produced by *E. coli* SHuffle T7 were at least two times higher than that of the native protein HPV-18 L1, encoded by pET26b-HPV-18 L1. L1 Δ C30 was produced at similar levels than Δ N5L1 Δ C30 and Δ N6L1 Δ C30 (Fig. 4, B, lanes 2-4 & 7-9), as it was observed in *E. coli* BL21(DE3), and confirmed that the carboxy-terminal truncation of the HPV-18 L1 was the deletion that led to an increase in the HPV-18 L1 amount in *E. coli*. The truncated proteins L1 Δ C30, Δ N5L1 Δ C30 and Δ N6L1 Δ C30 had similar solubility profiles and they were detected in a percentage higher than 50 % in the soluble fraction of *E. coli* SHuffle cytoplasm (Fig. 4, B, lanes 2-4 vs. 7-9), which was higher than the proportion obtained in *E. coli* BL21(DE3). Additionally, a clear band of about 50 kDa was detected at lower levels than that the truncated full size proteins in the soluble fractions, which were not present in the insoluble fractions of *E. coli* SHuffle T7 (Fig. 4, B, lanes 2-4 vs. 7-9) nor in the cellular fractions of *E. coli* BL21(DE3). This phenomenon could be related to the proteolytic activity of some proteases like OmpT, which is present in the genome of *E. coli* SHuffle T7, a K-12 *E. coli* derivative.^(40,41)



A: 10 % SDS-PAGE stained with Coomassie blue R-250, and B: Immunoblotting analysis using the HPV-16 L1 antibody CAMVIR-1. Lane 1, pET26b-HPV-18 L1 soluble fraction (sf); lane 2, pETHPV18L1ΔC30 sf; lane 3, pETHPV18ΔN5L1ΔC30 sf; lane 4, pETHPV18ΔN6L1ΔC30 sf; lane 5, pET28a-HPV-18L1-tag sf; lane 6, pET26b-HPV-18 L1 insoluble fraction (if); lane 7, pETHPV18L1ΔC30 if; lane 8, pETHPV18ΔN5L1ΔC30 if; lane 9, pETHPV18ΔN6L1ΔC30 if; lane 10, pET28a-HPV-18L1-tag if; M, Broad-range protein molecular weight markers (Promega, USA). The arrow in lane 10 (4A) shows the band corresponding to the expected Histag-HPV-18L1.

Fig. 4 - Soluble production of truncated and 6xHis-tagged variants of HPV-18 L1 achieved under conventional IPTG induction in *E. coli* SHuffle T7.

Histag-HPV-18L1 protein was mainly detected in the *E. coli* SHuffle T7 insoluble fraction (Fig. 4, A and 4, B, lanes 5 and 10), which suggested that the fusion protein was also forming insoluble aggregates or it was deposited in inclusion bodies (Ib), similar to the full-length HPV-18 L1 (Fig. 4, A and 4, B, lane 1 and 6). Taking into account that the Histag-HPV-18L1 protein was obtained at higher amounts than the full-length HPV-18 L1 in the insoluble fraction (Fig. 4, B, lanes 6 vs. 10), the *E. coli* SHuffle T7 [pET28a-HPV-18L1-tag] cells were analyzed by TEM. This analysis revealed the presence of Ib (Fig. 5), which indicated that the Histag-HPV-18L1 protein was aggregated in Ib in *E. coli* SHuffle T7.

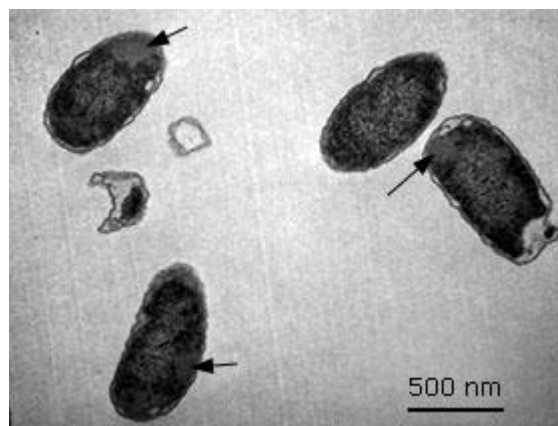
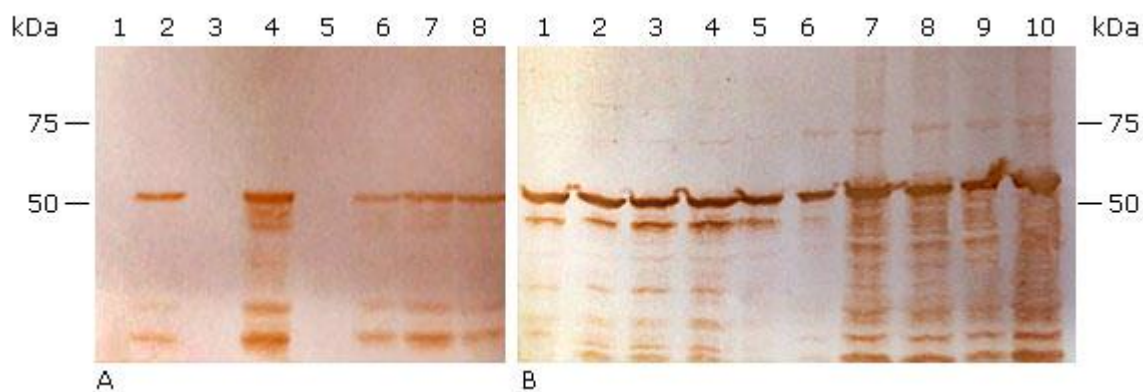


Fig. 5 - Ultrathin sections of *E. coli* SHuffle T7 [pET28a-HPV-18 L1-tag] observed by transmission electron microscopy. Cells were cultivated in TB medium at 28 °C for 4 h, upon 0.1 mM IPTG induction. The arrows indicate the inclusion bodies.

Production of the HPV-18 L1 variant truncated only at the carboxy terminus by *E. coli* SHuffle T7 in auto-induction conditions

Considering the low levels of HPV-18 L1 produced by *E. coli* SHuffle T7 when it was cultured under conventional induction with IPTG, we evaluated its production under auto-induction conditions, with lactose or IPTG as autoinducers.^(36,42) The variant truncated only at the carboxy terminus L1 Δ C30 was selected for this study, since it carries the deletion that contributed to increase the amounts and solubility of this recombinant protein under conventional IPTG induction (Fig. 4).

At 14 h of auto-induction, immunoreactive bands with the expected size (~52 kDa) were detected in whole cell lysates of the recombinant strain (Fig. 6, A, lanes 4 and 6-8). The relative band intensities of L1 Δ C30 were similar at all tested IPTG concentrations in auto-induction conditions (125 μ M, 60 μ M and 30 μ M) (Fig. 6, A, lanes 6-8). These results suggested that there is no a linear relationship between the IPTG concentration in autoinduction conditions and the expression levels of the truncated HPV-18 L1 in *E. coli* SHuffle T7, which was in agreement with the fact that the *E. coli* SHuffle T7 is not a *lacY* mutant. According to densitometric analysis, *E. coli* SHuffle T7 produced approximately three times more L1 Δ C30 under auto-induction with lactose, than by conventional induction with IPTG (Fig. 6, A, lanes 2 vs. 4). Thus, *E. coli* SHuffle T7 produced levels of L1 Δ C30 comparable to those obtained under conventional induction with IPTG by *E. coli* BL21(DE3). The solubility of L1 Δ C30 was a bit lower when *E. coli* SHuffle T7 was cultured under autoinduction conditions than in conventional induction with IPTG; since the full size L1 Δ C30 was present in about 40 % of the soluble fractions corresponding to autoinduction conditions (Fig. 6, B, lanes 1 and 6 vs. 2-5 and 7-10). Thus, *E. coli* SHuffle T7, grown in autoinduction conditions, was able to produce slightly higher amounts of soluble truncated full size L1 Δ C30 than *E. coli* BL1(DE3).



A: Immunodetection of L1ΔC30 in whole cell lysates. Lane 1, pET28a Conventional IPTG (c) 125 μM; lane 2, pETHPV18L1ΔC30 c 125 μM; lane 3, pET28a auto-induction lactose (A-L); lane 4, pETHPV18L1ΔC30 A-L; lane 5, pET28a auto-induction IPTG (A-IPTG) 125 μM; lane 6, pETHPV18L1ΔC30 A-IPTG 125 μM; lane 7, pETHPV18L1ΔC30 A-IPTG 60 μM; lane 8, pETHPV18L1ΔC30 A-IPTG 30 μM. B: Soluble production of L1ΔC30 by *E. coli* SHuffle T7 [pETHPV18L1ΔC30]. Lane 1, c 125 μM soluble fraction (sf); lane 2, A-L sf; lanes 3, 4 and 5: sf A-IPTG 125 μM, 60 μM and 30 μM, respectively, lane 6, c 125 μM insoluble fraction (if); lane 7, A-L if; lanes 8 9 and 10, if A-IPTG 125μM, 60 μM and 30 μM, respectively.

Fig. 6 - Production of L1ΔC30 by *E. coli* SHuffle T7 in autoinduction conditions.

DISCUSSION

In Cuba, several HPV genotyping studies have been conducted to estimate the prevalence of oncogenic types in female Cuban patients with different grades of cervical lesions and cancer.^(23,24,27) In those studies, most individuals were infected with high-risk HPV type. Particularly, the HPV-18 type was among the three most prevalent genotypes. These findings support the future inclusion of a preventive HPV vaccine in the Cuban National Program of Immunization.^(23,27) Considering these facts, we decided to study the expression of a wild-type HPV-18 L1 gene in *E. coli*, which is an efficient and inexpensive platform with potentials to produce proteins with self-assembling properties.^(13,43)

In this study, we have successfully isolated a HPV-18 L1 gene from a female Cuban patient and cloned it into *E. coli*. Analysis of its nucleotide sequence identified it as HPV-18 L1 gene and corroborated the previous diagnosis as HPV-18-positive. The cloned HPV-18 L1 gene was 99.9 % similar to the African variant EF202152, representative for HPV-18 sublineage B3, suggesting that the cloned L1 gene probably shares a common origin with the B lineage of genotype 18.

Taking into consideration that the expression of the full-length HPV-18 L1 gene has not been previously reported in *E. coli*, in the present study the full-length 18 L1 gene was subcloned into the plasmid vector, pET26b, and its expression was evaluated in *E. coli* BL21(DE3) and *E. coli* SHuffle T7. The native HPV-18 L1 protein was produced at low

levels in both *E. coli* strains, which was in agreement with the prediction of low translation initiation rate of the L1 gene. Subsequently, the effect of N- and C-terminal truncations on the production and solubility of the native HPV-18 L1 protein was assessed in *E. coli*. According to our results, double truncated L1 protein variants were produced at similar levels and solubility in both *E. coli* strains, compared to the carboxy-terminal-only truncated variant; which indicated that the carboxyl terminal truncation was responsible for increasing the HPV-18 L1 protein amount and solubility. This result was in agreement with previous works about the positive effect of the C-truncation on production and solubility of HPV-16 L1 protein in *E. coli*,^(21,44) and disagreed with the reported previously about the little or no effect of deletions of up to 30 C-terminal residues on stability or solubility of the HPV-16 L1 protein in *E. coli*.⁽⁵⁾ Unexpectedly, we did not find a positive effect of the amino terminal truncation on the HPV-18 L1 production and solubility, which was congruent with the reported recently by Akuzum et al about the no production of the wild-type HPV16 and HPV18 L1 proteins with N-terminal truncations in *E. coli*.⁽⁴⁵⁾ These findings could be related to an uncompleted removal of the potential inhibitory elements present at the 5' end of the cloned HPV-18 L1 gene, according to previous reports about the presence of inhibitory RNA elements in the HPV-16 L1 coding region.⁽⁴⁶⁾ Similar inhibitory elements have been found in the L1 coding regions of HPV-5, HPV-6, HPV-18, HPV-31, HPV-45 and HPV-56,⁽⁴⁷⁾ as well as in L1 from canine oral papillomavirus.⁽⁴⁸⁾ Consequently, the fusion of 20 codons, with a 6xHis tag included at the 5' end of the full-length HPV-18 L1 gene, led to the highest levels of HPV-18 L1 protein (Histag-HPV-18L1) in *E. coli*, which agreed with the highest TIR values predicted by the RBS Calculator. This last result could be explained by a possible displacement of the putative inhibitory elements due to the inserted fragment. Precisely, the transcriptional elements are one of the critical factors considered during optimization of synthetic genes for a chosen host. Thus, the use of a synthetic gene, with an optimized synthetic ribosome binding site sequence and with such inhibitory elements removed could promote higher amounts of the HPV-18 L1 protein in *E. coli*.

When previous studies on the effect of HPV L1 truncations on its production and solubility are reviewed, it is notorious that they were carried out with HPV L1 genes of different nucleotide sequences, and it is well known that the DNA sequence used to encode a polypeptide can have dramatic effects on its expression.⁽⁴⁹⁾ Codon identity, mRNA secondary structure and nucleotide composition of the genes markedly influence its

expression level in prokaryotic hosts.^(50,51) Consequently, the effect of N-terminal and C-terminal truncations of the HPV L1 protein on its production and solubility probably needs more experimental work and is actually a topic under active research.^(45,52)

Respect to the evaluated *E. coli* strains, BL21(DE3) produced the higher levels of the three truncated variants of HPV-18 L1 and Histag-HPV-18L1, when grown under conventional induction with IPTG. We previously tested *E. coli* Rosetta as host for the expression of HPV-18 L1 gene, considering the high content of rare codons in this gene, but the production levels of HPV-18 L1 protein were lower than the produced by *E. coli* BL21(DE3).⁽³⁴⁾ We had also evaluated *E. coli* BL21(DE3)-CodonPlus as host for the production of Histag-HPV-18L1 protein, but levels were similar to *E. coli* BL21(DE3) (data not shown). However, solubility of the three truncated variants of HPV-18 L1 was increased to more than 50 % in *E. coli* SHuffle T7, cultivated under conventional induction with IPTG. Particularly, *E. coli* SHuffle T7 produced about three times more amounts of the HPV-18 L1 variant truncated only at the carboxy terminus L1 Δ C30, when it was cultivated under autoinduction conditions and levels were comparable to those induced under conventional induction with IPTG by *E. coli* BL21(DE3). To our knowledge, this is the first report about the soluble production of HPV-18 L1 protein in an *E. coli* SHuffle strain. Since *E. coli* SHuffle T7 produced the higher levels of L1 Δ C30 under auto-induction with lactose is possible to increase the amounts and solubility of this protein through optimization of the fermentation conditions such as: pH, temperature, dissolved oxygen and growth medium.^(53,54) The soluble fraction of *E. coli* SHuffle T7 might have a suitable amount of properly folded HPV-18 L1, considering that its cytoplasm is maintained in an oxidative state and contains the Disulfide bond C (DsbC).⁽⁵⁵⁾ Thus, current experiments are in progress to purify the L1 Δ C30 protein from the soluble fraction of *E. coli* SHuffle T7, considering the potential higher quality of L1 protein in this fraction compared to Ib. In the future, other strategies should be evaluated such as: the use of a synthetic gene, with optimized codon usage for *E. coli*, with an optimized synthetic ribosome binding site sequence and with inhibitory elements removed. All this with the aim to contribute to increase the amounts of HPV-18 L1 protein in *E. coli*.

Conclusions

The HPV-18 L1 gene cloned in this study had the highest level of sequence similarity (99.9 %) to the African variant EF202152, the representative for HPV-18 sublineage B3, suggesting that the cloned L1 gene probably shares a common origin with the B lineage of

genotype 18. *E. coli* BL21(DE3) produced higher levels of the three truncated variants of HPV-18 L1 and Histag-HPV-18L1 than *E. coli* SHuffle T7, when conventional induction with IPTG was used. However, higher amounts of the three truncated proteins of HPV-18 L1 (more than 50 %) were detected in the soluble fraction of *E. coli* SHuffle T7. The variant truncated only by the carboxyl terminus, L1 Δ C30 was produced to similar levels and solubility than HPV-18 L1s truncated at both termini, which indicated that the carboxy-terminal truncation of the HPV-18 L1 had a major contribution to the production and solubility of the wild-type HPV-18 L1 protein in the two *E. coli* strains tested. In autoinduction conditions, *E. coli* SHuffle T7 produced about three times more amounts of the variant truncated only by the carboxyl terminus than in IPTG's conventional induction and levels were comparable to those obtained under conventional induction with IPTG by *E. coli* BL21(DE3). Thus, for the first time it is shown that *E. coli* SHuffle T7 strain produced the HPV-18 L1 protein in its soluble fraction. However, higher amounts of the L1 protein are needed to scale-up its production for developing a HPV vaccine candidate.

Acknowledgement

We would like to thank M.Sc. Diamilé González Roche (Direction of Technological Development, Center for Genetic Engineering and Biotechnology, Cuba) for the help with the protein translation initiation prediction software tools. We thank Mariuska Matos (Analytical Unit, Center for Genetic Engineering and Biotechnology, Cuba) for preparing cell samples for the transmission electron microscopy. The authors declare no conflict of interest in this article.

BIBLIOGRAPHIC REFERENCES

1. Munoz N, Castellsagué X, de González AB, Gissmann L. HPV in the etiology of human cancer. *Vaccine*. 2006;24:S1-S10.
2. Baker T, Newcomb W, Olson N, Cowser L, Olson C, Brown J. Structures of bovine and human papillomaviruses. Analysis by cryoelectron microscopy and three-dimensional image reconstruction. *Biophys J*. 1991;60(6):1445-56.

3. Hagensee ME, Yaegashi N, Galloway DA. Self-assembly of human papillomavirus type 1 capsids by expression of the L1 protein alone or by coexpression of the L1 and L2 capsid proteins. *J. Virol.* 1993;67(1):315-22.
4. Kirnbauer R, Booy F, Cheng N, Lowy D, Schiller J. Papillomavirus L1 major capsid protein self-assembles into virus-like particles that are highly immunogenic. *Proc Natl Acad Sci USA.* 1992;89(24):12180-4.
5. Chen XS, Garcea RL, Goldberg I, Casini G, Harrison SC. Structure of small virus-like particles assembled from the L1 protein of human papillomavirus 16. *Mol Cell.* 2000;5(3):557-67.
6. Kirnbauer R, Taub J, Greenstone H, Roden R, Dürst M, Gissmann L, et al. Efficient self-assembly of human papillomavirus type 16 L1 and L1-L2 into virus-like particles. *J Virol.* 1993;67(12):6929-36.
7. Lowy DR. HPV vaccination to prevent cervical cancer and other HPV-associated disease: from basic science to effective interventions. *J Clin Invest.* 2016 Jan;126(1):5-11. doi: 10.1172/JCI85446.
8. Bruni L, Barrionuevo-Rosas L, Serrano B, Mena M, Gómez D, Muñoz J, et al; ICO Information Centre on HPV and Cancer (HPV Information Centre). Human Papillomavirus and Related Diseases. Summary Report May 19, 2017.
9. Pirog EC, Lloveras B, Molijn A, Tous S, Guimerà N, Alejo M, et al. HPV prevalence and genotypes in different histological subtypes of cervical adenocarcinoma, a worldwide analysis of 760 cases. *Mod Pathol.* 2014;27(12):1559-67.
10. Kim J-Y, Nam BH, Lee J-A. Is human papillomavirus genotype an influencing factor on radiotherapy outcome? Ambiguity caused by an association of HPV 18 genotype and adenocarcinoma histology. *J Gynecol Oncol.* 2011;22(1):32-8.
11. Sapp M, Fligge C, Petzak I, Harris JR, Streeck RE. Papillomavirus assembly requires trimerization of the major capsid protein by disulfides between two highly conserved cysteines. *J. Virol.* 1998;72(7):6186-9.
12. Kim H, Yoo SJ, Kang HA. Yeast synthetic biology for the production of recombinant therapeutic proteins. *FEMS Yeast Res.* 2015 Feb;15(1):1-16.
13. Gu Y, Wei M, Wang D, Li Z, Xie M, Pan H, et al. Characterization of an *Escherichia coli*-derived human papillomavirus type 16 and 18 bivalent vaccine. *Vaccine.* 2017;35:4637-45.

14. Bishop B, Dasgupta J, Klein M, Garcea RL, Christensen ND, Zhao R, et al. Crystal structures of four types of human papillomavirus L1 capsid proteins: understanding the specificity of neutralizing monoclonal antibodies. *J Biol Chem*. 2007;282(43):31803-11.
15. Chen XS, Casini G, Harrison SC, Garcea RL. Papillomavirus capsid protein expression in *Escherichia coli*: purification and assembly of HPV11 and HPV16 L1. *J Mol Biol*. 2001;307(1):173-82.
16. Bang HB, Lee YH, Lee YJ, Jeong KJ. High-level production of human papillomavirus (HPV) type 16 L1 in *Escherichia coli*. *J Microbiol Biotechnol*. 2016;26(2):356-63.
17. Hanslip SJ, Zaccai NR, Middelberg AP, Falconer RJ. Assembly of Human Papillomavirus Type-16 Virus-Like Particles: Multifactorial Study of Assembly and Competing Aggregation. *Biotechnol Prog*. 2006;22(2):554-60.
18. Ishii Y, Tanaka K, Kanda T. Mutational analysis of human papillomavirus type 16 major capsid protein L1: the cysteines affecting the intermolecular bonding and structure of L1-capsids. *Virology*. 2003;308(1):128-36.
19. Webb E, Cox J, Edwards S. Cervical cancer-causing human papillomaviruses have an alternative initiation site for the L1 protein. *Virus genes*. 2005;30(1):31-5.
20. Seo P, Heo S, Han E, Seo J, Ghim S, Kim Ch. Bacterial Expression and Purification of Human Papillomavirus Type 18 L1. *Biotechnol. Bioprocess Eng*. 2009;14:168-74.
21. Schadlich L, Senger T, Gerlach B, Mucke N, Klein C, Bravo IG, et al. Analysis of modified human papillomavirus type 16 L1 capsomeres: the ability to assemble into larger particles correlates with higher immunogenicity. *J Virol*. 2009;83(15):7690-705.
22. Deschuyteneer M, Elouahabi A, Plainchamp D, Plisnier M, Soete D, Corazza Y, et al. Molecular and structural characterization of the L1 virus-like particles that are used as vaccine antigens in Cervarix, the AS04-adjuvanted HPV-16 and -18 cervical cancer vaccine. *Hum Vaccin*. 2010;6(5):407-19.
23. Soto Y, Torres G, Kouri V, Limia CM, Goicolea A, Capo V, et al. Molecular epidemiology of human papillomavirus infections in cervical samples from Cuban women older than 30 years. *J Low Genit Tract Dis*. 2014;18(3):210-7.
24. Soto Y, Mune M, Morales E, Goicolea A, Mora J, Sanchez L, et al. Human papillomavirus infections in Cuban women with cervical intraepithelial neoplasia. *Sex Transm Dis*. 2007;34(12):974-6.

25. Ríos Hernández MA, Hernández Menéndez M, Aguilar Vela de Oro FO, Silveira Pablos M, Amigó de Quesada M, Aguilar Fabrè K. Tipos de papilomavirus humanos más frecuentes en muestras cubanas de cáncer cervical. Rev Cubana Obstet Ginecol. 2010;36(2):104-11.
26. Piña Napal JC, Crespo Campos G, Fando Calzado R, Casanova Corona G, Curbelo Toledo M, Guerra Rodríguez MM. Identificación molecular de genotipos papilomavirus humanos en pacientes con cáncer de cuello uterino. Rev Arch Med Camagüey. 2016;20(3):288-98.
27. Soto Y, León CML, Cardellá VK, Maiza AG, de Paz VC, Jiménez MM. Papilomavirus humanos y otros factores asociados al desarrollo de lesiones cervicouterinas en mujeres cubanas. Panorama Cuba y Salud. 2016;11(1):24-33.
28. Soto Y, Limia CM, González L, Grá B, Hano OM, Martínez PA, et al. Molecular evidence of high-risk human papillomavirus infection in colorectal tumours from Cuban patients. Mem Inst Oswaldo Cruz. 2016;111(12):731-6.
29. Limia CM, Soto Y, García Y, Blanco O, Kourí V, López MV, et al. Human papillomavirus infection in anal intraepithelial lesions from HIV infected Cuban men. Infect Agent Cancer. 2017;12(1):5.
30. Ortega D, Palenzuela A, Tamayo L, Pascual M, Santana A, López M, et al. Prevalencia y distribución de genotipos de alto riesgo del virus del papiloma humano en una población de mujeres en La Habana. 8vo. Congreso Cubano de Microbiología y Parasitología en Cuba. La Habana, 14-16 de Octubre, 2014.
31. Chen Z, Schiffman M, Herrero R, DeSalle R, Anastos K, Segondy M, et al. Evolution and taxonomic classification of alphapapillomavirus 7 complete genomes: HPV18, HPV39, HPV45, HPV59, HPV68 and HPV70. PloS One. 2013;8(8):e72565.
32. Salis HM, Mirsky EA, Voigt CA. Automated design of synthetic ribosome binding sites to control protein expression. Nat Biotechnol. 2009;27(10):946-50.
33. Seo SW, Yang J-S, Kim I, Yang J, Min BE, Kim S, et al. Predictive design of mRNA translation initiation region to control prokaryotic translation efficiency Metab Eng. 2013;15:67-74.
34. Pimienta E, Aldama G, Serrano Y, Rodríguez S, Otero A, Fando R, et al. Expresión del gen L1 del Virus del Papiloma Humano tipo 18, aislado de una biopsia de una paciente cubana, en cepas de *Escherichia coli*. Rev CENIC Ciencias Biológicas. 2018;49(3).

35. Studier FW. Protein production by auto-induction in high-density shaking cultures. *Protein Expr Purif.* 2005;41(1):207-34.
36. Diederichs S, Korona A, Staaden A, Kroutil W, Honda K, Ohtake H, et al. Phenotyping the quality of complex medium components by simple online-monitored shake flask experiments. *Microb Cell Fact.* 2014;13(1):149.
37. Laemmli UK. Cleavage of structural proteins during the assembly of the head of bacteriophage T4. *Nature.* 1970;227(5259):680.
38. Sambrook J, Fritsch E, Maniatis T. *Molecular Cloning: a Laboratory Manual.* 2nd ed. New York, EE UU: Cold Spring Harbor Laboratory Press, Cold Spring Harbor; 1989.
39. Lazar I, Lazar I. Gel Analyzer 2010a: Freeware 1D gel electrophoresis image analysis software. 2010 [cited 2017 Aug 20]. Available from: <http://www.gelanalyzer.com/>
40. Kelsall S, Kulski J. Expression of the major capsid protein of human papillomavirus type 16 in *Escherichia coli* *J Virol Methods.* 1995;53(1):75-90.
41. Doorbar J, Gallimore PH. Identification of proteins encoded by the L1 and L2 open reading frames of human papillomavirus 1a. *J. Virol.* 1987;61(9):2793-9.
42. Faust G, Stand A, Weuster-Botz D. IPTG can replace lactose in auto-induction media to enhance protein expression in batch-cultured *Escherichia coli*. *Eng Life Sci.* 2015;15(8):824-9.
43. Huang X, Wang X, Zhang J, Xia N, Zhao Q. *Escherichia coli*-derived virus-like particles in vaccine development. *NPJ Vaccines.* 2017;2(1):3.
44. Muller M, Zhou J, Reed TD, Rittmuller C, Burger A, Gabelsberger J, et al. Chimeric papillomavirus-like particles. *Virology.* 1997;234(1):93-111.
45. Akuzum B, Kim S, Nguyen TT, Hong J, Lee S, Kim E, et al. L1 Recombinant Proteins of HPV Tested for Antibody Forming Using Sera of HPV Quadrivalent Vaccine. *Immune Netw.* 2018;18(3).
46. Mori S, Ozaki S, Yasugi T, Yoshikawa H, Taketani Y, Kanda T. Inhibitory cis-element-mediated decay of human papillomavirus type 16 L1-transcript in undifferentiated cells. *Mol Cell Biochem.* 2006;288(1-2):47-57.
47. Collier B, Oberg D, Zhao X, Schwartz S. Specific inactivation of inhibitory sequences in the 5' end of the human papillomavirus type 16 L1 open reading frame results in production of high levels of L1 protein in human epithelial cells. *J Virol.* 2002;76(6):2739-52.

48. Berg M, Di Fatta J, Hoiczky E, Schlegel R, Ketner G. Viable adenovirus vaccine prototypes: high-level production of a papillomavirus capsid antigen from the major late transcriptional unit. *Proc Natl Acad Sci USA*. 2005;102(12):5.
49. Gustafsson C, Minshull J, Govindarajan S, Ness J, Villalobos A, Welch M. Engineering genes for predictable protein expression. *Protein Expr Purif*. 2012;83(1):37-46.
50. Allert M, Cox JC, Hellinga HW. Multifactorial determinants of protein expression in prokaryotic open reading frames. *J Mol Biol*. 2010;402(5):905-18.
51. Buhr F, Jha S, Thommen M, Mittelstaet J, Kutz F, Schwalbe H, et al. Synonymous codons direct cotranslational folding toward different protein conformations. *Mol Cell*. 2016;61(3):341-51.
52. Wei M, Wang D, Li Z, Song S, Kong X, Mo X, et al. N-terminal truncations on L1 proteins of human papillomaviruses promote their soluble expression in *Escherichia coli* and self-assembly *in vitro*. *Emerg Microbes Infect*. 2018;7(1):160.
53. Wurm DJ, Quehenberger J, Mildner J, Eggenreich B, Slouka C, Schwaighofer A, et al. Teaching an old pET new tricks: tuning of inclusion body formation and properties by a mixed feed system in *E. coli*. *Appl Microbiol Biotechnol*. 2018;102(2):667-76.
54. Samuelson JC, Causey TB, Berkmen M. Disulfide-bonded protein production in *E. coli*. *Genet Eng Biotechnol News*. 2012;32(3).
55. Lobstein J, Emrich CA, Jeans C, Faulkner M, Riggs P, Berkmen M. SHuffle, a novel *Escherichia coli* protein expression strain capable of correctly folding disulfide bonded proteins in its cytoplasm. *Microb Cell Fact*. 2012;11(1):753.

Conflict of interest

The author declare no conflict of interest in this article.