


# HPV-16 E6/E7 DNA tattoo vaccination using genetically optimized vaccines elicit clinical and immunological responses in patients with usual vulvar intraepithelial neoplasia (uVIN): a phase I/II clinical trial

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## ABSTRACT

**Background** Usual vulvar intraepithelial neoplasia (uVIN) is a premalignancy caused by persistent infection with high-risk types of human papillomavirus (HPV), mainly type 16. Even though different treatment modalities are available (eg, surgical excision, laser evaporation or topical application of imiquimod), these treatments can be mutilating, patients often have recurrences and 2%–8% of patients develop vulvar carcinoma. Therefore, immunotherapeutic strategies targeting the pivotal oncogenic HPV proteins E6 and E7 are being explored to repress carcinogenesis.

**Method** In this phase I/II clinical trial, 14 patients with HPV16 + uVIN were treated with a genetically enhanced DNA vaccine targeting E6 and E7. Safety, clinical responses and immunogenicity were assessed. Patients received four intradermal HPV-16 E6/E7 DNA tattoo vaccinations, with a 2-week interval, alternating between both upper legs. Biopsies of the uVIN lesions were taken at screening and +3 months after last vaccination. Digital photography of the vulva was performed at every check-up until 12 months of follow-up for measurement of the lesions. HPV16-specific T-cell responses were measured in blood over time in ex vivo reactivity assays.

**Results** Vaccinations were well tolerated, although one grade 3 suspected unexpected serious adverse reaction was observed. Clinical responses were observed in 6/14 (43%) patients, with 2 complete responses and 4 partial responses (PR). 5/14 patients showed HPV-specific T-cell responses in blood, measured in ex vivo reactivity assays. Notably, all five patients with HPV-specific T-cell responses had a clinical response.

**Conclusions** Our results indicate that HPV-16 E6/E7 DNA tattoo vaccination is a biologically active and safe treatment strategy in patients with uVIN, and suggest that T-cell reactivity against the HPV oncogenes is associated with clinical benefit.

**Trial registration number** NTR4607.

## INTRODUCTION

Usual vulvar intraepithelial neoplasia (uVIN), also known as vulvar high-grade squamous intraepithelial lesions, is a premalignant chronic skin disorder of the vulva and associated with a persistent infection with high risk types of human papillomavirus (HPV), mainly HPV type 16.<sup>1–3</sup> Spontaneous regression is rare, restricted to 1%–2% of women, and progression to vulvar cancer is observed in 2%–8% of cases.<sup>4–8</sup> Current treatment strategies are laser ablation, local excision or topical treatment with the toll-like receptor (TLR) 7-ligand imiquimod. Since patients frequently suffer from recurrent disease, different sequential therapies are often applied over the years.<sup>5 7–9</sup> Multiple surgical treatments can however be mutilating, and induce psychosexual dysfunction.<sup>10 11</sup> Also, topical treatment with imiquimod is associated with side effects such as pruritus and pain.<sup>12</sup> In order to avoid the need for debilitating treatments, and prevent relapses and potential malignant transformation, new therapeutic strategies should be explored with a final goal to eradicate transformed, oncoprotein E6 and E7 expressing epithelial cells.

Infection with high-risk genotypes of HPV leads to the expression of the oncogenic HPV proteins E6 and E7. Together, E6 and E7 drive cellular immortalization and maintain the transformed phenotype during tumor progression.<sup>13–15</sup> The E6 and E7 oncoproteins are continuously expressed in transformed cells, consequently enabling presentation of E6 and E7 epitopes by the transformed

cells and creating the opportunity for T-cell recognition. Notably, patients with persistent uVIN often have dysfunctional HPV16-specific T-cell responses,<sup>16–18</sup> suggesting that immune stimulating therapies that induce or enhance functional HPV16-specific T-cell responses may lead to clinical benefit.

In line with this notion, several HPV-vaccination studies targeting E6 and/or E7 have been performed with some promising immunological and clinical responses, confirming the suitability of the target proteins. Strategies that have been studied included genetic vaccines (DNA/RNA/virus/bacterial), protein-based, peptide-based or dendritic cell-based vaccines.<sup>19–22</sup> To date, these vaccines have not found their way to clinical practice because of little efficacy, high production costs, or cumbersome production processes like dendritic cell-based vaccines which requires a personalized cell product. Also upscaling the cell expansion protocol for adoptive transfer can be complicated and troublesome.

DNA vaccination forms an attractive approach for the induction of cellular immune responses, as these vaccines are easy to produce, very stable, relatively cheap and do not suffer from the drawback of pre-existing immunity or induction of antivector immunity, as is the case for most viral vectors.<sup>23,24</sup> Since subcutaneous administration with adjuvant of peptide-based therapeutic HPV-vaccines can cause significant adverse events (such as local skin swelling)<sup>21</sup> we focused on improving the administration route and optimization of immunogenicity of the vaccine. Therefore, we developed a DNA vaccination strategy based on DNA tattoo vaccination, which demonstrated a 10–100 fold increase in vaccine specific T-cell responses as compared with classical intramuscular DNA vaccination when tested in non-human primates.<sup>25</sup>

Recently, we performed for the first time a phase I clinical trial using the E7 directed DNA vaccine tetanus toxin fragment C (TTFC)-E7SH, which was delivered using the tattooing technique in patients with uVIN.<sup>26</sup> This DNA vaccine was well tolerated and the tattoo-induced skin damage was completely reversible. However, no induction of E7 directed CD8<sup>+</sup> responses nor clinical responses could be observed.<sup>26</sup>

The aim of the current study is to improve the immunological response and monitor clinical outcome in patients with uVIN. Therefore, we developed a novel DNA vaccine that can be administered by DNA tattoo vaccination.<sup>27</sup> Since targeting both E6 and E7 has been reported to have a synergistic effect on HPV infection control,<sup>26,28</sup> both oncogenes are targeted in this new format. With the combined novel DNA vaccines sig-HELP-E6SH-KDEL and sig-HELP-E7SH-KDEL (further referred to as HPV-16 E6/E7 DNA tattoo vaccine), we aim to increase the immunogenicity towards E6 and E7 by inducing CD4<sup>+</sup> helper T cells and including signals for enhanced endoplasmic reticulum targeting and retention. Here, we describe the results of a phase I/II clinical trial in which we evaluated the toxicity, clinical response and immunogenicity of this HPV-16 E6/E7 DNA tattoo vaccination in patients with uVIN.

## MATERIALS AND METHODS

### Patients

Fourteen female patients with histology and PCR proven HPV16 + uVIN lesions were included between January 2017 and December 2019. Patients needed to have adequate bone marrow function, renal function and liver function. Exclusion criteria were pregnancy/lactation, active infectious disease, autoimmune disease or immunodeficiency. Other exclusion criteria were use of oral anticoagulant drugs or an indication of severe cardiac, respiratory or metabolic disease. Furthermore, patients could not participate if the uVIN was treated with another modality within 6 weeks prior to enrolment, if patients were treated before with therapeutic HPV vaccines, or if patients participated in a study with another investigational drug (for different indications than uVIN) within 30 days prior to enrolment. Patient characteristics are shown in [table 1](#).

### Vaccine composition

The HPV-16 E6/E7 DNA vaccine comprises of sig-HELP-E6SH-KDEL and sig-HELP-E7SH-KDEL, which are plasmid DNA constructs of 4814 and 5240 base pairs, respectively ([figure 1A](#)). In this plasmid, the cytomegalovirus promoter drives the continuous expression of E6SH and E7SH. To prevent toxicity and protect against the transforming properties of E6 and E7, coding sequences were rearranged ('shuffled'). To prevent loss of potential immunogenic epitopes, sequences flanking the positions where the coding sequence was cut were added 3' from the coding regions ([figure 1B](#)). The HPV-16 E6/E7 DNA vaccine includes three CD4 helper sequences: antigenic epitopes of the negative factor protein from HIV (39 bp),<sup>29</sup> the P30 epitope derived from tetanus toxin (63 bp)<sup>30</sup> and the universal synthetic, non-natural pan human leukocyte antigen (HLA) DR epitope (39 bp).<sup>31</sup> By only inserting the relevant CD4 epitopes, and not the full protein domains, the risk of antigenic competition and skewing of the CD8<sup>+</sup> T cell response towards the helper epitopes was minimized. The C-terminal KDEL amino acid sequence was included to achieve endoplasmic reticulum targeting and retention, resulting in higher immunogenicity.<sup>24,32</sup>

For the manufacturing of both vaccines, a standard Good manufacturing practice production process was followed as described earlier.<sup>33</sup> Resulting DNA vaccines were formulated as a lyophilized powder for solution for intradermal injection, using sucrose as stabilizer.<sup>33</sup> Just before administration, 1 mg of sig-HELP-E6SH-KDEL was reconstituted with 0.4 mL water for injection and mixed with 1 mg reconstituted sig-HELP-E7SH-KDEL to obtain 2 mg of the combined HPV-16 E6/E7 DNA tattoo vaccine at a concentration of 5 mg/mL. For each of the four subsequent vaccinations, 2 mg of the combined HPV-16 E6/E7 DNA tattoo vaccine was used.

### Study design

This was a single center, non-randomized phase I/II study, consisting of two cohorts. In the first cohort, five

**Table 1** Baseline characteristics of the study population

Patient no.	Age	Multi/unifocal	Symptoms	Smoker	Previous treatment(s)	First diagnosis uVIN	Lesion size (cm <sup>2</sup> )
1	51	Uni	Pruritus	No	Laser, LE (2×), imiquimod	2012	1.4
2	64	Multi	Pruritus	Former smoker (stopped in 2016)	Laser, imiquimod	2015	1.3
3	55	Multi	Pruritus	Smoker	None	2017	0.6
4	37	Multi	None	Former smoker (stopped in 2017)	LE	2013	3.5
5	65	Uni	Pain	Former smoker (stopped in 1998)	None	2017	3.5
6	69	Uni	None	Former smoker	Laser (2×), imiquimod	1996	0.9
7	46	Multi	None	Smoker	LE (3×)	2010	3.7
8	45	Uni	None	Former smoker (stopped in 2018)	Imiquimod	2018	3.8
9	41	Multi	Pruritus	Smoker	Laser (3×), LE (3×), imiquimod (3×)	2005	36
10	50	Multi	Pruritus	Smoker	LE (3×), laser (6×), imiquimod	1993	6.8
11	46	Multi	None	Smoker	Laser (2×), imiquimod	2016	1.7
12	61	Multi	Pruritus, pain	Former smoker (stopped in 1995)	Laser, LE, imiquimod	2003	3.5
13	29	Multi	None	Smoker	Imiquimod	2019	0.7
14	36	Multi	Pruritus, pain	Smoker	Laser	2017	2.0

All patients were diagnosed with human papillomavirus (HPV) type 16, but patient #10 had a coinfection with HPV type 56 and patient #13 had a coinfection with HPV type 40.

LE, local excision; uVIN, usual vulvar intraepithelial neoplasia.

patients were treated, followed by an interim analysis that assessed vaccine immunogenicity. Since the criteria for continuation after interim analysis were met (a twofold increase in the T cell response compared with baseline in  $\geq 2$  out of 5 patients), an additional 9 patients were enrolled. Patients in both cohorts were treated identically. The primary objective of this trial was to study the systemic HPV-specific immune response of patients with HPV16 + uVIN that received the HPV-16 E6/E7 DNA tattoo vaccine. Secondary objectives were the safety and clinical responses. However, to improve the readability of the paper, we will first discuss our clinical findings, followed by the immunogenicity data.

The HPV-16 E6/E7 DNA tattoo vaccine was applied topically on the skin of the upper legs (close to a regional lymph node area) on days 0, 14, 28 and 42 and administered into the skin using a permanent make-up tattoo device (Derm.MT GmbH, Berlin, Germany). Patients received 2 mg of vaccine injected over a skin surface of 16 cm<sup>2</sup>. Prior to tattoo vaccination, the skin area was treated with an epilating cream (Veet; Reckitt Benckiser Healthcare B.V., Hoofddorp, The Netherlands). Vaccination at day 28 was administered to the same area as vaccination at day 0, and vaccination at day 42 was administered to the same area as vaccination at day 14. Patients were observed during 1 hour after tattooing. Peripheral blood mononuclear cell (PBMC) isolation was performed at day 0 and day 28 before vaccine administration, and at follow-up on day 56 and day 84. A biopsy of the uVIN was taken

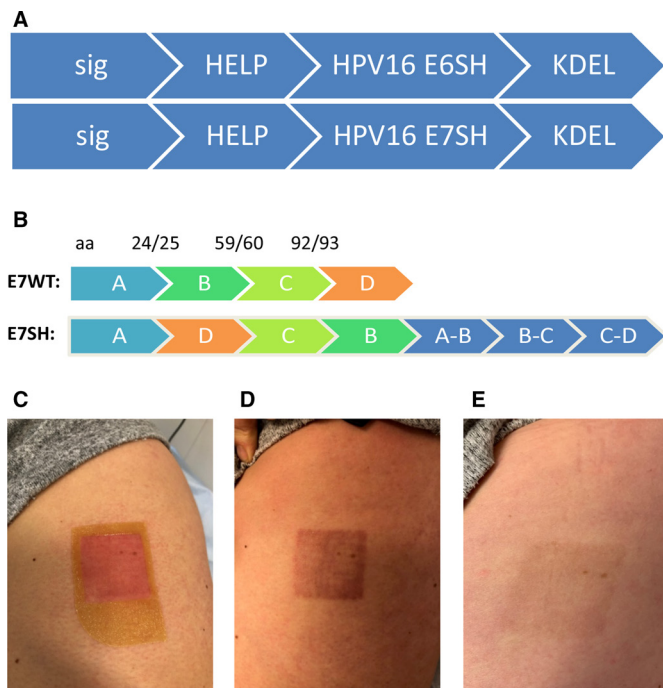
before treatment and 3 months after the last vaccination. Patients were seen for follow-up after 3, 6, 9 and 12 months after last vaccination with evaluation of the vulvar lesions including photography and measurement of the size of the lesion(s).

### Safety and toxicity

The Common Terminology Criteria for Adverse Events (CTCAE) V.4.03 was used for the assessment of adverse events. All patients that received at least one vaccine dose were included in the evaluation of safety. Vital signs were measured at baseline and at all visiting days. Hematology and biochemistry tests were performed before inclusion, and at days 0, 28, 56 and 84. Unacceptable toxicity was defined as an adverse event of the following types for which the relation to the study treatment was likely or not assessable: non-hematological toxicity of grade 3 or higher, hematological toxicity grade 4, neutropenia grade 3 plus fever, or non-reversible neurotoxicity of grade  $>2$ . In case unacceptable toxicity occurred in more than 30% of patients, the study would be discontinued. Local toxicity was scored as CTCAE ‘injection site reaction’.

### Clinical responses

Lesions were examined and the size was measured bi-dimensionally by an experienced gynecologist and another member of the study team. Drawings were made on a vulvoscopy form in the medical record. Furthermore, the lesions were monitored by digital photography.



**Figure 1** pUMC3 sig-HELP-E6SH-KDEL and pUMVC3 sig-HELP-E7SH-KDEL plasmids used in this trial and administered by tattoo vaccination. (A) Schematic representation of the therapeutic region of the plasmid, including three helper sequences: synthetic epitope pan human leukocyte antigen (HLA) DR epitope (39 bp), negative factor from HIV (39 bp) and P30 from tetanus toxin (63 bp) for CD4 help. Sig and KDEL for improved endoplasmic reticulum targeting and retention, resulting in better antigen uptake by dendritic cells, enhanced processing and presentation. (B) To prevent toxicity, E6 and E7 coding sequences were shuffled. Splice sites are added at the back of the construct so no potential immunogenic epitopes are lost. (C) Picture of the patients' skin immediately after vaccination with human papillomavirus (HPV)-16 E6/E7 tattoo vaccination. (D) Picture of the skin 2 weeks after vaccination. (E) Picture of the skin 6 months after last vaccination, demonstrating hardly any visible tissue scar remains.

The total area (in mm<sup>2</sup>) of the lesions was determined using ImageJ. A complete response (CR) was defined as a complete disappearance of the lesion(s) and a partial response (PR) defined as at least 50% regression of the lesion. A patient was classified as a non-responder (NR) if lesion size was reduced by less than 50% compared with the original lesion size, or in case of progressive disease.

### Immune monitoring

To assess systemic induction of HPV E6 and E7 specific T cells, PBMCs were collected at baseline (day 0) and at days 28, 56, and 84 after the first HPV-16 E6/E7 DNA tattoo vaccination. PBMCs were isolated from fresh heparinized blood samples by Ficoll density-gradient centrifugation and cryopreserved until further use.

Presence and magnitude of HPV E6 and E7 specific T-cell responses were determined by co-culture of T cells with autologous antigen presenting cells (APCs) loaded with long overlapping peptides for 6 hours (adapted

protocol based on method described by Samuels *et al*<sup>26</sup>). To obtain peptide loaded APCs, PBMCs were thawed and plated in 24 well plates at a concentration of 0.3–1.5\*10<sup>6</sup> cells/mL in T cell mixed media (20% Roswell Park Memorial Institute/ 80% AIM-V medium) without serum. Monocytes were separated by plate adherence, and the non-adherent cells were harvested to be used as T cell input in the co-culture. Monocytes were peptide loaded in T cell mixed media with 800 U/mL granulocyte-macrophage colony-stimulating factor (Invitrogen/Thermo Fisher Scientific, California, USA) with five different peptide pools. Long overlapping peptides covering the entire E6 protein were split over pool 1 and 2, long overlapping peptides covering the entire E7 protein were combined in pool 3. Pool 4 consisted of all epitopes that arose as a consequence of shuffling E6 and E7 proteins. The full amino acid sequences of the long overlapping peptides from these four pools are listed in online supplemental table 1. Pool 5 consisted of a set of 32 viral epitopes covering multiple HLA-alleles, and served as a positive control to assess immune competence (ICE peptide pool, U-CyTech biosciences, Utrecht, The Netherlands). Because these were short peptides that could be directly presented without processing, the ICE peptide pool was loaded onto the APCs for only 1.5 hours prior to the start of cocultures. An unloaded APC condition was taken along in order to determine the background reactivity. Five hours after peptide loading, monocytes were cultured overnight in the presence of 25 µg/mL poly(I:C) (InvivoGen, California, USA), to generate monocyte-derived APCs. The previously harvested non-adherent T cells were rested overnight in T cell mixed media without serum or cytokines. After overnight incubation, peptide loaded APCs were washed and T cells were added, alongside the CD107a antibody. After 1 hour, 0.7 µL/mL Golgistop and 1 µL/mL Golgiplug were added to each well (BD Biosciences, USA), and cultures were continued for an additional 5 hours. Subsequently, T cells were harvested and stained for surface markers and intracellular cytokines and analyzed by multiparametric flow cytometry (antibody panel listed in online supplemental table 2). Acquisition of cells was performed using an LSR II flow cytometer (BD Biosciences). Flow cytometry standard files were analyzed using FlowJo software (FlowJo\_V.10.6.1).

Immunological responses were assessed by measuring intracellular cytokine production (interferon gamma (IFN $\gamma$ ), tumor necrosis factor alpha (TNF $\alpha$ ) and interleukin 2 (IL-2)) and the degranulation marker CD107a (lysosomal-associated membrane protein-1). Gates were placed based on the negative population with the highest mean fluorescence intensity and consistent for stimulated and unstimulated conditions. Patients were considered an immunological responder when the frequency of positive cells for one or more readout molecules exceeded that of the unloaded APC control by at least a factor two at any time point. In addition, the magnitude of the response should be greater than 0.1% from respectively

the CD4<sup>+</sup>—or CD8<sup>+</sup> T-cell parent population. A T-cell response was considered vaccine induced, when the response was not yet present at baseline.

### Blood counts by hemocytometer

Routine blood counts were measured with a hemocytometer at the Clinical Chemistry Department at the Netherlands Cancer Institute. Blood was analyzed on the Xn2000 system (Sysmex). Lymphocyte, neutrophil, eosinophil and monocyte counts were extracted and analyzed from the patient records by the involved study team.

### Statistical analysis

For sample size calculation, an optimal Simons two-stage design was implemented, aimed to exclude an immunological response rate of 30% and targeting a response rate of 60%. With  $\alpha=0.1$  and power=80%, five patients had to be enrolled in the first stage and the vaccine-induced immune response had to be observed in at least two patients to continue to the next stage (second cohort of  $n=9$ ).

Patients were included in the evaluation of HPV-specific immune responses if they had received at least two doses of the vaccine, and if blood samples were drawn at baseline and at least two during therapy. Fishers exact test was used to test whether responding patients had significantly more immunological responses *ex vivo* compared with non-responding patients.

Blood counts were compared between responders (CR and PR) and NRs using the non-parametric two-tailed Mann-Whitney U test. Paired analysis of the same patient over two time points was performed using the Wilcoxon signed rank test.  $P<0.05$  is \* and  $p<0.01$  is \*\*.

## RESULTS

### Safety and toxicity

Thirteen patients received all four vaccinations and one patient received only two vaccinations due to adverse reactions. All adverse events are listed in [table 2](#). The patient (patient #12) who had to discontinue vaccination was diagnosed (by biopsy of a skin eruption) with a Stevens-Johnson syndrome grade 3, 2 weeks after the second vaccination. Although she presented with similar symptoms earlier that year during imiquimod treatment and before she received the first vaccination, an effect of the vaccination could not be excluded, and this event was therefore reported as a suspected unexpected serious adverse reaction (SUSAR). This patient fully recovered from the SUSAR, within 4 months after last vaccination all skin lesions had disappeared. Other patients did not have treatment-related adverse events higher than grade 1 ([table 2](#)). Pruritus at the injection site after vaccination was the most commonly observed adverse event (36%). A picture of the injected skin immediately after vaccination, 2 weeks after vaccination and 6 months after vaccination is shown in [figure 1C–E](#).

**Table 2** Overview of treatment-related adverse events

Toxicity	Grade	Related	No of patients
Steven Johnsons Syndrome	3	Unlikely	1
Pruritus	1	Definitely	5
Injection site reaction	1	Definitely	3
Fatigue	1	Possibly	3
Influenza-like symptoms	1	Possibly	3
Dizziness	1	Possibly	2
Dysgeusia	1	Possibly	2
Local infection after skin biopsy	1	Definitely	1
Hot flushes	1	Possibly	1
Pain of skin	1	Possibly	1

Grades according to the Common Terminology Criteria for Adverse Events V.4.03.

### Observation of clinical responses after HPV-vaccination in patients with uVIN lesions

In the first cohort, we included five patients. In this cohort, a CR was observed in two patients and a PR was seen in one patient ([figure 2](#)). Both CRs were seen after 6 months of follow-up and the PRs after 3 months. The uVIN lesions did not recur after a CR had been observed for the duration of follow-up (12 months after the last vaccination). Patient #3 showed no clinical response and was treated with laser evaporation 2 years after vaccination. Patient #5 showed no response and started with imiquimod treatment 3 months after the last vaccination. Clinical responses after the start of new treatments were not taken into account in this study. In the second cohort, nine patients were included. In this second cohort three patients showed a durable PR during follow-up. An example of a patient showing a PR is shown in [figure 2A,B](#). The biopsies of the vulva at 3 months follow-up showed uVIN in all of the vaccinated patients. This correlates with the clinical observation that CRs were first seen at 6 months after vaccination. Six patients showed no clinical response. One patient (patient #11) was diagnosed with microinvasive vulvar cancer after 6 months of follow-up for which a local excision was performed. Patient #10 underwent laser treatment. Patient #12 underwent laser excision after 84 days of follow-up. Patient #14 showed no response. An overview of all clinical responses is given in [figure 2C,D](#). In [figure 2E](#), the pretreatment size of the lesions per group (NR, PR, CR) is illustrated. The patients with the biggest lesion size (#9 and #10) were both NRs. These two patients also had received most previous treatments before inclusion in this study, as shown in [table 1](#).

### Phenotypic characterization of systemic T cells

Patient PBMCs from baseline samples, as well as from ~day 28, ~56, and ~84 after primary vaccination were subjected







**Table 3** Overview of immunological responses against E6 and E7 peptide pools

Patient	Ex vivo		E6-1				E6-2				E7				
	Response	Clinical Response	IFNy	TNFa	IL2	CD107a	IFNy	TNFa	IL2	CD107a	IFNy	TNFa	IL2	CD107a	
<b>1</b>	Yes	CR	CD4	D0	<0.1%	1.1	<0.1%	0.4	1.3	0.4	<0.1%	1.2	1.2	0.4	
			D56	<0.1%	0.4	0.7	3.4	0.5	2.0	0.6	1.4	0.7			
	CD8	D0	<0.1%	n.d.	<0.1%	<0.1%	1.5	n.d.	n.d.	<0.1%	n.d.	n.d.	<0.1%		
		D56	<0.1%	n.d.	<0.1%	8.7	n.d.	3.8	n.d.	<0.1%	2.0	0.0			
<b>2</b>	Yes	CR	CD4	D0	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	0.8	<0.1%	<0.1%	<0.1%	
			D56	0.7	<0.1%	15.9	2.3	<0.1%	39.9	<0.1%	<0.1%	4.9	<0.1%	<0.1%	
			CD8	D0	0.9	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	0.2
			D56	0.8	<0.1%	9.5	1.7	<0.1%	5.9	<0.1%	<0.1%	3.4	<0.1%	<0.1%	6.3
<b>3</b>	No	NR	CD4	D0	<0.1%	<0.1%	<0.1%	<0.1%	1.1	<0.1%	<0.1%	<0.1%	1.0	<0.1%	
			D56	<0.1%	1.0	<0.1%	<0.1%	0.9	<0.1%	<0.1%	<0.1%	1.0	<0.1%		
			CD8	D0	1.2	<0.1%	0.6	0.8	<0.1%	1.0	1.2	0.7	<0.1%	1.0	0.8
			D56	<0.1%	<0.1%	1.0	1.7	<0.1%	1.0	<0.1%	<0.1%	<0.1%	<0.1%	1.0	0.9
<b>4</b>	Yes	PR	CD4	D0	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
			D56	10.1	<0.1%	1.6	1.8	6.4	<0.1%	4.0	<0.1%	<0.1%	<0.1%		
			CD8	D0	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	1.2	<0.1%	<0.1%	1.1	0.9	
			D56	24.2	<0.1%	3.6	1.0	12.4	n.d.	2.8	1.1	<0.1%	<0.1%	2.1	1.0
<b>5</b>	No	NR	CD4	D0	<0.1%	<0.1%	<0.1%	0.9	<0.1%	0.9	<0.1%	<0.1%	<0.1%	<0.1%	
			D56	<0.1%	<0.1%	<0.1%	1.2	<0.1%	0.9	<0.1%	<0.1%	0.7			
			CD8	D0	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
			D56	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
<b>6</b>	No	NR	CD4	D0	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
			D56	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
			CD8	D0	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
			D56	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
<b>7</b>	Yes, Vaccine enhanced, not induced	PR	CD4	D0	<0.1%	<0.1%	5.2	<0.1%	6.0	<0.1%	<0.1%	2.4	<0.1%		
			D56	22.1	<0.1%	<0.1%	27.3	<0.1%	<0.1%	19.8	<0.1%	<0.1%	<0.1%		
			CD8	D0	13.8	<0.1%	<0.1%	1.2	5.3	<0.1%	0.8	<0.1%	<0.1%	0.8	
			D56	6.4	<0.1%	<0.1%	0.7	7.0	<0.1%	1.7	6.3	<0.1%	<0.1%	0.8	
<b>8</b>	Yes	PR	CD4	D0	<0.1%	<0.1%	<0.1%	1.4	<0.1%	1.7	<0.1%	<0.1%	<0.1%	1.4	
			D56	<0.1%	<0.1%	2.3	1.5	3.2	<0.1%	1.4	<0.1%	<0.1%	1.0		
			CD8	D0	<0.1%	<0.1%	<0.1%	0.8	1.7	<0.1%	0.9	<0.1%	<0.1%	1.1	
			D56	0.9	<0.1%	2.6	1.4	4.3	<0.1%	1.2	1.1	<0.1%	<0.1%	1.0	

Continued



**Table 3** Continued

Patient	Ex vivo		Clinical		E6-1			E6-2			E7					
	Response	No	Response	NR	IFNy	TNFa	IL2	CD107a	IFNy	TNFa	IL2	CD107a	IFNy	TNFa	IL2	CD107a
<b>9</b>	No	CD4	D0	NR	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
			D56		<0.1%	<0.1%	<0.1%	1.0	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
		CD8	D0		<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
			D56		<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	0.9	<0.1%	<0.1%	<0.1%	<0.1%
<b>10</b>	No	CD4	D0	NR	<0.1%	<0.1%	<0.1%	0.6	<0.1%	1.1	<0.1%	1.1	<0.1%	<0.1%	<0.1%	0.7
			D56		<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	1.2	<0.1%	<0.1%	<0.1%	<0.1%
		CD8	D0		<0.1%	<0.1%	<0.1%	0.7	<0.1%	<0.1%	<0.1%	1.2	<0.1%	<0.1%	<0.1%	0.8
			D56		<0.1%	<0.1%	<0.1%	1.2	<0.1%	<0.1%	<0.1%	0.9	<0.1%	<0.1%	<0.1%	1.1
<b>11</b>	No	CD4	D0	NR	<0.1%	<0.1%	1.7	<0.1%	<0.1%	<0.1%	0.7	<0.1%	<0.1%	<0.1%	1.0	1.8
			D56		<0.1%	<0.1%	<0.1%	1.0	<0.1%	<0.1%	0.9	1.0	<0.1%	<0.1%	0.6	0.9
		CD8	D0		<0.1%	<0.1%	<0.1%	0.9	1.1	<0.1%	<0.1%	1.0	1.1	<0.1%	<0.1%	1.1
			D56		1.1	<0.1%	<0.1%	0.9	1.2	<0.1%	<0.1%	0.9	1.1	<0.1%	<0.1%	1.0
<b>12</b>	No	CD4	D0	NR	<0.1%	<0.1%	<0.1%	0.9	<0.1%	<0.1%	1.0	0.9	<0.1%	<0.1%	1.7	0.7
			D56		<0.1%	<0.1%	<0.1%	1.2	<0.1%	<0.1%	<0.1%	1.6	<0.1%	<0.1%	1.0	1.3
		CD8	D0		<0.1%	<0.1%	<0.1%	1.0	<0.1%	<0.1%	<0.1%	1.1	<0.1%	<0.1%	<0.1%	<0.1%
			D56		0.7	<0.1%	<0.1%	0.9	0.7	<0.1%	1.8	0.9	0.5	<0.1%	<0.1%	0.9
<b>13</b>	No	CD4	D0	PR	<0.1%	<0.1%	<0.1%	1.8	<0.1%	<0.1%	<0.1%	1.8	<0.1%	<0.1%	<0.1%	<0.1%
			D56		<0.1%	<0.1%	<0.1%	1.9	<0.1%	<0.1%	<0.1%	1.7	<0.1%	<0.1%	<0.1%	<0.1%
		CD8	D0		<0.1%	<0.1%	<0.1%	0.7	<0.1%	1.0	<0.1%	1.0	<0.1%	<0.1%	<0.1%	<0.1%
			D56		<0.1%	0.8	<0.1%	0.7	<0.1%	0.6	<0.1%	0.9	<0.1%	<0.1%	<0.1%	1.2
<b>14</b>	No	CD4	D0	NR	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
			D56		<0.1%	<0.1%	<0.1%	1.9	<0.1%	<0.1%	<0.1%	1.2	<0.1%	<0.1%	<0.1%	<0.1%
		CD8	D0		<0.1%	<0.1%	0.6	0.8	<0.1%	<0.1%	1.0	0.7	<0.1%	<0.1%	<0.1%	<0.1%
			D56		<0.1%	<0.1%	<0.1%	0.8	<0.1%	<0.1%	<0.1%	0.9	<0.1%	<0.1%	1.1	0.6

Numbers represent the fold change over background (unloaded APCs). n.d.: no positive cells detected. Fold changes greater than two are highlighted in green. <0.1% indicates that the fraction of positive cells was less than 0.1% from its parent (CD4<sup>+</sup> or CD8<sup>+</sup> T cells).

CR, complete response; IFNy, interferon gamma; IL2, interleukin 2; NR, no response; PR, partial response; TNFa, tumor necrosis factor alpha.

the shuffle points is depicted at day 0 and day 56. CD8<sup>+</sup> T cells from patient #1 and patient #8 (both responders) produced IFN $\gamma$  on stimulation with the shuffle point peptide pool. For patient #8, shuffle point reactivity seemed vaccine induced and for patient #1 the reactivity was also found in the baseline samples, possibly indicating cross reactivity towards another epitope. The magnitude of the response against the shuffle points was occasionally higher than the magnitude of the response against E6 and E7 epitopes. We do not know the exact reason for this, although we could speculate that this is due to differences in antigen processing and/or presentation between patients. In general, we do not see common reactivity against the shuffle point epitopes and it is important to note that no ‘on target, of lesion’ toxicity was observed in any of the patients.

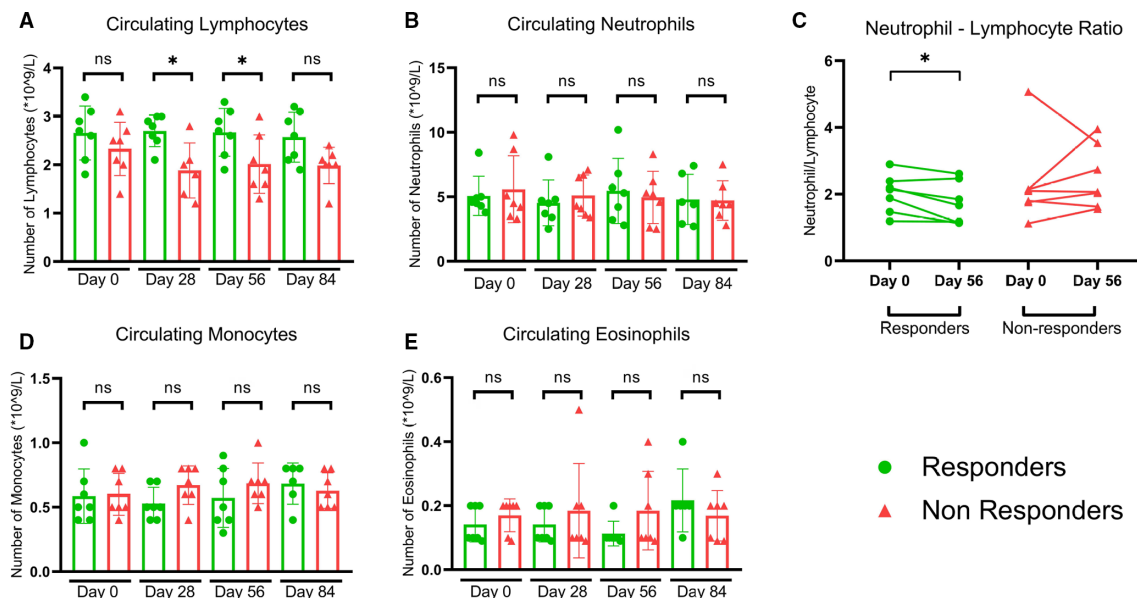
Reactivity against the ICE peptide pool consisting of 32 viral epitopes covering multiple HLA-alleles was tested to assess differences in immune competence between responding and non-responding patients (see online supplemental figure 6). In total, CD8<sup>+</sup> T cells from baseline samples of 9/14 patients produced cytokines on culturing with ICE peptide loaded APCs and no CD4 reactivity was measured against the ICE peptide pool (see online supplemental figure 6). As a positive control, we took along four healthy donors, which were all responsive towards the ICE peptide pool (see online supplemental figure 6). Also, all patient samples produced high amounts of cytokines after phorbol 12-myristate 13-acetate/ionomycin stimulation (data not shown).

### Correlation between T-cell reactivity against the HPV oncogenes and clinical benefit

Notably, all patients who showed ex vivo HPV E6 or E7 specific T-cell responses also experienced clinical benefit from the vaccine (figure 3C). In contrast, such HPV E6 or E7 specific T-cell responses were completely absent in clinical NRs (0/8). For one out of six patients that showed a clinical response, no ex vivo immune reactivity could be determined (table 3 and online supplemental figure 4, patient #13). Collectively, these findings demonstrate that there is a strong correlation between the induction of immune reactivity and clinical response (Fischer’s exact test,  $p=0.003$ ).

### Lymphocyte counts in relation to clinical response

Regular blood cell counts were established at matching time points with the PBMC isolation for ex vivo reactivity assays. At baseline, no statistically significant differences in number of circulating lymphocytes, neutrophils, monocytes and eosinophils could be found between responding and non-responding patients (shown in figure 4). During the vaccinations at day 28, as well as at the peak of the response at day 56, lymphocyte counts were significantly higher in responding patients than in non-responding patients (figure 4A). Systemic neutrophil to lymphocyte ratio was decreased at the peak of the response compared with baseline in responding patients. No significant change in neutrophil to lymphocyte ratio over time was found in non-responding patients (figure 4C). The number of circulating neutrophils, monocytes and



**Figure 4** Systemic blood counts reveal differences between responders and non-responders during- and post vaccination. (A) Significantly reduced number of circulating lymphocytes in non-responding patients, compared with responding patients. Two tailed Mann-Whitney test  $D28 p=0.015$ ,  $D56 p=0.048$ . (B) No statistically significant differences detected between responding and non-responding patients at any time point in neutrophils. (C) Responding patients show a decreased neutrophil to lymphocyte ratio at the peak the immune response compared with baseline. No significant changes in neutrophil to lymphocyte ratio in non-responding patients. Wilcoxon matched-pairs signed rank test  $p=0.0469$ . No statistically significant differences detected between responding and non-responding patients at any time point in circulating (D) monocytes and (E) eosinophils.

eosinophils remained similar for responders and NRs and unaltered compared with baseline levels (figure 4B,D,E).

Despite a variety of treatment modalities for patients suffering from uVIN, these patients are often confronted with recurrent disease and are at risk to progress to invasive disease. In this study, we have used a therapeutic HPV-16 E6/E7 DNA tattoo vaccine comprising of sig-HELP-E6SH-KDEL and sig-HELP-E7SH-KDEL. In mice, this DNA vaccine has shown to be much more immunogenic than the variants with other helper cassettes (such as TTFC) that were previously used in the clinic.<sup>24 32</sup> This is the first clinical trial using this optimized DNA vaccine targeting the HPV oncoproteins E6 and E7 in patients with uVIN.

Several HPV-vaccination studies targeting E6 and/or E7 have been performed with varying results. Intramuscular TA-cervical intraepithelial neoplasia (CIN) (fusion protein HPV16 E6E7L2) administration preceded by local imiquimod application has been studied, with a clinical response rate of 63% in patients with uVIN, but all patients in this study displayed moderate (n=5, 26%), or severe (n=14, 74%) side effects.<sup>22</sup> TA-HPV, a recombinant vaccinia virus, encoding modified HPV 16 and 18 E6 and E7, has also been successfully applied in uVIN and vaginal intraepithelial neoplasia patients. This was resulting in both a potent clinical responses (8/18 and 5/12, respectively) and immunological responses (13/18 and 6/10, respectively).<sup>16 36</sup> However, the use of live vaccinia virus limits the broad application of this therapy. In trials investigating subcutaneously administered HPV16 E6 and E7 synthetic long peptides (SLP), clinical responses were observed after 12 months in 52%–79% of women with uVIN.<sup>21 37</sup> However, grade 1 and grade 2 side effects were reported at very high frequencies and were probably linked to the use of the Montanide ISA51. In our trial, no adverse events higher than grade 1 were reported, (apart from one patient with a grade 3 SUSAR that was probably unrelated as symptoms had occurred before the first vaccination) and at much lower frequencies, suggesting that HPV-16 E6/E7 DNA tattoo vaccination is safe to use. This difference in toxicity and tolerability can likely be explained by the fact that we used the tattoo technique, and no adjuvant or other initial treatment modality such as imiquimod was used in our trial. Since subcutaneous administration of a therapeutic HPV peptide vaccine with adjuvant can cause significant adverse events (such as local skin swelling), we focused on improving the administration route and optimization of immunogenicity of the vaccine.

Our data indicate a 43% clinical response rate. A clinically durable and ongoing CR was seen in 14% of the patients. PRs were observed in 29% of patients and were ongoing at the time of most recent follow-up. Importantly, unlike other treatment modalities (eg, laser ablation, surgical excision or imiquimod application) in which up to one-third of patients show a recurrence,<sup>9 38</sup> none of the responders in our study had recurrences or increasing lesion size over time. A likely explanation for

this difference is that our vaccination strategy targets the cause of the disease, that is, HPV16 E6 and E7 expressing cells, and this is underlined by the fact that 83% of the responding patients showed a clear E6/E7 specific T-cell response in their blood. However, recurrences often occur over 1 year after treatment in this patient group and follow-up period in this study was only 12 months. Future studies have to point out whether the recurrence of uVIN is maintained more than a year after therapeutic HPV-vaccination. Furthermore, no HPV-testing at the end of follow-up was performed, which would be interesting to incorporate in follow-up studies to confirm the successful clearance of the virus at the uVIN lesions after vaccination.

Although responses were durable in our study, CR rates were still low (2/14). Therefore, we would like to advocate the combination of our vaccine with for instance immune checkpoint inhibitors such as (locally administered) anti PD-(L)1 or TLR\_agonists, such as poly (I:C) (TLR3 agonist) or Imiquimod (TLR7 agonist). Besides this, it might be beneficial for patients with large uVIN lesions to first decrease lesion size (eg, by laser or topical therapy), before administering our vaccine, because patients with largest uVIN lesion size at baseline did not show any response to vaccination in this trial. However, since the sample size in this study was quite small, future studies have to reveal whether this effect will still be observed. Interestingly though, Kenter *et al* also reported that lesions were smaller in the CR group after E6 and E7 synthetic long-peptide vaccination in patients with uVIN.<sup>21</sup>

Systemic immunological HPV-specific T-cell responses were found in both the CD4<sup>+</sup> as well as the CD8<sup>+</sup> compartment. These responses were either vaccine induced (4/5) or vaccine enhanced (1/5). Interestingly, five out of six patients with complete or PRs showed systemic HPV-specific T-cell responses in ex vivo assays. Likewise, patients *without* a clinical response did *not* show an HPV-specific T-cell response ex vivo. Previous HPV targeting vaccines, in the same patient group, observed a similar relationship. Both Kenter *et al* and van Poelgeest *et al* reported a correlation between (the magnitude of) the ex vivo response and the clinical outcome of the patients after vaccination with HPV16 E6 and E7 SLPs.<sup>21 37</sup> However, in a study evaluating the effect of a TA-HPV vaccine against E6 and E7, ex vivo responsiveness to the vaccine vector was confirmed in all patients, there was no relation with clinical benefit.<sup>20</sup> The differences between clinical and immunological responses between our study and previous studies could be explained by a different study design, different vaccine, different patient group and a different technique used to identify ex vivo immune responses.

At baseline, the number of circulating lymphocytes, neutrophils, monocytes and eosinophils did not differ statistically significant between responders and NRs. On treatment, NRs had statistically significant fewer circulating lymphocytes than responders, which could potentially be a reflection of a less competent immune system.

Future experiments will tell whether responders will have relatively higher numbers of VIN lesion infiltrating lymphocytes compared with NRs, and what potential immunosuppressive mechanisms in the lesions might have hampered a T-cell response in the non-responding patients.

Follow-up studies should be performed to determine the effects of this vaccination strategy in a larger cohort of patients with uVIN, as well as patients with other intraepithelial neoplasia caused by HPV 16, such as anal intraepithelial neoplasia, penile intraepithelial neoplasia and CIN. Patients with HPV-16 and HPV-18 CIN2/3 have already shown to respond to other types of DNA vaccination targeting E6 and E7 proteins.<sup>39</sup>

In conclusion, we found in this phase I/II clinical trial that HPV-16 E6/E7 DNA tattoo vaccination for the treatment of HPV16 positive uVIN is a safe and immunologically effective strategy. Interestingly, in five out of six clinically responding patients, E6/E7 specific CD4<sup>+</sup> and CD8<sup>+</sup> T cell reactivity could be detected in blood samples. Such responses were not observed in patients without a clinical response. Therefore, HPV-16 E6/E7 DNA tattoo could possibly be a clinically meaningful treatment strategy in patients with uVIN.

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**Contributors** NAMB constructed the plasmids and produced DNA vaccines, designed and performed immune monitoring experiments, interpreted data and cowrote the manuscript. JR vaccinated patients, collected and interpreted clinical data and co-wrote the manuscript. MvB involved in patient care. HJMAAZ involved in patient care. SS involved in writing the study protocol. MvR vaccinated patients and collected clinical data. BN and JB supervised DNA production. TS conceived the project, designed plasmids, interpreted data and reviewed the manuscript. JH conceived the project, designed plasmids and interpreted data. KDV interpreted data and reviewed the manuscript. TdG interpreted data. ESJ interpreted data. GGK conceived the project, interpreted data. JHvdB conceived the project, interpreted data, designed plasmids.

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**Ethics approval** The study was approved by the Central Committee on Research Involving Human Subjects (In Dutch: Centrale Commissie Mensgebonden Onderzoek; CCMO) in The Hague, the Netherlands (Number NL46637.000.13) and registered at [trialregister.nl](http://trialregister.nl) (NTR4607). All study protocols were conducted in accordance with the ICH Harmonised Tripartite Guideline for Good Clinical Practice and the principles of the Declaration of Helsinki. All patients provided written informed consent before enrolment.

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