Expression of the high-risk human papillomavirus type 18 and 45 E7 oncoproteins in cervical carcinoma biopsies

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E7 proteins are major oncoproteins of high-risk human papillomaviruses (HPVs), which play a key role in cervical carcinogenesis. These proteins have been shown to immortalize primary human cells. Due to the absence of antibodies with suitable sensitivity and specificity, little is known about expression of the E7 oncoproteins in naturally infected tissues. Recently, high-level expression of the E7 protein of HPV-16, the most prevalent oncogenic HPV type, was demonstrated in cervical carcinomas by immunohistochemistry; however, approximately 15 additional high-risk HPV types are known to be associated with cervical carcinoma. It is unknown whether the E7 oncoproteins of HPV-18 and -45, the second and third most prevalent HPV types, are expressed in cervical cancers. Using antibodies against HPV-18 and -45 E7 proteins, it is shown here for the first time that the HPV-18 and -45 E7 proteins can be detected in cervical carcinoma biopsies. Together with anti-HPV-16 E7 antibodies, this could create the possibility of detecting E7 oncoproteins in approximately 80% of all cervical cancers.

INTRODUCTION

Cervical cancer is considered the second most common gynaecological cancer worldwide (Pisani et al., 2002). Epidemiological studies have shown that human papillomaviruses (HPVs) are the main aetiological factors for cervical cancer (reviewed by zur Hausen, 2000). HPVs are small DNA viruses that infect basal proliferating epithelial cells of either the skin or mucosa, and more than 100 different HPV genotypes have been described to date. On the basis of epidemiological and biochemical data, the mucosal genotypes are subdivided into two groups: HPVs of the high-risk group, associated with squamous intraepithelial lesions with a high potential for progression to invasive squamous cell carcinoma, and papillomaviruses of the low-risk group, which cause benign hyperplasias (reviewed by Lowy & Howley, 2001). PCR-based studies have shown that more than 99% of invasive cervical cancers contain high-risk HPV DNA (Walboomers et al., 1999). HPV-16 being the most prevalent type with a worldwide incidence of 50–60%, followed by HPV-18 (approx. 15%) and HPV-45 (approx. 9%) (reviewed by Muñoz, 2000; Bosch et al., 2002).

The factors that determine viral persistence and tumorigenic progression are not completely defined. It was found that the high-risk viral DNA frequently integrates into the host genome in cervical cancer cell lines (Scharz et al., 1985) and HPV-related cervical carcinomas (Luft et al., 2001). These events are frequently correlated with dysregulated expression of the early viral genes E6 and E7 (Jeon et al., 1995), which exhibit the major oncogenic activity of the HPV DNA (Crook et al., 1989). E7, in cooperation with E6, can efficiently immortalize human primary keratinocytes, the natural host cell of HPV, as shown for the oncoproteins of HPV-16 (Münger et al., 1989) and HPV-18 (Barbosa & Schlegel, 1989; Hudson et al., 1990). Given the central role of the HPV-16 E7 protein in cell immortalization and

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METHODS

Generation of polyclonal antisera to high-risk HPV proteins.

Purified preparations of E7 proteins were used to produce polyclonal anti-HPV-18 and -45 E7 antibodies in goats (Charles River). For immunization, 1 mg each of the respective E7 protein was mixed with 1:1 ml complete Freund’s adjuvant (Sigma). The first, second and third boosts were each done 28 days apart with 1 mg E7 protein mixed with 1:1 ml incomplete Freund’s adjuvant. Two weeks after the third boost, the first production bleeding was performed. Blood (300 ml) was taken from the jugular vein and collected into a vessel containing 2 ml 32% sodium acetate solution per 100 ml blood. Blood was processed to citrate plasma and stored at −20°C. To purify type-specific polyclonal anti-E7 antibodies, E7 proteins from HPV-18 and -45 were coupled separately to NHS-activated Sepharose 4 (NHS-activated Sepharose HiTrap columns; General Electric); the final E7 concentration coupled to the column was 1 mg ml−1. For antibody purification, citrated plasma was diluted 1:2 in running buffer (PBS containing 200 mM NaCl, 5 mM EDTA, 0.05% NaN3, pH 7.4), adjusted to 0.64% sodium citrate and filtrated through a 0.22 μm filter. Upon equilibration with 10 column volumes (CVs) of running buffer, diluted plasma was passed at a flow rate of 0.5 ml min−1 through the respective affinity column. After loading, the columns were washed with 10 CVs washing buffer (PBS containing 1 M NaCl, 5 mM EDTA, 0.05% NaN3, pH 7.4) and 10 CVs running buffer at a flow rate of 1 ml min−1. Antibodies were eluted with 3 M potassium thiocyanate, 150 mM KCl, 10 mM potassium phosphate, pH 7.4, at a flow rate of 0.2 ml min−1. The fraction size was 1 ml. Antibody-containing fractions were pooled and passed through a HiLoad 16/60 Superdex 75 gel-filtration column (General Electric), thereby performing a buffer exchange into 166 mM potassium phosphate, 83 mM glycine, 0.05% NaN3, pH 7.2. Finally, antibody-containing fractions were pooled, concentrated to 1 mg ml−1 (using concentrators with a cut-off of 10 kDa; Vivascience/Sartorius), aliquotted and lyophilized (Chris Alpha 1-4 freeze dryer; Osterode).

Western blot analysis. Cells were lysed in PBS containing 1% Triton X-100 using an ultrasonic cell disruptor (Branson). Lysates were separated by SDS-PAGE (12.5% gel) and transferred to a PVDF membrane (NEN). The membrane was blocked in blocking buffer (PBS containing 0.2% Tween 20 and 5% milk powder) and incubated with the affinity-purified polyclonal goat antibodies against HPV-18 and -45 E7 for 1 h. After washing, a peroxidase-conjugated anti-goat IgG (Promega) was applied. The membrane was washed and the bound antibodies were visualized by using a chemiluminescence Western blotting detection system (NEN).
lysates of the HPV-16 E7 protein-expressing cervical carcinoma cell line Ca Ski (Fig. 1c), suggesting that the anti-HPV-18 E7 antibodies cross-react specifically with HPV-45 E7. The anti-HPV-45 E7 antibodies, which strongly recognize HPV-45 E7 (Fig. 1d), showed only weak cross-reactivity with the HPV-18 E7 protein in HeLa cell lysates (Fig. 1d) and did not recognize HPV-16 E7 in Ca Ski cells (Fig. 1d), suggesting that these antibodies are highly specific for HPV-45 E7. Taken together, these results demonstrate that the anti-E7 antibodies generated here are of sufficient quality to detect HPV-18 E7 and -45 E7 proteins specifically in Western blots.

Detection of HPV-18 and -45 E7 proteins in cervical cancer cell lines

To establish a reliable in situ detection procedure for HPV-18 and -45 E7 proteins, we first studied the subcellular distribution of these E7 proteins in cell lines by indirect immunofluorescence. Human osteosarcoma (U-2 OS) cells were transiently transfected with an expression vector for HPV-18 E7. The transfected cells were fixed with 4% paraformaldehyde (PFA)/0.1% Triton X-100 and co-stained with the DNA stain TO-PRO-3 and affinity-purified anti-HPV-18 E7 antibodies (Fig. 2a). Staining was visualized as either green (E7) or red (DNA) fluorescence, using a confocal laser-scanning microscope. Under these conditions, we were able to establish specific immunofluorescence detection of the HPV-18 E7 protein. In most of the transiently transfected cells, the anti-HPV-18 E7 antibodies predominantly stained structures in the nucleus and, to a minor extent, in the cytoplasm. In contrast, no signal was obtained in mock-transfected cells and pre-immune serum did not recognize the E7 antigen (data not shown). In the HPV-18-positive cervical carcinoma cell line HeLa, the anti-HPV-18 E7 antibodies stained the nucleus and cytoplasm (Fig. 2b), as shown previously for HPV-16 E7 (Smotkin & Wettstein, 2001).
No staining was observed with the anti-HPV-18 E7 antibodies in the HPV-negative cervical carcinoma cell line C33a (Fig. 2c), underlining the specificity of the anti-HPV-18 E7 antibodies. To test for antibody cross-reactivity, U-2 OS cells were transiently transfected with an expression vector for HPV-45 E7, which is structurally related to the HPV-18 E7 protein. Co-staining with TO-PRO-3 and affinity-purified anti-HPV-18 E7 antibodies showed that the anti-HPV-18 E7 antibodies cross-reacted with the native HPV-45 E7 protein in cells fixed with the mild fixative PFA (Fig. 2d).

U-2 OS cells transiently expressing HPV-45 E7 were co-stained with TO-PRO-3 and affinity-purified anti-HPV-45 E7 antibodies (Fig. 2e), showing predominantly stained structures in the nucleus and, to a minor extent, in the cytoplasm. Similar to HPV-16 E7 (Fiedler et al., 2004) and HPV-45 E7 (see above), the HPV-45 E7 protein was detected in the nucleus and cytoplasm in the HPV-45-positive cervical carcinoma cell line MS751 (Fig. 2f). Virtually no staining was observed with the anti-HPV-45 E7 antibodies in the HPV-negative cervical carcinoma cell line C33a (Fig. 2g), underlining the specificity of the anti-HPV-45 E7 antibodies. Finally, HPV-45 E7 antibody recognition of HPV-18 E7 protein expressed in transiently transfected U-2 OS cells was tested in immunofluorescence experiments. The affinity-purified anti-HPV-45 E7 antibodies clearly recognized the HPV-18 E7 protein (Fig. 2h), suggesting that the anti-HPV-45 E7 antibodies cross-react with the structurally related HPV-18 E7 protein under these conditions.

### High-level expression of HPV-18 and -45 E7 oncoprotein in cervical cancers

To determine whether HPV-18 E7 protein can be detected in cervical carcinoma biopsies, we performed immunohistochemistry experiments with the affinity-purified polyclonal anti-HPV-18 E7 antibodies on paraffin sections of normal cervical tissues and invasive cervical cancers (Fig. 3a). The tumour material was characterized as HPV-18 DNA-positive by PCR analysis essentially as described by Fiedler et al. (2004). The anti-HPV-18 E7 antibodies stained almost all cells in the HPV-18 DNA-positive tumour islets, but did not stain cells in adjacent connective tissue (Fig. 3a, upper middle panel). Staining by the anti-HPV-18 E7 antibodies could be blocked by pre-incubation of the antibodies with purified HPV-18 E7 antigen (Fig. 3a, upper right panel). The anti-HPV-18 E7 antibodies did not stain...
HPV DNA-negative normal squamous epithelium (Fig. 3a, upper left panel). No staining of cervical carcinoma sections was observed when pre-immune serum was used (Fig. 3a, lower left panel) or by the secondary anti-goat IgG alone (data not shown). It has been shown that the cyclin-dependent kinase inhibitor p16^{INK4a} is upregulated in
HPV-positive cervical carcinomas (Sano et al., 1998; Klaes et al., 2001). For this reason, an adjacent section of the HPV-18-positive cervical cancer was stained with anti-p16INK4a antibodies (Fig. 3a, lower middle panel), which revealed the same tumour cell pattern as the anti-HPV-18 E7 antibodies, indicating that both antibodies can detect HPV-18-positive invasive cervical cancer cells. We analysed histological sections of HPV-18 DNA-positive cervical carcinomas derived from six different patients, showing that HPV-18 E7 is readily detectable in HPV-18 DNA-positive cervical cancers. In all samples, the tumour areas were stained clearly positive by the anti-HPV-18 E7 antibodies. The use of anti-HPV-45 E7 antibodies did not yield a signal in HPV-18 E7-positive cervical cancer biopsies (data not shown). This suggested that the anti-HPV-45 E7 antibodies did not cross-react with the HPV-18 E7 protein in paraffin sections of the HPV-18 DNA-positive cervical cancers tested in this study.

To analyse whether the HPV-45 E7 protein is detectable in HPV-45-positive cervical carcinomas, we performed immunohistochemistry experiments with affinity-purified polyclonal anti-HPV-45 E7 antibodies on paraffin sections of HPV-45 DNA-positive invasive cervical cancers (Fig. 3b). The anti-HPV-45 E7 antibodies stained almost all cells in the HPV-45 DNA-positive tumour islets, but not in adjacent connective tissue (Fig. 3b, upper middle panel). Staining by the anti-HPV-45 E7 antibodies could be blocked by pre-incubation of the antibodies with purified HPV-45 E7 antigen (Fig. 3b, upper right panel). The anti-HPV-45 E7 antibodies did not stain normal squamous epithelium (Fig. 3b, upper left panel) and no staining of cervical carcinoma sections was observed when pre-immune serum (Fig. 3b, lower left panel) or secondary anti-goat IgG alone (data not shown) was used. Staining of an adjacent section of the HPV-45-positive cervical cancer with anti-p16INK4a antibodies (Fig. 3b, lower middle panel), resulted in a staining pattern similar to that obtained with the anti-HPV-45 E7 antibodies, suggesting that both the anti-HPV-45 E7 and the anti-p16INK4a antibodies can stain HPV-45-positive tumour cells in invasive cervical carcinoma sections. Finally, we investigated whether the anti-HPV-18 E7 antibodies cross-react with the HPV-45 E7 protein in cervical cancer biopsies. As shown in Fig. 3(b) (lower right panel), the anti-HPV-18 E7 antibodies stained HPV-45 DNA-positive cervical carcinomas strongly and specifically, indicating that the anti-HPV-18 E7 antibodies cross-react with the HPV-45 E7 protein in cervical cancer sections. We analysed paraffin sections derived from five different HPV-45 DNA-positive cervical carcinoma patients and, in all specimens, the tumour areas were stained positive by the anti-HPV-45 E7 antibodies, indicating that the HPV-45 E7 protein is detectable in HPV-45 DNA-positive cervical cancers. In summary, the findings presented in this study indicate that both the HPV-18 and -45 E7 oncoproteins are clearly expressed in natural cervical cancer biopsies.

There is ample evidence that expression of the E7 oncoprotein is necessary for induction and maintenance of the transformed phenotype (reviewed by zur Hausen, 2000); however, the role of the oncoprotein in cervical carcinogenesis has remained elusive, due to the lack of antibodies allowing its detection in clinical samples (reviewed by von Knebel Doeberitz, 2002). Recently, we showed that the HPV-16 E7 oncoprotein is expressed at a high level in cervical cancer biopsies by using rabbit anti-HPV-16 E7 antibodies (Fiedler et al., 2004); however, the expression levels of the HPV-18 and -45 E7 oncoproteins in cervical carcinomas were unknown. In this study, we have generated polyclonal goat anti-HPV-18 and -45 E7 antibodies. Using affinity-purified batches of these antibodies, we have demonstrated, for the first time, that the HPV-18 and -45 E7 oncoproteins are expressed in HPV-18- and -45-positive cervical cancer biopsies. The E7 proteins were detected in both the nucleus and the cytoplasm of the tumour cells, underlining the fact that the E7 oncoproteins act in both cellular compartments (reviewed by Zwerschke & Jansen-Dürr, 2000). Together with the study by Fiedler et al. (2004), these findings suggest that the high-risk E7 oncoproteins of HPV-16, -18 and -45 are expressed continuously in cervical carcinomas. These three HPV types are aetologically linked to approximately 80% of all cervical cancers worldwide (reviewed by Muñoz, 2000). Thus, the antibodies described here may have diagnostic potential as tumour markers for cervical cancer.

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