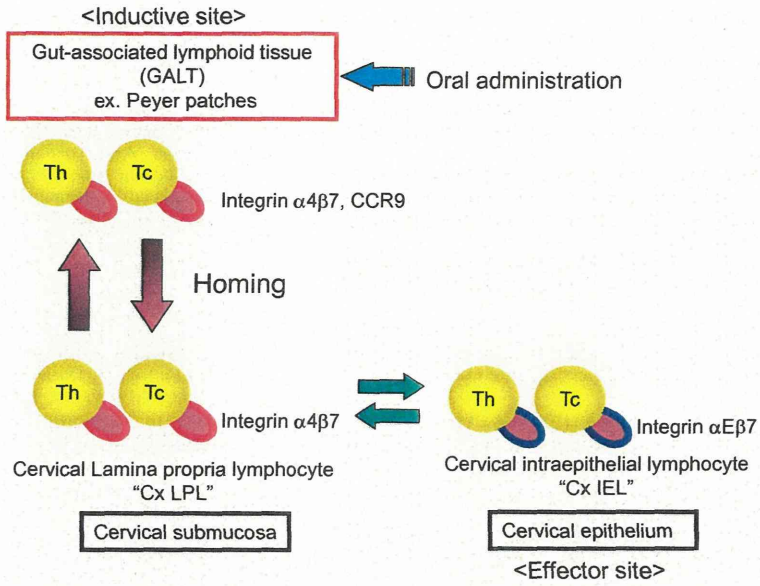

Fig. (2). Mucosal immune system in cervix. GALT is thought to act as the inductive site for cervical IELs. GALT and cervical mucosal connect through mucosa-specific T cells which express homing receptors, integrin α4β7 and/or CCR9. Integrin α4β7+ T cells can differentiate into αEβ7+ T cells upon exposure to TGF-β and expression of integrin αEβ7 facilitates retention of lymphocytes in the epithelium *via* interactions with E-cadherin. Integrin αEβ7 is a specific marker of IELs residing in mucosal epithelia and those cells expressing this antigen on their surface were initially educated in the gut. Oral administration of the therapeutic vaccine can stimulate directly to the inductive site. LPL: lamina propria lymphocytes.

In these studies, full-length mutated E7 was transduced into the *Lactobacillus casei* common to many lactic acid containing foods, and the bacterial cells were attenuated to the destroy exogenous plasmid gene. We compared mucosal vaccination *via* oral administration of the agent (GLBL101c) to systemic vaccination *via* intramuscular or subcutaneous injection of HPV16 E7 protein. Intramuscular and subcutaneous antigen administration induced small numbers of mucosal E7-CMI, but oral administration doubled these levels [45]. This implies that oral vaccination may surmount some of the deficiencies seen with systemic immunization that have been documented in previous clinical trials. Our preclinical data encouraged us to embark on a clinical trial using GLBL101c, which has now been advanced to the Ph-I/IIa stage. Patients with CIN3 who are positive for only for HPV16 alone are presently being enrolled in dose escalation study of the effects of orally administer GLBL101c on the progression or remission of their neoplastic lesions (unpublished data).

SUMMARY

The utility of the commercially-available HPV vaccines is great but incomplete. These vaccines are a valuable step toward the control of cervical cancer and should be advanced for worldwide distribution. However, cervical cancer and its precursor lesions cannot be eradicated extant vaccination strategies costly cervical cytology screening will remain essential until new, more broadly protective HPV vaccines are developed and vaccination coverage approaches 100 % among adolescents worldwide. Until then, strategies for the development of the next generation of HPV vaccines must include both prevenative and therapeutic products.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

We are grateful to Dr. Terufumi Yokoyama for excellent experiments concerning oral vaccination of GLBL101c to mice and human cervical intraepithelial lymphocytes in CIN patients and Dr. D. J. Schust for careful and critical editing of the manuscript.

REFERENCES

[1] zur Hausen H. Papillomavirus and cancer: from basic studies to clinical application. Nat Rev Cancer 2002; 2: 342-50

[2] Dunne EF, Unger ER, Sternberg M, *et al.* Prevalence of HPV infection among females in the United States. JAMA 2007; 297: 813-9

[3] Bosch FX, de Sanjose S. Human papillomavirus and cervical cancer – burden and assessment of causality. J Natl Cancer Inst Monogr 2003; 31: 3-13

[4] Masumoto N, Fujii T, Ishikawa M, *et al.* Dominant human papillomavirus 16 infection in cervical neoplasia in young Japanese women; study of 881 outpatients. Gynecol Oncol 2004; 94: 509-14

[5] The current status of development of prophylactic vaccines against human papillomavirus infection. Report of a technical meeting. 16-18 February 1999; Geneva.

[6] Ho GY, Bierman R, Beardsley L, Chang CJ, Burk RD. Natural history of cervicovaginal papillomavirus infection in young women. N Engl J Med 1998; 338: 423-8

[7] de Sanjosé S, Diaz M, Castellsagué X, *et al.* Worldwide prevalence and genotype distribution of cervical human papillomavirus DNA in women with normal cytology: a meta-analysis. Lancet Infect Dis 2007; 7: 453-9

[8] Koutsky L. Epidemiology of genital human papillomavirus infection. Am J Med 1997; 102: 3-8

[9] Trottier H, Franco EL. The epidemiology of genital human papillomavirus infection. Vaccine 2006; 24S1: S1/4-S1/15

[10] Holowaty P, Miller AB, Rohan T, To T. Natural history of dysplasia of the uterine cervix. J Natl Cancer Inst 1999; 91: 252-8
[11] Gravitt, PE. The known unknows of HPV natural history. J. Clin. Invest 2011; 121: 4593-9.
[12] Ellerbrock TV, Chiasson MA, Bush TJ, *et al.* Incidence of cervical squamous intraepithelial lesions in HIV-infected women. JAMA 2000; 283: 1031-7
[13] Ognenovski VM, Marder W, Somers EC, *et al.* Increased incidence of cervical intraepithelial neoplasia in women with systemic lupus erythematosus treated with intravenous cyclophosphamide. J Rheumatol 2004; 31:1763-7
[14] Kawana K, Yasugi T, Taketani Y. Human papillomavirus vaccines: current issues and future: Review. Indian J Med Res 2009; 130: 341-7.
[15] Trimble CL, Peng S, Thoburn C, Kos F, Wu TC. Naturally occurring systemic immune responses to HPV antigens do not predict regression of CIN2/3. Cancer Immunol Immunother 2010; 59: 799-803.
[16] Nakagawa M, Gupta SK, Coleman HN, Sellers MA, Banken JA, Greenfield WW. A favorable clinical trend is associated with CD8 T-cell immune responses to the human papillomavirus type 16 E6 antigens in women being studied for abnormal pap smear results. J Low Genit Tract Dis 2010; 14:124-9
[17] Koutsky LA, Ault KA, Wheeler CM, *et al.* A controlled trial of a human papillomavirus type 16 vaccine. N Engl J Med 2002; 347: 1645-51
[18] Ochi H, Kondo K, Matsumoto K, *et al.* Neutralizing antibodies against human papillomavirus types 16, 18, 31, 52, and 58 in serum samples from women in Japan with low-grade cervical intraepithelial neoplasia. Clin Vaccine Immunol 2008; 15: 1536-40
[19] Villa LL, Costa RL, Petta CA, *et al.* High sustained efficacy of a prophylactic quadrivalent human papillomavirus types 6/11/16/18 L1 virus-like particle vaccine through 5 years of follow-up. Br J Cancer 2006; 95: 1459-66
[20] Harper DM, Franco EL, Wheeler CM, Moscicki AB, *et al.* Sustained efficacy up to 4·5 years of a bivalent L1 virus-like particle vaccine against human papillomavirus types 16 and 18: follow-up from a randomised control trial. Lancet 2006; 367: 1247-55
[21] Miura S, Matsumoto K, Oki A, *et al.* Do we need a different strategy for HPV screening and vaccination in East Asia? Int J Cancer 2006; 119: 2713-5
[22] Clifford GM, Smith JS, Plummer M, Muñoz N, Franceschi S. Human papillomavirus types in invasive cervical cancer worldwide: a meta-analysis. Br J Cancer 2003; 88: 63-73
[23] Wright TC Jr. Current status of HPV vaccination recommendation. HPV Today 2008; 14: 8-9
[24] Muñoz N, Kjaer SK, Sigurdsson K, *et al.* Impact of Human papillomavirus (HPV)-6/11/16/18 vaccine on all HPV-associated genital diseases in young women. J Natl Cancer Inst 2010; 102:325-39
[25] Paavonen J, Naud P, Salmerón J, *et al.* Efficacy of human papillomavirus (HPV)-16/18 AS04-adjuvanted vaccine against cervical infection and precancer caused by oncogenic HPV types (PATRICIA): Final analysis of a double-blind, randomised study in young women. Lancet 2009; 374: 301-14
[26] Kanodia S, Da Silva DM, Kast WM. Recent advances in strategies for immunotherapy of human papillomavirus-induced lesions. Int J Cancer 2008; 122: 247-59
[27] Einstein MH, Kadish AS, Burk RD, *et al.*, Heat shock fusion protein-based immunotherapy for treatment of cervical intraepithelial neoplasia III. Gynecol Oncol 2007; 106: 453-60
[28] Roman LD, Wilczynski S, Muderspach LI, *et al.* A phase II study of Hsp-7 (SGN-00101) in women with high-grade cervical intraepithelial neoplasia. Gynecol Oncol 2007; 106: 558-66
[29] Kaufmann AM, Nieland JD, Jochmus I, *et al.* Vaccination trial with HPV16 L1E7 chimeric virus-like particles in women suffering from high grade cervical intraepithelial neoplasia (CIN 2/3. Int J Cancer 2007; 121: 2794-800
[30] Davidson EJ, Boswell CM, Sehr P, *et al.* Immunological and clinical responses in women with vulval intraepithelial neoplasia vaccinated with a vaccinia virus encoding human papillomavirus 16/18 oncoproteins. Cancer Res 2003; 63: 6032-41
[31] Fiander AN, Tristram AJ, Davidson EJ, *et al.* Prime-boost vaccination strategy in women with high-grade, noncervical anogenital intraepithelial neoplasia: clinical results from a multicenter phase II trial. Int J Gynecol Cancer 2006; 16:1075-81
[32] García-Hernández E, González-Sánchez JL, Andrade-Manzano A, *et al.* Regression of papilloma high-grade lesions (CIN 2 and CIN 3) is stimulated by therapeutic vaccination with MVA E2 recombinant vaccine. Cancer Gene Ther 2006; 13: 592-7
[33] Garcia F, Petry KU, Muderspach L, *et al.* ZYC101a for treatment of high-grade cervical intraepithelial neoplasia: a randomized controlled trial. Obstet Gynecol 2004; 103: 317-26
[34] Kenter GG, Welters MJ, Valentijn AR, *et al.* Vaccination against HPV-16 oncoproteins for vulvar intraepithelial neoplasia. N Engl J Med 2009; 361: 1838-47
[35] Gorfu G, Nieves JR, Ley K. Role of beta7 integrins in intestinal lymphocyte homing and retention. Curr Mol Med 2009; 9: 836-50
[36] Iwata M, Hirakiyama A, Eshima Y, Kagechika H, Kato C, Song SY. Retinoic acid imprints gut-homing specificity on T cells. Immunity 2004; 21: 527-38
[37] Ericsson A, Svensson M, Arya A, Agace WW. CCL25/CCR9 promotes the induction and function of CD103 on intestinal intraepithelial lymphocytes. Eur J Immunol 2004; 34: 2720-9
[38] Trimble CL, Clark RA, Thoburn C, *et al.* Human Papillomavirus 16-associated cervical intraepithelial neoplasia in humans excludes CD8 T cells from dysplastic epithelium. J Immunol 2010; 185: 7107-14
[39] Pudney J, Quayle AJ, Anderson DJ, Immunological microenvironments in the human vagina and cervix: Mediators of cellular immunity are concentrated in the cervical transformation zone. Biol Reprod 2005; 73: 1253-63
[40] Kelly KA, Wiley D, Wiesmeier E, Briskin M, Butch A, Darville T. The combination of the gastrointestinal integrin ($\alpha4\beta7$) and selectin ligand enhances T-cell migration to the reproductive tract during infection with Chlamydia trachomatis. Am J Reprod Immunol 2009; 61: 446-52
[41] Kojima S, Kawana K, Fujii T, *et al.* Characterization of intraepithelial lymphocytes (IELs) residing in the cervical mucosa of patients with human papillomavirus (HPV)-infected intraepithelial neoplastic lesions. Am J Reprod Immunol 2011; 66: 435-43
[42] Bermúdez-Humarán LG, Cortes-Perez NG, Lefèvre F, *et al.* A novel mucosal vaccine based on live Lactococci expressing E7 antigen and IL-12 induces systemic and mucosal immune responses and protects mice against human papillomavirus type 16-induced tumors. J Immunol 2005; 175: 7297-302
[43] Cortes-Perez NG, Lefèvre F, Corthier G, Adel-Patient K, Langella P, Bermúdez-Humarán LG. Influence of the route of immunization and the nature of the bacterial vector on immunogenicity of mucosal vaccines based on lactic acid bacteria. Vaccine 2007; 25: 6581-8
[44] Poo H, Pyo HM, Lee TY, *et al.* Oral administration of human papillomavirus type 16 E7 displayed on Lactobacillus casei induces E7-specific antitumor effects in C57/BL6 mice. Int J Cancer 2006; 119: 1702-9
[45] Adachi K, Kawana K, Yokoyama T, *et al.* Oral immunization with *Lactobacillus casei* vaccine expressing human papillomavirus (HPV) type 16 E7 is an effective strategy to induce mucosal cytotoxic lymphocyte against HPV16 E7. Vaccine 2010; 28: 2810-7

Received: February 16, 2012 Revised: July 28, 2012 Accepted: August 10, 2012

Vaccine 30 (2012) 5368–5372

Contents lists available at SciVerse ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

Adjuvant effect of Japanese herbal medicines on the mucosal type 1 immune responses to human papillomavirus (HPV) E7 in mice immunized orally with *Lactobacillus*-based therapeutic HPV vaccine in a synergistic manner

Ayumi Taguchi[a], Kei Kawana[a,*], Terufumi Yokoyama[b], Katsuyuki Adachi[a], Aki Yamashita[a], Kensuke Tomio[a], Satoko Kojima[a], Katsutoshi Oda[a], Tomoyuki Fujii[a], Shiro Kozuma[a]

[a] Department of Obstetrics and Gynecology, Faculty of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan
[b] GENOLAC BL Corp. 503, Okinawa Industry Support Center, 1831-1, Oroku, Naha, Okinawa 901-0152, Japan

ARTICLE INFO

Article history:
Received 20 April 2012
Received in revised form 31 May 2012
Accepted 10 June 2012
Available online 21 June 2012

Keywords:
Japanese herbal medicines
HPV therapeutic vaccine
Mucosal immune response
Lactobacillus-based vaccine
Oral immunization

ABSTRACT

The Japanese herbal medicines, Juzen-taiho-to (JTT) and Hochu-ekki-to (HET), have been shown to enhance humoral immune responses to vaccine antigen when used as adjuvants for prophylactic vaccines. However, their adjuvant effect on mucosal cellular immune responses remains unstudied. The precursor lesion of cervical cancer, high-grade CIN that expresses HPV E7 oncoprotein ubiquitously is a target for HPV therapeutic vaccines that elicit mucosal E7-specific type 1 T cell responses. We have demonstrated that oral immunization with recombinant *Lactobacillus casei* expressing HPV16 E7 (LacE7) is more effective in eliciting mucosal E7-specific IFNγ-producing cells than subcutaneous or intramuscular antigen delivery. Here we report the synergistic effect of an oral *Lactobacillus*-based vaccine and Japanese herbal medicines on mucosal immune responses. Oral immunization of mice with LacE7 plus either a Japanese herbal medicine (JTT or HET) or a mucosal adjuvant, heated-labile enterotoxin T subunit (LTB), promotes systemic E7-specific type 1 T cell responses but not mucosal responses. Administration of LacE7 plus either Japanese herbal medicine and LTB enhanced mucosal E7-specific type 1 T cell response to levels approximately 3-fold higher than those after administration of LacE7 alone. Furthermore, secretion of IFNγ and IL-2 into the intestinal lumen was observed after oral administration of LacE7 and was enhanced considerably by the addition of Japanese herbal medicines and LTB. Our data indicated that Japanese herbal medicines, in synergy with *Lactobacillus* and LTB, enhance the mucosal type 1 immune responses to orally immunized antigen. Japanese herbal medicines may be excellent adjuvants for oral *Lactobacillus*-based vaccines and oral immunization of LacE7, HET and LTB may have the potential to elicit extremely high E7-specific mucosal cytotoxic immune response to HPV-associated neoplastic lesions.

1. Introduction

Human papillomavirus (HPV) infection is a major risk factor for the development of cervical cancer which is the second most common cancer among women [1]. HPV prophylactic vaccines hold promise to reduce the worldwide incidence of cervical cancer. However, limitations in current HPV vaccine strategies make the development of HPV therapeutic vaccines for the treatment of HPV-associated lesions essential. HPV E7 is an attractive target protein for HPV therapeutic vaccine strategies that are directed against a precursor lesion of cervical cancer, high-grade cervical intraepithelial neoplasia (CIN) [2]. Many therapeutic vaccines against HPV E7 have been developed and several clinical vaccination trials against high-grade CIN have been completed [3–11]. However, no therapeutic HPV vaccines are yet available. The current vaccine candidates have been shown to elicit systemic cellular immunity after intramuscular or subcutaneous injection and clinical trials have shown cellular immune responses to the vaccines in peripheral monocytes but fail to show local immunity in the cervical mucosa after vaccination. Cervical mucosal lesions may be poorly responsive to systemic cellular immunity since precursor lesions develop in the mucosal epithelium; mucosal intraepithelial lymphocytes (IELs) should be the central effector cells for the elimination of CIN. Lymphocytes involved in the mucosal immune system are found in the inductive sites of organized mucosa-associated lymphoid tissues and in a variety of effector sites such as the mucosa of the intestine, respiratory tract and genital tract [12]. The efficient homing of lymphocytes to the gut is dependent on the homing receptors integrin α4β7 [13]. Several studies have demonstrated that gut-derived integrin $\alpha4\beta7^+$ lymphocytes subsequently home to the genital mucosa [14–17].

* Corresponding author. Tel.: +81 3 3815 5411; fax: +81 3 3816 2017.
E-mail address: kkawana-tky@umin.ac.jp (K. Kawana).

0264-410X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.vaccine.2012.06.027

We have reported previously that the oral *Lactobacillus*-based vaccine expressing HPV16 E7 (LacE7) has substantial potential to be a novel HPV therapeutic vaccine [18]. Oral immunization with LacE7 elicited E7-specific IFNγ-producing cells (T cells with E7-type1 immune responses) among integrin $\alpha4\beta7^+$ mucosal lymphocytes collected from gut mucosa. In our previous study, oral immunization with LacE7 preferentially elicited E7-specific type1 T cell responses in mucosal lymphocytes when compared to splenocytes. Taken together with the data that gut-derived integrin $\alpha4\beta7^+$ T cells home to the cervical mucosa [19], we predicted that vaccine-induced mucosal $CD4^+$ and $CD8^+$ T cells will have antitumor effects on mucosal HPV E7-related neoplastic lesions.

Traditional Chinese herbal medicines and their Japanese counterparts, Japanese herbal medicines, are used not merely to improve weak constitutions but also to suppress many constitutional symptoms. The Japanese herbal medicines, Juzen-taiho-to (JTT) and Hochu-ekki-to (HET), have been reported to exert beneficial effects on various aspects of the immune response [20] and are thought to have great potential as adjuvants for prophylactic vaccination against a variety of microbes [21–23]. JTT's immunomodulatory actions include an enhancement of the mitogenic activity of spleen cells, a promotion of phagocytosis and anti-tumor effect [24,25]. HET activates natural killer cells and macrophages [26,27]. Orally administered HET increases antibody titers against influenza virus in mice immunized with influenza vaccines and promotes secretory IgA production after oral OVA vaccination [28,29].

Viewing the actions of JTT and HET on innate immunity within the intestinal mucosa after oral vaccination, we hypothesized that concurrent oral administration of JTT or HET and LacE7 would enhance mucosal cellular immune responses against HPV16 E7. To address the immunomodulatory effects of JTT or HET on anti-E7 immune responses, mice were given oral JTT or HET in addition to a LacE7 oral vaccine with or without the known adjuvant, a heat-labile lymphotoxin T subunit (LTB).

2. Materials and methods

2.1. Immunization protocols

LacE7 was provided from BioLeaders Corp. (Korea) and GENOLAC BL Corp. (Japan). LacE7 was generated from the recombinant *Lactobacillus casei* expressing HPV16 mutated E7 as previously described [18] and attenuated using heat. The attenuated *L. casei* were purified by washing several times with distilled water then dried to powder. LacE7 was insoluble in water-based solvents. Six-week-old female SPF C57BL/6 mice (CLEA Japan Inc., Japan) were used for immunization experiments. 1.0 mg/head of LacE7 were administered four times at weeks 1, 2, 4, and 6. All inoculums were suspended in PBS (200 μL/head) and administered once per day for five days each week via an intra-gastric tube after 3 h of fasting.

The Japanese herbal medicines, JTT or HET (40 mg/head/day, gifted from Dr. Keiichi Koizumi, University of Toyama) were mixed with powdered foods (5 g/head/day) which were taken consumed completely by five mice in a single cage. JTT or HET was administered to mice every day during each of the four rounds of LacE7 administration (weeks 0–6). Heat-labile *Escherichia coli* lymphotoxin, B subunit (LTB: 10 μg/head) was added to each LacE7 inoculum and administrated orally on the third day of each round of vaccination.

2.2. Sample collection

Lymphocytes, serum and intestinal washes were collected from immunized mice one week after the last inoculation (at week 7). After sacrifice, intestine, spleen and peripheral blood were obtained from five mice. Spleens were washed 3 times in HBSS. For intestinal specimens, the inside of intestinal tract was washed with 10 mL of HBSS with protease inhibitors after feces removal. The collected sera and intestinal washes were stored at −80 °C until use.

2.3. Preparation of murine splenocytes and intestinal mucosal lymphocytes

The intestines were opened longitudinally and shaken vigorously in RPMI1640 containing 10% FBS, 100 units/mL of penicillin and 100 μg/mL of streptomycin for 30 min at 37 °C. The resulting cell suspensions were passed through a BD Falcon Cell-strainer (BD Bioscience, USA) to remove tissue debris and were subjected to discontinuous density gradient centrifugation in a 15 mL tube layered from the bottom with 70% and 40% Percoll PLUS (GE Healthcare UK Ltd., England). The interface between the 70% and 40% layers contained lymphocytes with a cell viability of more than 95%. Splenocytes were prepared by gently teasing the spleen in PBS. Clumped debris was removed by centrifugation. Approximately $5–10 \times 10^6$ intestinal mucosal lymphocytes and 10^7 splenocytes were obtained from individual mice.

2.4. ELISPOT assays

50 μL of intestinal mucosal lymphocytes or splenocytes (5×10^6 cells/mL) were incubated for 24 h at 37 °C with antigen presenting cells comprised of 50 μL of splenocytes (5×10^6 cells/mL) treated with mitomycin C (75 μg/mL, Sigma, USA), and washed three times with PBS. 10 μL of synthetic peptide (working conc. = 1 μg/mL) corresponding to amino acids 49–57 of HPV16 E7 (a reported CTL epitope for C57BL/6 mice), mitogen (PMA 40 ng/mL + ionomycine 4 μg/mL), or medium alone (negative control) were added to a 96-well ELIIP plate (Millipore, USA) coated with anti-mouse IFNγ monoclonal antibodies from the Mouse IFNγ Kit (MABTECH AB, Sweden). IFNγ spot numbers were analyzed with a fully automated computer assisted video imaging analysis system, KS ELISPOT (Carl Zeiss Vision, Germany).

2.5. Cytokine measurements

Intestinal washes obtained from five mice were pooled and cytokine concentrations measured using the mouse Th1/Th2 ELISA Ready SET Go Kit (BD Bioscience, San Diego, CA, USA), which include IFNγ and IL-2 as representative Th1-type cytokines. The cytokine levels in each sample were normalized by total protein concentration. Measurements were repeated at least three times.

2.6. Statistical analysis

ELISPOT and ELISA data were presented as means ± standard deviations. Measurements and relative rates were compared between the immunization groups (5 mice/each group) using non-paired, two tailed Student's *t*-tests. A *p*-value of <0.05 was considered to be significant.

3. Results

3.1. The adjuvant effect of Japanese herbal medicines on E7-specific type 1 T cell responses

To examine the effect of oral administration of LacE7 vaccine plus Japanese herbal medicines on E7-specific type 1 T cell responses, the number of IFNγ-producing cells among mucosal lymphocytes or splenocytes was assessed by ELISPOT assay (Fig. 1). Each group of five mice was administered LacE7 (1.0 mg/head) orally or LacE7 plus JTT or HET (40 mg/head). JTT and HET were

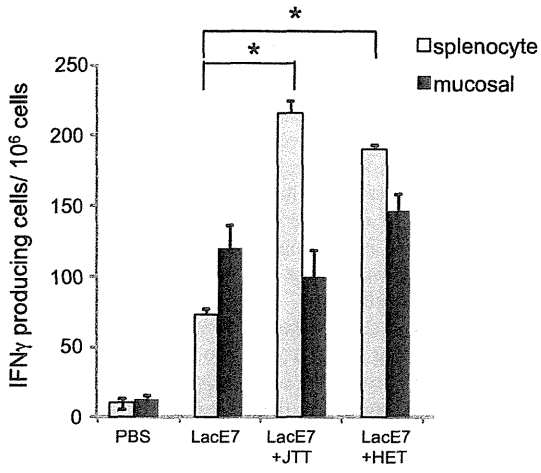

Fig. 1. Adjuvant effects of Japanese herbal medicines on type 1 T cell responses in mice orally immunized with Lac E7. The number of E7-specific IFNγ-producing cells among intestinal mucosal lymphocytes and splenocytes were assessed using ELISPOT assay. Five mice per group were immunized with LacE7 (1.0 mg/head) or PBS four times at weeks 1, 2, 4, and 6. JTT or HET was administered to mice every day during the four rounds of LacE7 administration. Mucosal lymphocyte and splenocytes were collected from immunized mice one week after last inoculation (at week 7) and approximately 10^5 of each type of lymphocyte were stimulated with the E7 peptide corresponding to HPV16E7 49–57 aa. Mean values with standard deviations are presented. Asterisks indicate those comparisons with statistical significance ($p < 0.05$) ($n = 5$).

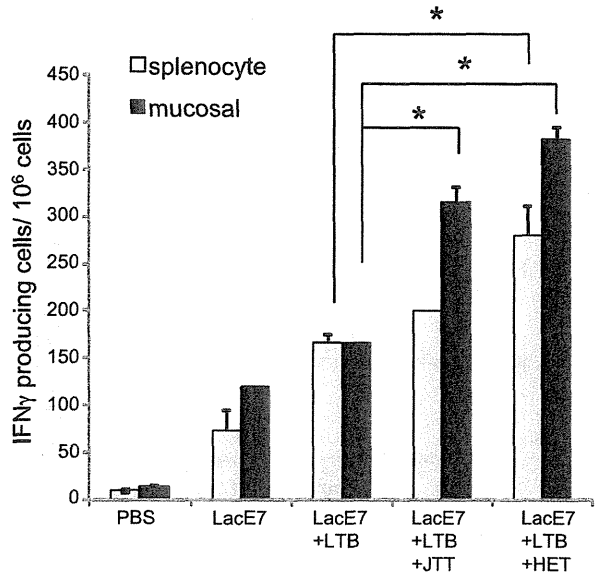

Fig. 2. Synergistic adjuvant effect of Japanese herbal medicines and LTB on type 1 T cell response. LTB (10 μg/head) was added to each LacE7 inoculum and administrated orally on the third day of each round of vaccination. This was performed in mice contemporaneously exposed to JTT, HET or control (no exposure). The number of E7-specific IFNγ producing cells among the collected intestinal mucosal lymphocytes and splenocytes was assessed using the ELISPOT assay as shown in Fig. 1. Mean values with standard deviations are presented. Asterisks indicate those comparisons with statistical significance ($p < 0.05$) ($n = 5$).

administered to mice as supplements to powdered food every day during four rounds of the LacE7 oral immunization. To detect potential adjuvant effects of the supplements on mucosal and systemic immunity, intestinal mucosal lymphocytes and splenocytes were collected from each mouse one week after the last immunization. The numbers of E7-specific IFNγ-producing cells among both mucosal lymphocytes and splenocytes increased significantly in LacE7-immunized mice but not in non-immunized (PBS) mice (Fig. 1). Oral immunization with LacE7 elicited a predominant mucosal E7-specific type 1 T cell response with E7-specific IFNγ-producing cell levels approximately 1.5–2.0-fold higher than those among splenocytes. Administration of LacE7 plus JTT or HET significantly improved systemic E7-specific type 1 T cell responses in splenocytes. However, neither JTT nor HET exhibited significant adjuvant effects on mucosal type 1 T cell responses (Fig. 1).

3.2. Adjuvant effects of the Japanese herbal medicines when combined with LTB on mucosal immune responses

Our initial data suggested that the use of additional adjuvants might be necessary to improve the mucosal cellular immune response to E7. We therefore repeated our investigations, adding oral LTB to LacE7 with each round of LacE7 oral immunization. Although the levels of E7-specific type 1 T cell response in mice given LacE7 plus LTB tended to increase, no significant differences were noted when comparing LacE7/LTB to LacE7 alone (Fig. 2). Mice exposed to either JTT or HET together with LTB and-LacE7 had improved mucosal E7-specific type 1 T cell response with approximately 2–2.5-fold higher levels of E7-specific mucosal IFNγ-producing cells when compared with sole exposure to LacE7 plus LTB (Fig. 2). Comparing Figs. 1 and 2, we noted that the addition of LTB to LacE7 plus either JTT or HET doubled the number of the IFNγ-producing cells among mucosal T cells, but not splenocytes. These data indicated that LTB and the Japanese herbal medicines act synergistically on the mucosal type 1 T cell response elicited by LacE7.

3.3. Local cytokine production induced by oral immunization with LacE7, LTB and Japanese herbal medicines

To confirm the characteristics of local cellular T cell responses stimulated by oral immunization, type 1 cytokine secretions were measured in the mucosal compartment. Levels of IFNγ and IL-2 production in intestinal washes obtained from immunized mice were measured by ELISA (Figs. 3 and 4). Both IFNγ and IL-2 levels in the mucosal fluid increased significantly in mice immunized orally with LacE7 when compared with non-immunized mice (PBS), consistent with a previous data that mucosal administration of *L. casei* alone induces Th1 cytokine production in a mucosal compartment [30]. Using comparisons mimicking those in Fig. 2, LacE7 plus either JTT or HET and LTB promoted secretion of both IFNγ and IL-2 into the intestinal lumen (Figs. 3 and 4). The secretion levels were 6–8-fold higher for IFNγ (Fig. 3) and 2–4-fold higher for IL-2 (Fig. 4) when compared with LacE7 alone. Administration of LacE7 plus LTB did stimulate increased cytokine secretion when compared with LacE7 alone. These results confirm that JTT or HET have synergistic effects when added to LacE7/LTB oral immunization protocols on local Th1 cytokine secretion, as well as the induction of E7-specific IFNγ-producing cells.

4. Discussion

The therapeutic HPV vaccines tested to date can induce enhanced cellular immune responses but none have demonstrated clinical efficacy against CIN [31–33]. We hypothesize that by using intramuscular or subcutaneous injection strategies, these approaches promote systemic cellular immunity, but not local mucosal immunity. Intraepithelial lymphocytes (IELs) residing in the cervical mucosa are most likely to represent the central effector cells for elimination of CIN and systemic vaccination with HPV E7 is not thought to elicit and retain enough E7-specific CTL within the cervical mucosa to eliminate CIN. We have previously observed

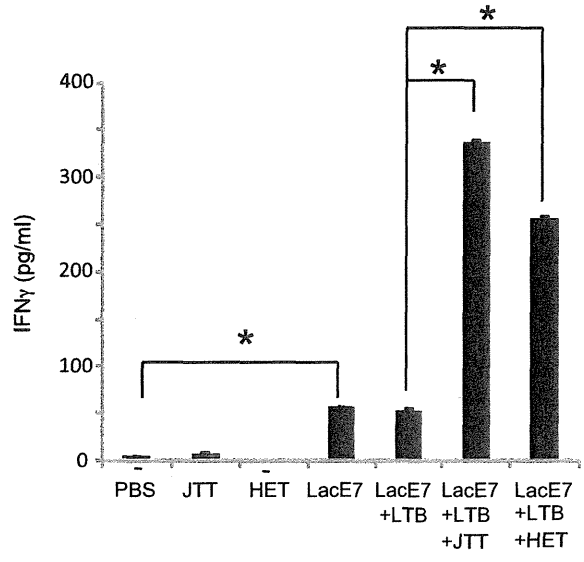

Fig. 3. IFNγ secretion into the intestinal compartment after immunization with LacE7 plus JTT or HET and LTB. IFNγ levels in the intestinal washes were measured by ELISA. The intestinal washes were collected at the same time points that were assessed in Fig. 1. Cytokine levels in each sample were normalized to corresponding total protein concentrations. Mean values with standard deviations are presented. The asterisks indicate those comparisons with statistical significance ($p < 0.05$) ($n = 5$).

and reported the induction of integrin $\alpha4\beta7^+$ mucosal T cells that provide E7-specific type 1 T cell responses after oral administration of LacE7 to mice [18]. We have also demonstrated that 25–30% of the $CD3^+$ cervical lymphocytes are integrin $\beta7^+$ T cells [34]. In

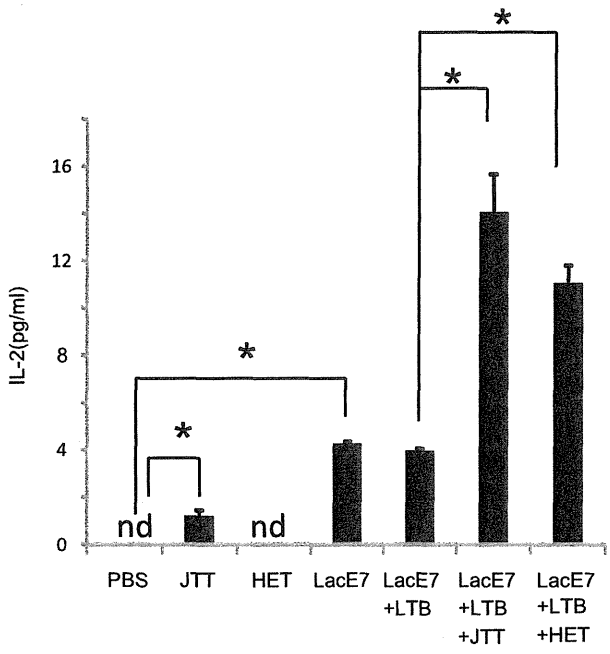

Fig. 4. IL-2 secretion into the intestinal compartment after immunization with LacE7 plus Japanese herbal medicine and LTB. IL-2 levels in the intestinal washes were measured by ELISA. The intestinal washes were collected at the same time points that were assessed in Fig. 1. Cytokine levels in each sample were normalized to corresponding total protein concentrations. Mean values with standard deviations are presented. The asterisks indicate those comparisons with statistical significance ($p < 0.05$) ($n = 5$).

our previous data, the number of vaccine induced E7-specific type1 T cells peaked at exposure levels of 1.0 mg/head and decreased with doses over 3.0 mg/head when mice were orally immunized with various doses of LacE7 (0.3–100 mg/head). We believe that 1.0 mg/head may be the optimal dose of LacE7 for induction of mucosal E7-specific type 1 T cells, because high-dose antigen may induce development of E7-specific regulatory T cells. These limitations led us to consider that the addition of an effective adjuvant agent might be more effective in improving E7-specific Th1 type responses than dose-escalation of LacE7. We chose to focus on two Japanese herbal medicines that have been reported to exhibit immunomodulatory effects.

Our data indicate that while JTT or HET alone exerts adjuvant effects on systemic but not mucosal type 1 T cell responses to LacE7, a combination of the mucosal adjuvant (LTB) with either Japanese herbal medicine dramatically improved the desired mucosal E7-specific type 1 T cell responses. These Japanese herbal medicine, when added to a conventional mucosal adjuvant, such as LTB, appear to act synergistically on mucosal vaccine-induced immune responses. The demonstrated adjuvant effects on mucosal immune response may be partially attributed to the strategy involving oral immunization of *L. casei*, which acts as an efficient vaccine carrier that delivers antigen across the gut to GALT but also exhibits its own vaccine adjuvant activities that promote type 1 T cell responses [4,35]. *Lactobacillus* species promote this type 1 T cell response polarization through interactions with dendritic cells (DCs) [36]. *Lactobacillus* activate DCs through TLR-2 and the activated DCs stimulate the proliferation of autologous $CD4^+$ and $CD8^+$ T cells and their secretion of IFNγ [37]. Recombinant *L. casei* alone can induce IFNγ production at mucosal sites [35]. Taken together, *L. casei* appears to be an excellent antigen delivery vehicle when mucosal type 1 T cell responses to vaccine antigen are desired. In our study, the levels of type 1 T cell responses to E7 barely increased in mice immunized with LacE7 and LTB when compared with LacE7 alone. However, the addition of Japanese herbal medicines to LacE7 and LTB resulted in two to three-fold higher levels of type 1 mucosal T cell responses when compared to LacE7 and LTB. In summary, the Japanese herbal medicines, JTT and HET act in synergy with *L. casei* and LTB in mucosal antigen delivery strategies. When Th1-type local T cell responses to vaccine antigen are desired, the combination of a Japanese herbal medicine and LTB promote efficient and mucosa-specific adjuvant activities when added to Lactobacillus delivery systems.

More specifically, the addition of specifically, the addition of specific Japanese herbal medicines and mucosal adjuvant to LacE7 may be an outstanding approach to generate E7-specific mucosal cytotoxic immune responses to HPV-associated neoplastic lesions.

Acknowledgements

We thank to Dr. Ai Kawana-Tachikawa for expert advice on ELISPOT assays. This work was supported by a grant from the Ministry of Health, Labour and Welfare of Japan for the Third-Term Comprehensive Strategy for Cancer Control and for Comprehensive Strategy for Practical Medical Technology and by a grant from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] Ferlay J, Bray F, Pisani P. Cancer incidence, mortality and prevalence worldwide. IARC Cancer base no. 5, version 2.0. Lyon: IARC Press; 2004.
[2] Ressler S, Scheiden R, Dreier K, Laich A, Müller-Holzner E, Pircher H, et al. High-risk Human Papillomavirus E7 oncoprotein detection in cervical squamous cell carcinoma. Clin Cancer Res 2007;13(23):7067–72.
[3] Trimble CL, Frazer IH. Development of therapeutic HPV vaccines. Lancet Oncol 2009;10(10):975–80.

[4] Poo H, Pyo HM, Lee TY, Yoon SW, Lee JS, Kim CJ, et al. Oral administration of human papillomavirus type 16 E7 displayed on *Lactobacillus casei* induces E7-specific antitumor effects in C57/BL6 mice. Int J Cancer 2006;119(7):1702–9.
[5] van der Burg SH, Kwappenberg KM, O'Neill T, Brandt RM, Melief CJ, Hickling JK, et al. Pre-clinical safety and efficacy of TA-CIN, a recombinant HPV16 L2E6E7 fusion protein vaccine, in homologous and heterologous prime-boost regimens. Vaccine 2001;19(27):3652–60.
[6] Feltkamp MC, Smits HL, Vierboom MP, Minnaar RP, de Jongh BM, Drijfhout JW, et al. Vaccination with cytotoxic T lymphocyte epitope-containing peptide protects against a tumor induced by human papillomavirus type 16-transformed cells. Eur J Immunol 1993;23(9):2242–9.
[7] Kaufmann AM, Nieland JD, Jochmus I, Baur S, Friese K, Gabelsberger J, et al. Vaccination trial with HPV16 L1E7 chimeric virus-like particles in women suffering from high grade cervical intraepithelial neoplasia (CIN 2/3). Int J Cancer 2007;121(12):2794–800.
[8] Fiander AN, Tristram AJ, Davidson EJ, Tomlinson AE, Man S, Baldwin PJ, et al. Prime-boost vaccination strategy in women with high-grade, noncervical anogenital intraepithelial neoplasia: clinical results from a multicenter phase II trial. Int J Gynecol Cancer 2006;16(3):1075–81.
[9] Roman LD, Wilczynski S, Muderspach LI, Burnett AF, O'Meara A, Brinkman JA, et al. A phase II study of Hsp-7 (SGN-00101) in women with high-grade cervical intraepithelial neoplasia. Gynecol Oncol 2007;106(3):558–66.
[10] García-Hernández E, González-Sánchez JL, Andrade-Manzano A, Contreras ML, Padilla S, Guzmán CC, et al. Regression of papilloma high-grade lesions (CIN 2 and CIN 3) is stimulated by therapeutic vaccination with MVA E2 recombinant vaccine. Cancer Gene Ther 2006;13(6):592–7.
[11] Garcia F, Petry KU, Muderspach L, Gold MA, Braly P, Crum CP, et al. ZYC101a for treatment of high-grade cervical intraepithelial neoplasia: a randomized controlled trial. Obstet Gynecol 2004;103(2):317–26.
[12] Kunisawa J, Kurashima Y, Kiyono H. Gut-associated lymphoid tissues for the development of oral vaccines. Adv Drug Deliv Rev 2011:30.
[13] Martinelli E, Tharinger H, Frank I, Arthos J, Piatak Jr M, Lifson JD, et al. HSV-2 infection of dendritic cells amplifies a highly susceptible HIV-1 cell target. PLoS Pathog 2011;7(6):e1002109.
[14] Csencsits KL, Jutila MA, Pascual DW. Nasal-associated lymphoid tissue: phenotypic and functional evidence for the primary role of peripheral node addressin in naive lymphocyte adhesion to high endothelial venules in a mucosal site. J Immunol 1999;163(3):1382–9.
[15] Hänninen A, Taylor C, Streeter PR, Stark LS, Sarte JM, Shizuru JA, et al. Vascular addressins are induced on islet vessels during insulitis in nonobese diabetic mice and are involved in lymphoid cell binding to islet endothelium. J Clin Invest 1993;92(5):2509–15.
[16] Kelly KA, Rank RG. Identification of homing receptors that mediate the recruitment of CD4T cells to the genital tract following intravaginal infection with *Chlamydia trachomatis*. Infect Immun 1997;65(12):5198–208.
[17] Mantis NJ, Wagner J. Analysis of adhesion molecules involved in leukocyte homing into the basolateral pockets of mouse Peyer's patch M cells. J Drug Target 2004;12(2):79–87.
[18] Adachi K, Kawana K, Yokoyama T, Fujii T, Tomio A, Miura S, et al. Oral immunization with *Lactobacillus casei* vaccine expressing human papillomavirus (HPV) type 16 E7 is an effective strategy to induce mucosal cytotoxic lymphocyte against HPV16 E7. Vaccine 2010;28:2810–7.
[19] Hawkins RA, Rank RG, Kelly KA. Expression of mucosal homing receptor alpha4beta7 is associated with enhanced migration to the Chlamydia-infected murine genital mucosa in vivo. Infect Immun 2000;68(10):5587–94.
[20] Kiyohara H, Nagai T, Munakata K, Nonaka K, Hanawa T, Kim SJ, et al. Stimulating effect of Japanese herbal (kampo) medicine, hochuekkito on upper respiratory mucosal immune system. Evid Based Complement Alternat Med 2006;3(4):459–67.
[21] Zhao X, Fan Y, Wang D, Hu Y, Guo L, Ruan S, et al. Immunological adjuvant efficacy of glycyrrhetinic acid liposome against Newcastle disease vaccine. Vaccine 2011;29(52):9611–7.
[22] Ma X, Guo Z, Shen Z, Wang J, Hu Y, Wang D. The immune enhancement of propolis adjuvant on inactivated porcine parvovirus vaccine in guinea pig. Cell Immunol 2011;270(1):13–8.
[23] Underwood JR, Chivers M, Dang TT, Licciardi PV. Stimulation of tetanus toxoid-specific immune responses by a traditional Chinese herbal medicine. Vaccine 2009;27(47):6634–41.
[24] Saiki I. A Kampo medicine "Juzen-taiho-to" – prevention of malignant progression and metastasis of tumor cells and the mechanism of action. Biol Pharm Bull 2000;23(6):677–88.
[25] Tsuchiya M, Kono H, Matsuda M, Fujii H, Rusyn I. Protective effect of Juzen-taiho-to on hepatocarcinogenesis is mediated through the inhibition of Kupffer cell-induced oxidative stress. Int J Cancer 2008;123(11):2503–11.
[26] Cho JM, Sato N, Kikuchi K. Prophylactic antitumor effect of Hochu-ekki-to (TJ-41) by enhancing natural killer cell activity. In Vivo 1991;5:389–92.
[27] Kataoka T, Akagawa KS, Tokunaga T, Nagao S. Activation of macrophages with Hochu-ekki-to. Jpn J Cancer Chemother 1989;16:1490–3.
[28] Takagi Y, Azuma N, Kawai S, Maeda A. Antibody response of Kampo-hozai after influenza B immunization in old mice. Jpn Soc Vaccinol 2002;6:72.
[29] Matsumoto T, Noguchi M, Hayashi O, Makino K, Yamada H. Hochuekkito, a Kampo (traditional Japanese herbal) Medicine enhances mucosal IgA antibody response in mice immunized with antigen-entrapped biodegradable microparticles. Evid Based Complement Alternat Med 2010;7(1):69–77.
[30] Vintiñi EO, Medina MS. Host immunity in the protective response to nasal immunization with a pneumococcal antigen associated to live and heat-killed *Lactobacillus casei*. BMC Immunology 2011;12:46–59.
[31] Davidson EJ, Boswell CM, Sehr P, Pawlita M, Tomlinson AE, McVey RJ, et al. Immunological and clinical responses in women with vulval intraepithelial neoplasia vaccinated with a vaccinia virus encoding human papillomavirus 16/18 oncoproteins. Cancer Res 2003;63:6032–41.
[32] Fiander AN, Tristram AJ, Davidson EJ, Tomlinson AE, Man S, Baldwin PJ, et al. Prime-boost vaccination strategy in women with high-grade, noncervical anogenital intraepithelial neoplasia: clinical results from a multicenter phase II trial. Int J Gynecol Cancer 2006;16:1075–81.
[33] Kenter GG, Welters MJ, Valentijn AR, Lowik MJ, Berends-van der Meer DM, Vloon AP, et al. Vaccination against HPV-16 oncoproteins for vulvar intraepithelial neoplasia. N Engl J Med 2009;361:1838–47.
[34] Kojima S, Kawana K, Fujii T, Yokoyama T, Miura S, Tomio K, et al. Characterization of intraepithelial lymphocytes (IELs) residing in the cervical mucosa of patients with human papillomavirus (HPV)-infected intraepithelial neoplastic lesions. Am J Reprod Immunol 2011;66:435–43.
[35] Kajikawa A, Satoh E, Leer RJ, Yamamoto S, Igimi S. Intragastric immunization with recombinant *Lactobacillus casei* expressing flagellar antigen confers antibody-independent protective immunity against *Salmonella enterica* serovar Enteritidis. Vaccine 2007;25(18):3599–605.
[36] Mohamadzadeh M, Olson S, Kalina WV, Ruthel G, Demmin GL, Warfield KL, et al. Lactobacilli activate human dendritic cells that skew T cells toward T helper 1 polarization. Proc Natl Acad Sci USA 2005;102(8):2880–5.
[37] Koizumi S, Wakita D, Sato T, Mitamura R, Izumo T, Shibata H, et al. Essential role of Toll-like receptors for dendritic cell and NK1.1(+) cell-dependent activation of type 1 immunity by *Lactobacillus pentosus* strain S-PT84. Immunol Lett 2008;120(1–2):14–9.

ORIGINAL ARTICLE

The Prevalence of Cervical Regulatory T Cells in HPV-Related Cervical Intraepithelial Neoplasia (CIN) Correlates Inversely with Spontaneous Regression of CIN

Satoko Kojima[1], Kei Kawana[1], Kensuke Tomio[1], Aki Yamashita[1], Ayumi Taguchi[1], Shiho Miura[1], Katsuyuki Adachi[1], Takeshi Nagamatsu[1], Kazunori Nagasaka[1], Yoko Matsumoto[1], Takahide Arimoto[1], Katsutoshi Oda[1], Osamu Wada-Hiraike[1], Tetsu Yano[1], Yuji Taketani[1], Tomoyuki Fujii[1], Danny J. Schust[2], Shiro Kozuma[1]

[1]Department of Obstetrics and Gynecology, Faculty of Medicine, University of Tokyo, Bunkyo-ku, Tokyo, Japan;
[2]Division of Reproductive Endocrinology and Fertility, Department of Obstetrics, Gynecology and Women's Health, University of Missouri School of Medicine, Columbia, MO, USA

Keywords
CD4+CD25+Foxp3+ regulatory T cells, cervical intraepithelial neoplasia, cervical lymphocytes, programmed cell death-1

Correspondence
Kei Kawana, Department of Obstetrics and Gynecology, Faculty of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan.
E-mail: kkawana-tky@umin.ac.jp

Submission June 24, 2012;
accepted September 13, 2012.

Citation
Kojima S, Kawana K, Tomio K, Yamashita A, Taguchi A, Miura S, Adachi K, Nagamatsu T, Nagasaka K, Matsumoto Y, Arimoto T, Oda K, Wada-Hiraike O, Yano T, Taketani Y, Fujii T, Schust DJ, Kozuma S. The prevalence of cervical regulatory T cells in HPV-related cervical intraepithelial neoplasia (CIN) correlates inversely with spontaneous regression of CIN. Am J Reprod Immunol 2013; 69: 134–141

doi:10.1111/aji.12030

Problem
Local adaptive cervical regulatory T cells (Tregs) are the most likely direct suppressors of the immune eradication of cervical intraepithelial lesion (CIN). PD-1 expression on T cells induces Tregs. No studies have quantitatively analyzed the Tregs and PD-1+ cells residing in CIN lesions.

Method of study
Cervical lymphocytes were collected using cytobrushes from CIN patients and analyzed by FACS analysis. Comparisons were made between populations of cervical Tregs and PD-1+ CD4+ T cells in CIN regressors and non-regressors.

Results
A median of 11% of cervical CD4+ T cells were Tregs, while a median of 30% were PD-1+ cells. The proportions of cervical CD4+ T cells that were Tregs and/or PD-1+ cells were significantly lower in CIN regressors when compared with non-regressors.

Conclusions
The prevalence of cervical tolerogenic T cells correlates inversely with spontaneous regression of CIN. Cervical Tregs may play an important role in HPV-related neoplastic immunoevasion.

Introduction

HPV infection is a major cause of cervical cancer and its precursor lesion, cervical intraepithelial neoplasia (CIN). Natural history studies of CIN[1,2] show that most infections and most CIN lesions resolve spontaneously; only a minority persists and progress to cervical cancer. Studies showing that HIV-infected women and patients who are under treatment with immunosuppressive agents have an increased incidence of CIN lesions[3,4] suggest that cell-mediated immune response against HPV viral protein is important in the control of HPV infection and progression to CIN. We have previously reported that the presence of gut-derived effector lymphocytes within the cervix plays an important role in local cell-mediated

immune responses and correlates with CIN regression.[5] The presence of robust local tolerogenic cervical T-cell responses to HPV-related neoplastic lesions would be predicted to attenuate the effects of these local effector responses. We hypothesized that the proportion of tolerogenic lymphocytes among the CD4+ T cells in the cervix would decrease among women experiencing CIN regression, thereby allowing full effect of the changes previously seen among local effector cells.

It has been reported that CD4+CD25+Foxp3+ regulatory T cells (Tregs) play an important role in tumor-associated immunoevasion in cancers (ovarian, uterine cervical, endometrial, lung, breast, pancreas, renal cell, and thyroid cancers) as well as in other proliferative disorders such as melanoma and hepatoma.[6–15] Mechanisms underlying Treg suppressive functions have been abundantly reported. The high expression of CD25 (IL-2R) on Tregs has been thought to result in cytokine deprivation-induced apoptosis of effector T cells.[16] IL-10, TGF-β, and IL-35 are also important mediators of Treg suppressive function.[16] Tregs have been reported to suppress T effectors by ligating T-effector-expressed CD80, thereby inhibiting T-cell proliferation and cytokine production. Tregs kill effector T cells, other antigen-presenting cells, and NK cells in a manner dependent on granzyme and perforin.[16]

Natural Treg cells (nTregs) differentiate in the thymus and migrate to peripheral tissues while adaptive/induced Treg cells (iTregs) differentiate in secondary lymphoid organs and tissues including mucosa-associated lymphoid tissues (MALT).[17] iTregs play essential roles in mucosal tolerance, in the control of severe chronic allergic inflammation, in the prevention of parasite and other microorganism clearance, and in the obstruction of tumor immunosurveillance while nTregs have roles in preventing autoimmunity and preventing exaggerated immune responses. iTregs appear in the mesenteric lymph nodes during induction of oral tolerance, differentiate in the lamina propria of the gut in response to microbial signals, and are generated in chronically inflamed tissues. At a minimum, Foxp3+ iTreg development requires TCR stimulation and the cytokines TGF-β and IL-2. Integrin αEβ7+ dendritic cells (DCs) residing in the MALT produce both TGF-β and retinoic acid (RA), which mediate the differentiation of naïve T cells into Foxp3+ iTregs.[17]

The programmed cell death-1 (PD-1) and PD-ligand (PD-L) pathway is also critical in the suppression of immune responses. PD-1 is a molecule inducibly expressed on peripheral CD4+ and CD8+ T cells, NKT cells, B cells, monocytes, and some DC subsets when these cells are activated by antigen receptor signaling and cytokines.[16] nTregs and iTregs can express PD-1 and PD-L1, and the expression of ligand and receptor on the same cell conveys interesting implications. Engagement of PD-1 by its ligands during T-cell receptor (TCR) signaling results in two possible T-cell responses: 1) a diminution in T-effector responses and 2) an augmentation in differentiation of naïve T cells into Foxp3+ iTreg in a TGF-β-dependent manner.[16] There are synergistic effects between the PD-1/PD-L1 pathway and TGF-β in promoting Treg development. PD-L1 is expressed on a wide variety of tumors, and high levels of PD-L1 expression strongly correlate with unfavorable prognosis in a number of cancers.[18] To this point, ligation of PD-1 may induce and maintain iTregs within the tumor microenvironment, enhance the suppression of anti-tumor T-cell responses, and thereby allow tumor progression.

Several previous studies have shown that the prevalence of Tregs among PBMCs increases in CIN patients when compared with healthy controls.[19,20] These studies assess populations of circulating Tregs using flow cytometry. Characterization of the local lymphocytes residing in cervical lesions should better reflect local immune responses to pathogen. While Nakamura et al.[21] used Foxp3 immunostaining of human CIN lesions to report the number of local Foxp3+ cells residing in the CIN lesions by immunostaining of the tissues for Foxp3 and report that the number of Foxp3-immunoreactive cells is higher in CIN3 lesions than normal or CIN1-2 lesions, no studies have quantitatively assessed populations of local Tregs, likely iTregs, in the CIN lesions using flow cytometry. Possible associations between iTregs and the natural course of CIN have also never been studied.

We have previously characterized cervical lymphocytes collected from CIN lesions using a cytobrush and have demonstrated that the majority of cervical lymphocytes in these lesions are CD3+ T cells (median 74%) and that half of the cervical CD3 + T cells are CD4+ (median 54%).[5] In the present investigations, we have analyzed the relative proportions of two tolerogenic T-cell subsets, CD25+Foxp3+ Tregs and PD-1+ T cells, among cervical CD4+ T cells collected from CIN lesions. To determine whether there was a correlation between the frequency of cervical tolerogenic T cell and the natural course of

CIN, comparisons were made between tolerogenic T-cell subsets in the lesions of CIN regressors and non-regressors.

Materials and methods

Study Population

Cervical cell samples were collected using a cytobrush from 24 patients under observation after being diagnosed with CIN by colposcopically directed biopsy. All women gave written informed consent, and the Research Ethics Committee of the University of Tokyo approved all aspects of the study. Patients with known, symptomatic or macroscopically visible vaginal inflammation, or sexually transmitted infections were excluded from our study. To study the association between cervical tolerogenic lymphocytes and CIN progression, CIN patients with regression of cervical cytology (cases) were matched with control patients who did not exhibit cytologic regression over the same time period (measured from initial detection of abnormal cytology). In this study, cytological regression was defined as normal cytology at two or more consecutive evaluations conducted at 3–4 months intervals. For the comparison of CD4+CD25+Foxp3 Tregs and PD1+CD4+ cells, 12 patients were enrolled in the regression group, and the median follow-up duration was 16.5 (8–33) months. Twelve pairs of follow-up time-matched patients with persistent cytological abnormalities were enrolled in the non-regression group, and the median follow-up time was 19 (9–34) months. Patients were interviewed about their smoking history and their last menstrual period.

Collection and Processing of Cervical Lymphocytes

Cervical cells were collected using a Digene cytobrush as described previously.[5] The cytobrush was inserted into the cervical os and rotated several times. The cytobrush was immediately placed in a 15-mL tube containing R10 media (RPMI-1640 medium, supplemented with 10% fetal calf serum, 100 mg/mL streptomycin, and 2.5 μg/mL amphotericin B) and an anticoagulant (0.1 IU/mL of heparin and 8 nM EDTA). After incubating the sample with 5 mM DL-dithiothreitol at 37 °C for 15 min with shaking, the cytobrush was removed. The tube was then centrifuged at 330 *g* for 4 min. The resulting pellet was resuspended in 10 mL of 40% Percoll. This mixture was layered onto 70% Percoll and centrifuged at 480 *g* for 18 min. The mononuclear cells at the Percoll interface were removed and washed with PBS. Cell viability was greater than 95%, as confirmed by trypan blue exclusion, and fresh samples were immediately used for further analyses.

Immunolabeling and Flow Cytometry

Cervical immune cell preparations were immunolabeled with fluorochrome-conjugated mouse monoclonal antibodies specific for the following human leukocyte surface antigens: a programmed death-1 marker (FITC–anti-PD-1), a phycoerythrin cyanine 5.5 (PC5.5)-conjugated helper T-cell marker (PC5.5–anti-CD4), and an allophycocyanin (APC)-conjugated IL-2 receptor marker (APC–anti-CD25). After exposure to primary surface-labeling antibodies, cells were washed twice with FACS buffer (10% fetal calf serum, 1 mM EDTA, 10 mM NaN3), permeabilized with Foxp3 Fixation/Permeabilization working solution (eBioscience, San Diego, CA, USA), and immunolabeled with the anti-intracellular antigen antibody, phycoerythrin (PE)-conjugated anti-Foxp3 marker (PE–anti-Foxp3). Cells were then washed twice with Flow Cytometry Staining Buffer (eBioscience) and resuspended in Flow Cytometry Staining Buffer. Additional aliquots of the cell preparations were labeled in parallel with appropriate isotype control antibodies. Antibodies were purchased from eBioscience and BD (Franklin Lakes, NJ, USA). Data were acquired using four-color flow cytometry on FACSCalibar (Becton-Dickinson, Texarkana, TX, USA). A minimum of 5000 CD4+ T cells was analyzed per sample. The position of CD4+ T cells was determined by CD4 vs SSC gating. We used KALUZA® Flow Analysis Software (Becman Coulter, Brea, CA, USA) for data analysis.

HPV Genotyping

DNA was extracted from cervical smear samples using the DNeasy Blood Mini Kit (Qiagen, Crawley, UK). HPV genotyping was performed using the PGMY-CHUV assay method.[22] Briefly, standard PCR was conducted using the PGMY09/11 L1 consensus primer set and human leukocyte antigen-DQ (HLA-DQ) primer sets. Reverse blotting hybridization was performed. Heat-denatured PCR amplicons were hybridized to specific probes for 32 HPV genotypes

American Journal of Reproductive Immunology 69 (2013) 134–141

and HLA-DQ reference samples. The virological background (HPV genotyping) of 24 patients in our study is shown in Table I. HPVs 16, 18, 31, 33, 35, 39, 45, 51, 52, 53, 56, 58, 59, 68, 73, and 82 were defined as high-risk HPVs according to an International Agency for Research on Cancer (IARC) multicenter study.[23]

Statistical Analysis

Statistical analyses, including calculation of medians and interquartile ranges (IQRs), were performed using the commercial statistical software package JMP® (SAS, Cary, NC, USA). Wilcoxon rank sum tests or Fisher's exact tests were applied for matched pair comparisons. *P*-values ≤ 0.05 were considered significant.

Results

Isolation of Cervical Tolerogenic T-cell Subsets in CIN Lesions

To assess cervical tolerogenic T cells, cervical samples were collected from CIN lesions positive for any HPV genotype and fractionated over a discontinuous Percoll density gradient to remove cervical epithelial cells. Cervical lymphocytes were then isolated from the interphase between Percoll and culture medium.[5] Cervical CD4+ T cells were identified among the isolated lymphocytes using CD4 vs SSC gating. The percentages of CD4+ cervical T cells that were CD25+Foxp3+ Tregs or that were PD-1+ were determined by flow cytometry. Two representative cases are displayed in Fig. 1(a,b), respectively. The proportion of cervical CD4+ T cells that were CD25+Foxp3+ was 14.2% whereas the proportion of CD4+ T cells that displayed PD-1 was 33.6% (bold lines). Among all CIN patients, a median of 11.7% (IQR: 7.3–14.6, $n = 24$) of CD4+ cervical T cells were CD25+Foxp3+ Tregs, while a median of 30.7% (20.2–38.5, $n = 24$) of CD4+ cells expressed PD-1. The proportions of tolerogenic T-cell subsets found in cervical preparations were markedly higher than those reported in circulating peripheral blood where approximately 5% of PBMCs are CD25+Foxp3+ Tregs[24] and 5% of peripheral CD4+ T cells are PD-1+.[25] These data indicate that the cervical mucosal T cells separation technique used for these investigations isolated a population of T cells with characteristics that suggest little to no contamination by peripheral blood. Further, should small amounts of contamination occur during isolation the effect on overall results would be predicted to be minimal.

Table I Patients infected with multiple HPV types were included.

HPV type	Total numbers (%)
16	5 (16.6)
18	2 (6.6)
31	1 (3.3)
45	1 (3.3)
51	1 (3.3)
52	3 (10)
53	3 (10)
55	3 (10)
56	4 (13.3)
58	5 (16.6)
70	2 (6.6)
Total	30 (100)

Of 24 patients, 4 (16.6%) were infected with multiple types. HPVs 16, 18, 31, 33, 35, 39, 45, 51, 52, 53, 56, 58, 59, 68, 73, and 82 were defined as high-risk HPVs.

Correlation of Cervical Tregs and PD-1+ CD4+ cells in CIN Lesions with Menstrual Phase, HPV Types, Smoking History, and CIN Course

Many factors, including HPV genotypes, smoking, and other microbial infections, have been reported to associate with spontaneous regression or progression of CIN.[26] In this study, we obtained cervical Tregs from histologically diagnosed CIN patients and sought correlations between cervical Tregs and potential clinical factors, which may associate with the natural course of CIN. Patients with known, symptomatic or macroscopically visible vaginal inflammation, or sexually transmitted infections other than HPV were excluded from our study. All patients were diagnosed with CIN1-2 at the time of enrollment and followed with colposcopy and cervical cytology smears every 4 months.

To account for possible confounding factors, samples from our 24 CIN patients were reanalyzed after segregation by each of the following characteristics: menstrual phase (proliferative vs secretory), HPV genotype (high risk vs low risk), and smoking history (smoking vs non-smoking). The prevalence of CD25+Foxp3+ Tregs and of PD-1+ T cells among cervical CD4+ cells was compared between each of the

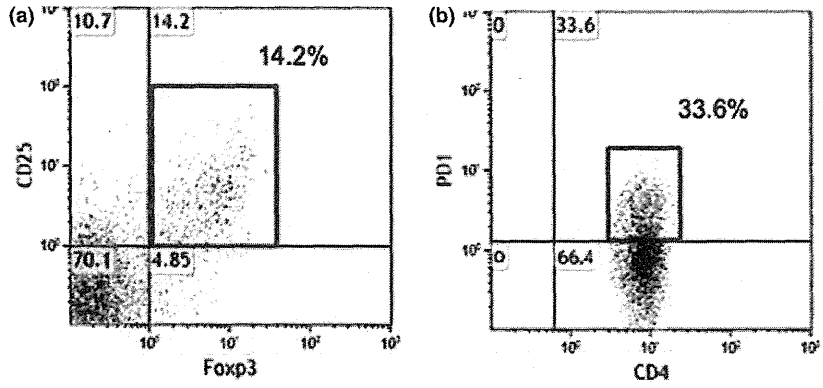

Fig. 1 Representatives of flow cytometric analysis of immune cells isolated from cervical intraepithelial neoplasia lesions. Bold lines delimit cervical CD4+CD25+Foxp3+ Tregs (a) and PD1+ CD4+ T cells (b). The indicated percentages represent percentage of total CD4+ T cells.

two groups using Wilcoxon rank sum testing (Table II). None of these possible confounders correlated with CD25+Foxp3+ Tregs and PD-1+ T cells results in CIN lesions, indicating that the tolerogenic T cells residing in the cervical mucosa were not influenced by smoking, hormonal status, or infecting HPV subtypes.

Next, we compared populations of CD25+Foxp3+ Tregs and PD-1+ T cells residing in the CIN lesions of regressors (n = 12) and non-regressors (n = 12) to determine whether there was an association between the frequency of cervical tolerogenic T-cell subsets and spontaneous regression of CIN. Twelve patients had spontaneous regression of their CIN lesions, and these women had a median follow-up duration of 16.5 (8–33) months. The non-regression group consisted of twelve women with persistent cytological abnormalities who were matched to the spontaneous regressor cohort by follow-up time. No significant differences were seen in the detection rates of high-risk HPV (58.3% vs 83.3%, P = 0.37), percent of CIN 2 at the enrollment (33.3% vs 58.3%, P = 0.4), and the median ages (33 years old vs 36, P = 0.44) of patients in the regression and non-regression groups. Among regressors, cervical CD25+Foxp3+ Tregs comprised a median of 7.3% (IQR: 6.3–11.4) of cervical CD4+ cells; the rate among non-regressors was 13.9% (IQR: 11.6–16.9). The frequency of cervical CD25+Foxp3+ Tregs in regressors was significantly lower than that in non-regressors (P = 0.0012) (Table II and Fig. 2). Similarly, cervical PD1+ CD4+ cells comprised a median of 20.8% (IQR: 15.8–31.9) of cervical CD4+ cells among regressors whereas a median of 35.1% (IQR:

Table II Correlation of the proportions of cervical Treg and PD-1+ cells among cervical CD4+ T-cell populations with clinical characteristics

		Percentage of total cervical CD4+ T cells			
Factors	Groups	CD25+Foxp3+ Tregs		PD-1+ cells	
Menstrual phase	Proliferative	10.26 (7.04–15.4)	P = 0.94	29.8 (22.7–39.5)	P = 0.72
	Secretory	12.0 (7.1–14.2)		28.1 (18.9–36.7)	
HPV genotype	High risk	11.8 (7.8–14.2)	P = 0.67	29.8 (20.3–38.2)	P = 0.82
	Low risk	7.4 (6.7–15.7)		33.5 (18.5–45.4)	
Smoking	Smoking	10.2 (7.3–14.7)	P = 0.73	29.8 (19.5–39.5)	P = 0.80
	Non-smoking	10.8 (5.0–15.9)		24.6 (19.6–40.9)	
CIN course	Regression	7.3 (6.3–11.4)	P = 0.0012	20.8 (15.8–31.9)	P = 0.018
	Non-regression	13.9 (11.6–16.9)		35.1 (30.2–42.6)	

Association of cervical CD4+CD25+Foxp3+ Tregs and PD1+CD4+ cells with menstrual cycle, HPV genotype, smoking, and cervical intraepithelial neoplasia (CIN) course were shown.

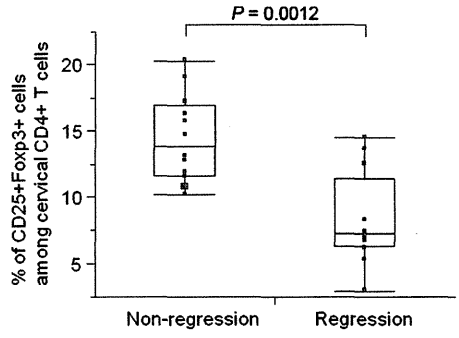

Fig. 2 Association of cervical Tregs with the natural course of cervical intraepithelial neoplasia. Among regressors, cervical Tregs comprised a median of 7.33% [Interquartile ranges (IQR): 6.38–11.4, $n = 12$] of CD4+ cervical T cells; the rate among non-regressors was 13.9% (IQR: 11.6–16.9, $n = 12$); $P = 0.0012$.

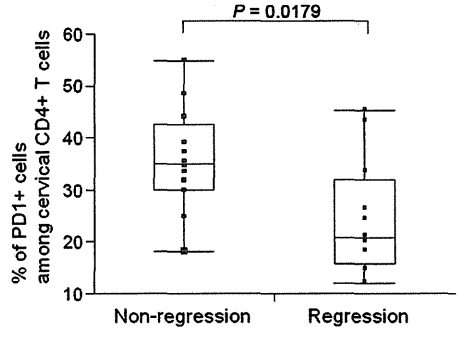

Fig. 3 Association of cervical PD-1+ CD4+ T cells with the natural course of cervical intraepithelial neoplasia. Among regressors, cervical PD1+ cells comprised a median of 20.8% [Interquartile ranges (IQR): 15.8–31.9, $n = 12$] of CD4+ cervical T cells; the rate among non-regressors was 35.1% (IQR: 30.2–42.6, $n = 12$); $P = 0.0179$.

30.2–42.6) among non-regressors. Again, the frequency of cervical PD-1+ CD4+ cells in regressors was significantly lower than that in non-regressors ($P = 0.017$) (Table II and Fig. 3).

Discussion

Although many studies have been reported about the positive association between tolerogenic lymphocytes and poor prognosis in many cancers, there are limited data on similar associations in women with HPV-related cervical precursor lesions. Our results show that the prevalence of CD25+ Foxp3+ Tregs and of PD1+ CD4+ T cells residing in cervical precursor lesions inversely correlates with spontaneous regression of CIN.

The peripheral population of Foxp3+ Tregs includes nTregs and iTregs. iTregs play essential roles in mucosal tolerance, in the control of severe chronic allergic inflammation, and in the prevention of organism clearance and tumor immunosurveillance, while nTregs have roles in preventing autoimmunity and exaggerated immune responses.[17] We would predict that the majority of cervical CD25 +Foxp3+ Tregs assessed in this study are iTregs although definitive isolation of iTregs is hampered by the lack of suitable surface markers that distinguish iTreg and nTreg cell populations.

In this study, cervical Treg prevalence negatively correlated with regression of CIN (Fig. 2) but did not correlate with CIN grade (data not shown). Supporting our data, several previous studies have shown a positive correlation between Treg prevalence in peripheral blood and high grade of CIN.[19,20] Of course, cervical iTregs and circulating Tregs may differ in their TCR repertoire. iTregs are known to differentiate from mature naïve CD4+ cells through the effects of TGF-β and RA secreted by mucosa-associated DCs.[17] In our data, the proportion of CD25 +Foxp3+ Tregs among total cervical CD4+ cells (a median of 11%) was twofold higher than previously reported peripheral blood levels (approximately 5%). This suggests that iTregs may be generated continuously, probably in an antigen-depending manner, and accumulate in chronically HPV-infected tissues and CIN lesions. Others have reported that Foxp3 mRNA levels in cervical samples that included exfoliated epithelial cells and cervical lymphocytes are higher among high-grade squamous intraepithelial lesion (HSIL) patients when compared with low-grade squamous intraepithelial lesion (LSIL) patients.[27] However, it is unknown whether Foxp3 mRNA levels in these cervical samples parallel the number of Tregs because cervical lymphocytes were not specifically isolated in this study.

Although the persistence of HPV infection was not followed in the present study, Molling et al.[20] reported that CD4+CD25hi Treg frequency correlates with persistence of HPV type 16. Tregs may inhibit the HPV clearance by immune cells such as invariant natural killer T cells.

TGF-β is critical to the induction and maintenance of Foxp3+ Tregs, with particular importance in the induction of iTregs from naive T cells and in the conversion of effector T cells to iTregs. Several studies have demonstrated that the expression of TGF-β and RA receptors in cervical specimens is lower in

CIN lesions when compared with normal epithelium.[28,29] In these studies, there was no correlation between TGF-β mRNA levels and either CIN grade or CIN natural course. TGF-β-induced iTreg frequency may be a more direct predictor of CIN progression than TGF-β. In fact, measurement of tolerogenic T-cell frequency in CIN lesions has the potential to prove useful in determining individualized screening and treatment paradigms.

Whether sex hormones modulate the prevalence and function of Tregs remains controversial. Arruvito et al. reported that the proportion of Foxp3+ cells within the peripheral blood CD4+ T-cell population increases during the late follicular phase when compared with the luteal phase.[29] The expansion of Tregs during the follicular phase was highly correlated with serum estradiol (E2) levels.[30] In contrast, Weinberg et al. reported recently that there are no significant correlations between changes in serum E2 levels and the prevalence of any circulating Treg subtypes or between changes in serum progesterone levels and the proportion of CD8+ Foxp3+ Tregs in peripheral blood samples.[31] The effect of smoking on the generation of tolerogenic T cells is also controversial.[32–34] Note that all of the above studies assess peripheral circulating rather than local cervical Tregs. Our data on the latter cells revealed no correlations between cervical Treg prevalence and either menstrual phase or smoking.

In this study, we focused on PD-1+ CD4+ T cells as well as Foxp3+ Tregs as engagement of PD-1 by its ligands on T cells is critical to the differentiation of naïve T cell into Foxp3+ iTregs. Furthermore, Tregs and the PD-1/PD-L pathway are integral in terminating immune responses and augmenting the suppression of anti-tumor T-cell responses. In short, the PD-1 pathway controls the development, maintenance, and function of iTregs at mucosal sites. Here, we show that PD-1+ T cells are more frequently found among cervical T cells than among PBMCs and that the prevalence of PD1+ T cells in CIN lesions (likely reflecting cervical iTregs) correlates inversely with spontaneous regression of CIN. Assessment for other tolerogenic T-cell subsets (e.g., Foxp3-IL10+ Tr1, Foxp3-TGF-β+ Th3) in this study, while potentially informative, was limited by the number of cervical lymphocytes that could be isolated from a single cytobrush sample.

In summary, even the study population is small and the results are limited, our flow cytometric analyses demonstrate for the first time that a prevalence of CD4+ CD25+ Foxp3+ Tregs infiltrating into CIN lesions significantly correlates with regression of CIN regardless of HPV subtype. Conversely, a high prevalence of lesional cervical Tregs may be responsible for CIN persistence as well as HPV infections and might function as a useful predictive biomarker for progression of CIN.

Acknowledgements

We thank Dr. Ai Tachikawa-Kawana for expert advice about flow cytometry. This work was supported by a grant from the Ministry of Health, Labour and Welfare of Japan for the Third-Term Comprehensive Strategy for Cancer Control and for Comprehensive Strategy for Practical Medical Technology and by a grant from the Ministry of Education, Culture, Sports, Science and Technology of Japan and by a grant from Tokyo IGAKUKAI.

References

1 Holowaty P, Miller AB, Rohan T, To T: Natural history of dysplasia of the uterine cervix. *J Natl Cancer Inst* 1999; 91:252–258.
2 Moscicki AB, Schiffman M, Kjaer S, Villa LL: Chapter 5: updating the natural history of HPV and anogenital cancer. *Vaccine* 2006; 24:42–51.
3 Ellerbrock TV, Chiasson MA, Bush TJ, Sun XW, Sawo D, Brudney K, Wright TC Jr: Incidence of cervical squamous intraepithelial lesions in HIV-infected women. *JAMA* 2000; 283:1031–1037.
4 Ognenovski VM, Marder W, Somers EC, Johnston CM, Farrehi JG, Selvaggi SM, McCune WJ: Increased incidence of cervical intraepithelial neoplasia in women with systemic lupus erythematosus treated with intravenous cyclophosphamide. *J Rheumatol* 2004; 31:1763–1767.
5 Kojima S, Kawanna K, Fujii T, Yokoyama T, Miura S, Tomio K, Tomio A, Yamashita A, Adachi K, Sato H, Nagamatsu T, Schust DJ, Kozuma S, Taketani Y: Characterization of Gut-Derived Intraepithelial Lymphocyte (IEL) Residing in Human Papillomavirus (HPV)-Infected Intraepithelial Neoplastic Lesions. *Am J Reprod Immunol* 2011; 66:435–443.
6 Wolf D, Wolf AM, Rumpold H, Fiegl H, Zeimet AG, Muller-Holzner E, Deibl M, Gastl G, Gunsilius E, Marth C: The expression of the regulatory T cell-specific forkhead box transcription factor FoxP3 is associated with poor prognosis in ovarian cancer. *Clin Cancer Res* 2005; 11:8326–8331.
7 Jordanova ES, Gorter A, Ayachi O, Prins F, Durrant LG, Kenter GG, van der Burg SH, Fleuren GJ: Human leukocyte antigen class I, MHC class I chain-related molecule A, and CD8+/regulatory T-cell ratio: which variable determines survival of cervical cancer patients? *Clin Cancer Res* 2008; 14:2028–2035.
8 Yamagami W, Susumu N, Tanaka H, Hirasawa A, Banno K, Suzuki N, Tsuda H, Tsukazaki K, Aoki D: Immunofluorescence-detected infiltration of CD4+FOXP3+ regulatory T cells is relevant to the prognosis of patients with endometrial cancer. *Int J Gynecol Cancer* 2011; 21:1628–1634.

9 Koyama K, Kagamu H, Miura S, Hiura T, Miyabayashi T, Itoh R, Kuriyama H, Tanaka H, Tanaka J, Yoshizawa H, Nakata K, Gejyo F: Reciprocal CD4+ T-cell balance of effector CD62Llow CD4+ and CD62LhighCD25+ CD4+ regulatory T cells in small cell lung cancer reflects disease stage. *Clin Cancer Res* 2008; 14:6770–6779.

10 Liu F, Lang R, Zhao J, Zhang X, Pringle GA, Fan Y, Yin D, Gu F, Yao Z, Fu L: CD8 cytotoxic T cell and FOXP3 regulatory T cell infiltration in relation to breast cancer survival and molecular subtypes. *Breast Cancer Res Treat* 2011; 130:645–655.

11 Yamamoto T, Yanagimoto H, Satoi S, Toyokawa H, Hirooka S, Yamaki S, Yui R, Yamao J, Kim S, Kwon AH: Circulating CD4 +CD25+ regulatory T cells in patients with pancreatic cancer. *Pancreas* 2012; 41:409–415.

12 Jacobs JF, Nierkens S, Figdor CG, de Vries IJ, Adema GJ: Regulatory T cells in melanoma: the final hurdle towards effective immunotherapy? *Lancet Oncol* 2012; 13:32–42.

13 Liotta F, Gacci M, Frosali F, Querci V, Vittori G, Lapini A, Santarlasci V, Serni S, Cosmi L, Maggi L, Angeli R, Mazzinghi B, Romagnani P, Maggi E, Carini M, Romagnani S, Annunziato F: Frequency of regulatory T cells in peripheral blood and in tumour-infiltrating lymphocytes correlates with poor prognosis in renal cell carcinoma. *BJU Int*, 2011; 107:1500–1506.

14 Fu J, Xu D, Liu Z, Shi M, Zhao P, Fu B, Zhang Z, Yang H, Zhang H, Zhou C, Yao J, Jin L, Wang H, Yang Y, Fu YX, Wang FS: Increased regulatory T cells correlate with CD8 T-cell impairment and poor survival in hepatocellular carcinoma patients. *Gastroenterology* 2007; 132:2328–2339.

15 French JD, Weber ZJ, Fretwell DL, Said S, Klopper JP, Haugen BR: Tumor-associated lymphocytes and increased FoxP3+ regulatory T cell frequency correlate with more aggressive papillary thyroid cancer. *J Clin Endocrinol Metab* 2010; 95:2325–2333.

16 Francisco LM, Sage PT, Sharpe AH: The PD-1 pathway in tolerance and autoimmunity. *Immunol Rev* 2010; 236:219–242.

17 Maria A, Lafaille C, Lafaille JJ: Natural and adaptive Foxp3+ regulatory T cells: more of the same or a division of labor? *Immunity* 2009; 30:626–635.

18 Driessens G, Kline J, Gajewski TF: Costimulatory and coinhibitory receptors in anti-tumor immunity. *Immunol Rev* 2009; 229:126–144.

19 Visser J, Nijman HW, Hoogenboom BN, Jager P, van Baarle D, Schuuring E, Abdulahad W, Miedema F, van der Zee AG, Daemen T: Frequencies and role of regulatory T cells in patients with (pre) malignant cervical neoplasia. *Clin Exp Immunol* 2007; 150:199–209.

20 Molling JW, de Gruijl TD, Glim J, Moreno M, Rozendaal L, Meijer CJ, van den Eertwegh AJ, Scheper RJ, von Blomberg ME, Bontkes HJ: CD4(+)CD25hi regulatory T-cell frequency correlates with persistence of human papillomavirus type 16 and T helper cell responses in patients with cervical intraepithelial neoplasia. *Int J Cancer* 2007; 121:1749–1755.

21 Nakamura T, Shima T, Saeki A, Hidaka T, Nakashima A, Takikawa O, Saito S: Expression of indoleamine 2, 3-dioxygenase and the recruitment of Foxp3-expressing regulatory T cells in the development and progression of uterine cervical cancer. *Cancer Sci* 2007; 98:874–881.

22 Gravitt PE, Peyton CL, Alessi TQ, Wheeler CM, Coutlee F, Hildesheim A, Schiffman MH, Scott DR, Apple RJ: Improved amplification of genital human papillomaviruses. *J Clin Microbiol* 2000; 38:357–361.

23 Bosch FX, Sanjose S: Human papillomavirus and cervical cancer – burden and assessment of causality. *J Natl Cancer Inst Monogr* 2003; 31:3–13.

24 Baecher-Allan C, Brown JA, Freeman GJ, Hafler DA: CD4 +CD25high regulatory cells in human peripheral blood. *J Immunol* 2001; 167:1245–1253.

25 Shen T, Zheng J, Liang H, Xu C, Chen X, Zhang T, Xu Q, Lu F: Characteristics and PD-1 expression of peripheral CD4 +CD127loCD25hiFoxP3+ Treg cells in chronic HCV infected-patients. *Virol J* 2011; 8:279–287.

26 zur Hausen H: Papillomavirus and cancer: from basic studies to clinical application. *Nat Rev Cancer* 2002; 2:342–350.

27 Scott ME, Ma Y, Kuzmich L, Moscicki AB: Diminished IFN-gamma and IL-10 and elevated Foxp3 mRNA expression in the cervix are associated with CIN 2 or 3. *Int J Cancer* 2009; 124:1379–1383.

28 El-Sherif AM, Seth R, Tighe PJ, Jenkins D: Decreased synthesis and expression of TGF-beta1, beta2, and beta3 in epithelium of HPV 16-positive cervical precancer: a study by microdissection, quantitative RT-PCR, and immunocytochemistry. *J Pathol* 2000; 192:494–501.

29 Xu XC, Mitchell MF, Silva E, Jetten A, Lotan R: Decreased expression of retinoic acid receptors, transforming growth factor beta, involucrin, and cornifin in cervical intraepithelial neoplasia. *Clin Cancer Res* 1999; 5:1503–1508.

30 Arruvito L, Sanz M, Banham AH, Fainboim L: Expansion of CD4 +CD25+ and FOXP3+ regulatory T cells during the follicular phase of the menstrual cycle: implications for human reproduction. *J Immunol* 2007; 178:2572–2578.

31 Weinberg A, Enomoto L, Marcus R, Canniff J: Effect of menstrual cycle variation in female sex hormones on cellular immunity and regulation. *J Reprod Immunol* 2011; 89:70–77.

32 Brandsma CA, Hylkema MN, Geerlings M, van Geffen WH, Postma DS, Timens W, Kerstjens HA: Increased levels of (class switched) memory B cells in peripheral blood of current smokers. *Respir Res* 2009; 10:108.

33 Barceló B, Pons J, Ferrer JM, Sauleda J, Fuster A, Agustí AG: Phenotypic characterisation of T-lymphocytes in COPD: abnormal CD4+CD25+ regulatory T-lymphocyte response to tobacco smoking. *Eur Respir J* 2008; 31:555–562.

34 Vargas-Rojas MI, Ramírez-Venegas A, Limón-Camacho L, Ochoa L, Hernández-Zenteno R, Sansores RH: Increase of Th17 cells in peripheral blood of patients with chronic obstructive pulmonary disease. *Respir Med* 2011; 105:1648–1654.

Int J Clin Oncol
DOI 10.1007/s10147-012-0486-5

ORIGINAL ARTICLE

Association between carotenoids and outcome of cervical intraepithelial neoplasia: a prospective cohort study

Takuma Fujii · Naoyoshi Takatsuka · Chisato Nagata · Koji Matsumoto · Akinori Oki · Reiko Furuta · Hiroo Maeda · Toshiharu Yasugi · Kei Kawana · Akira Mitsuhashi · Yasuo Hirai · Tsuyoshi Iwasaka · Nobuo Yaegashi · Yoh Watanabe · Yutaka Nagai · Tomoyuki Kitagawa · Hiroyuki Yoshikawa

Received: 14 May 2012 / Accepted: 1 October 2012

Abstract
Background It has been suggested that micronutrients such as alpha-tocopherol, retinol, lutein, cryptoxanthin, lycopene, and alpha- and beta-carotene may help in the prevention of cervical cancer. Our aim was to investigate whether serum concentrations and/or dietary intake of micronutrients influence the regression or progression of low-grade cervical abnormalities.
Methods In a prospective cohort study of 391 patients with cervical intraepithelial neoplasia (CIN) grade 1–2 lesions, we measured serum micronutrient concentrations in addition to a self-administered questionnaire about dietary intake. We evaluated the hazard ratio (HR) adjusted for CIN grade, human papillomavirus genotype, total energy intake and smoking status.

The Japan HPV and Cervical Cancer (JHACC) Study Group.

T. Fujii (✉)
Department of Obstetrics and Gynecology, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan
e-mail: fujiit@a5.keio.jp

N. Takatsuka · C. Nagata
Department of Epidemiology and Preventive Medicine, Gifu University, Graduate School of Medicine, Yanagito 1-1, Gifu, Gifu 501-1194, Japan

K. Matsumoto · A. Oki · H. Yoshikawa
Department of Obstetrics and Gynecology, Graduate School of Comprehensive Human Science, University of Tsukuba, 1-1, 1-chome, Tennoudai, Tsukuba, Ibaraki 305-8575, Japan

R. Furuta · T. Kitagawa
Department of Pathology, The Cancer Institute, Japanese Foundation for Cancer Research, 8-31, 3-chome, Ariake, Kouto-ku, Tokyo 135-8550, Japan

H. Maeda
Department of Transfusion Medicine and Cell Therapy, Saitama Medical Center, Saitama Medical University, 1981 Kamoda, Kawagoe, Saitama 350-8550, Japan

T. Yasugi · K. Kawana
Department of Obstetrics and Gynecology, The University of Tokyo, 3-1, 7-chome, Hongo, Bunkyo-ku, Tokyo 113-8655, Japan

A. Mitsuhashi
Department of Reproductive Medicine, Graduate School of Medicine, Chiba University, 8-1, 1-chome, Inohana, Chuo-ku, Chiba 260-8670, Japan

Y. Hirai
Department of Gynecology and Cytopathology, The Cancer Institute Hospital, Japanese Foundation of Cancer Research, 8-31, 3-chome, Ariake, Kouto-ku, Tokyo 135-8550, Japan

T. Iwasaka
Department of Obstetrics and Gynecology, Faculty of Medicine, Saga University, 1-1, 5-chome, Nabeshima, Saga, Saga 849-8501, Japan

N. Yaegashi
Department of Obstetrics and Gynecology, Tohoku University School of Medicine, 1-1 Seiryo-cho, Aoba-ku, Sendai, Miyagi 980-8574, Japan

Y. Watanabe
Department of Obstetrics and Gynecology, Kinki University, School of Medicine, 377-2 Ohnohigashi, Osakasayama, Osaka 589-8511, Japan

Y. Nagai
Department of Obstetrics and Gynecology, Faculty of Medicine, University of the Ryukyus, 207 Uehara, Nishihara-cho, Nakagamigun, Okinawa 903-0215, Japan

Published online: 25 October 2012

Results In non-smoking regression subjects, regression was significantly associated with serum levels of zeaxanthin/lutein (HR 1.25, 0.78–2.01, $p = 0.024$). This benefit was abolished in current smokers. Regression was inhibited by high serum levels of alpha-tocopherol in smokers ($p = 0.042$). In progression subjects, a significant protective effect against progression to CIN3 was observed in individuals with a medium level of serum beta-carotene [HR 0.28, 95 % confidence interval (CI) 0.11–0.71, $p = 0.007$), although any protective effect from a higher level of serum beta-carotene was weaker or abolished (HR 0.52, 95 % CI 0.24–1.13, $p = 0.098$). Increasing beta-carotene intake did not show a protective effect (HR 2.30, 95 % CI 0.97–5.42, $p = 0.058$).

Conclusions Measurements of serum levels of carotenoids suggest that regression is modulated by smoking status. Maintaining a medium serum level of beta-carotene has a protective effect for progression; however, carotene intake is not correlated with serum levels of carotenoids.

Keywords Human papillomavirus · Cervical intraepithelial neoplasia · Low-grade squamous intraepithelial lesion · Micronutrients · Carotenoids

Introduction

Persistent infection with human papillomavirus (HPV) may potentially lead to the development of cervical cancer. Most women are exposed to at least one type of genital HPV in their lifetime [1]. HPV infections often cause cervical intraepithelial neoplasia 1 (CIN1) [2]. Only a subset of individuals with CIN1 progress to CIN3 or invasive cervical cancer, suggesting that environmental cofactors are related to cervical carcinogenesis [3–5]. Numerous environmental candidates such as oral contraceptives, parity, smoking status, micronutrient status, nutrient intake, *Chlamydia trachomatis* infection and herpes simplex virus type 2 infection have been investigated as potential cofactors related to progression of CIN.

Much attention has been given to the role of dietary factors and serum micronutrients in the etiology of cervical cancer and CIN. Carotenoids and tocopherols are lipid-soluble micronutrients with potent antioxidant activities and modulatory effects on immunity. Recent publications have reported that the association of carotenoids and tocopherols with reduced risk has not been observed consistently [6–10]; however, these inconsistent results may be due to the study designs. Furthermore, the majority of case–control studies of the associations between micronutrients and outcome of CIN were conducted to assess either dietary intake or circulating micronutrients only [7–9, 11].

Foods are composites of several biologically active dietary components. Micronutrients in foods, as well as other possible anti-carcinogenic compounds such as detoxification enzymes, may have synergistic effects and interact with one another [11–13]. A recent multi-center cohort study reported an association between dietary intake of micronutrients and outcome of CIN. However, this study reported no information about circulating micronutrients [6]. Conversely, some prospective cohort studies reported an association between circulating micronutrient levels and outcome of CIN but no information about dietary intake [14, 15]. Both dietary intake and circulating serum concentrations of micronutrients are important in assessing the role of micronutrients in cervical carcinogenesis. We previously conducted a case–control study including 156 pairs of women with CIN1–3 and matched controls with normal cytology and found an inverse relationship between serum levels of alpha-carotene, lycopene and zeaxanthin/lutein and the risk of CIN development [16]. Because retrospective analysis of previous study findings provides only limited information, we report here the results of a prospective study that was conducted in an attempt to confirm these findings.

Materials and methods

Study design

We used follow-up data from the Japan HPV and Cervical Cancer Study, a prospective non-intervention cohort study conducted to identify determinants of low-grade squamous intraepithelial lesion (LSIL)/CIN regression and progression. Among a total of 570 study subjects with low-grade cervical abnormalities (cytological LSIL and histological CIN1/2) recruited from nine hospitals between 1998 and 2004, 391 women with data concerning serum micronutrients and complete entry questionnaires were enrolled in the present study. Details of the design, methods and primary results have been provided elsewhere [17, 18]. Participants entered the study only after voluntarily giving signed, informed consent. The subjects were routinely followed at 3- to 4-month intervals and received cytology and colposcopy examinations at each visit. To avoid interference of the biopsy procedure on the natural course of the disease, cervical biopsy was performed only when women had HSIL smears and major colposcopic changes that were suggestive of progression to CIN3 or worse. Progression was defined as histological CIN3 lesions or worse, diagnosed on central pathology review. We defined regression as at least two consecutive negative smears and normal colposcopy. Women were regarded as having persistent lesions when they did not have either regression or

progression over the period of follow-up. At enrollment, study subjects were tested for cervical HPV-DNA and circulating serum micronutrients. Information about smoking and dietary intake was obtained from a self-administered questionnaire. Participants were not obliged to answer the questionnaire and their participation was unrelated to their clinical evaluation, treatment or follow-up evaluation. The simplified diet history questionnaire used in the current study had been developed and validated previously [19]. Originally, a prototype diet history questionnaire including 169 traditional Japanese foods and dishes was developed. To alleviate the participants' burden, our simplified diet history questionnaire was developed to employ a stepwise regression method to select from the 169 diet history questionnaire items. This simplified questionnaire was composed of 14 categories: (1) dishes of meat and vegetables; (2) meat (without dishes including vegetables); (3) fish; (4) cereals; (5) eggs and soybean products; (6) vegetables; (7) seaweed; (8) juice; (9) fruits; (10) milk and dairy products; (11) desserts and snacks; (12) pickles; (13) seasoning; and (14) alcoholic beverages. Supplement use was not assessed in this study because of a lack of complete information regarding availability. Because it was impossible to distinguish between intake of alpha- and beta-carotene from the questionnaire, total carotene intake was described. Questions on smoking habits included status (never, former or current smoker) and intensity (number of cigarettes smoked per day).

Circulating micronutrients

Blood was collected in foil-wrapped glass tubes without heparin. Serum was separated by centrifugation at $1{,}000 \times g$ for 10 min and stored in the dark at −70 °C prior to sample preparation. Serum levels of retinol, alpha-tocopherol and various carotenoids were determined by a high-pressure liquid chromatography method described previously [21].

Statistical analysis

The association between smoking status and nutrient intake was analyzed by one-way analysis of variance. The association between smoking status and serum micronutrients was analyzed by analysis of covariance. The data were adjusted for age, body mass index (BMI) and alcohol intake frequency. For regression or progression, time to event was measured from the date of the index visit to the date of the visit at which cytological transition to normal or CIN3 was first detected. To estimate the association between the CIN outcomes and circulating serum micronutrients, serum micronutrient tertiles were examined. Hazard ratios (HRs) and 95 % confidence intervals (CIs) for each tertile with reference to the lowest tertile were calculated using a proportional hazard model. For nutrient intake, identical estimation was conducted. The Brinkman Index (BI) was calculated by multiplying the average number of cigarettes smoked per day by the smoking years. We detected HPV-DNA in exfoliated cervical cells by a PCR-based methodology described previously [20]. HPV DNA was amplified by PCR using consensus-primers (L1C1/L1C2 + L1C2M) for the HPV L1 region. HPV genotypes were identified by a restriction fragment-length polymorphism (RFLP) PCR method that has been shown to identify at least 26 genotypes of genital HPV [18]. HRs were adjusted for potential confounders, including CIN grade, HPV genotype, age, total energy intake and smoking status. Statistical analyses were performed using Stata statistical software, release 11.1 (Stata Corporation; College Station, TX, USA).

Results

Of the 570 women enrolled in the parent study, 391 met the eligibility requirements of the current study for tests of serum micronutrients and completion of entry questionnaires. Of these, 329 and 62 women were diagnosed as CIN1 and CIN2, respectively. The mean age of the women was 36.3 years (median 36.0, range 19–54). Of the 391 women, regression, persistence and progression occurred in 218, 135 and 38, respectively.

Influence of smoking status on circulating levels and intake of micronutrients

At enrollment, 190 women had never smoked, while 142 women were current smokers (BI >100). Data from three women were lost and the remaining 56 women were past smokers. We found a 22 and 10 % decrease in carotene and vitamin E intake in current smokers compared with non-smokers, respectively (Table 1). Among the three groups, there was a significant difference in the intake of fiber, calcium, carotenes, vitamin A, vitamin C and vitamin E. As shown in Table 2, current smokers had significantly lower serum levels of alpha-carotene, beta-carotene and cryptoxanthin compared with non-smokers. Smokers had marginally lower levels of lycopene. Retinol, zeaxanthin/lutein and alpha-tocopherol were not related to smoking status.

The effects of serum micronutrients and nutrient intake in regression subjects

Significantly more inhibition of regression was observed in women in the middle tertiles of serum alpha-tocopherol

Table 1 Relationship between estimated daily nutrient intake and tobacco smoking status

Nutrient intake per day	Non smokers ($N = 190$)		Past smokers ($N = 56$)		Current smokers ($N = 142$)		p value
	Mean	SD	Mean	SD	Mean	SD	
Total energy intake (kcal)	2,220.1	576.1	2,221.6	679.7	2,149.1	574.9	0.520
Protein intake (g)	85.2	26.2	85.2	31.0	79.4	27.3	0.127
Fat intake (g)	60.2	21.9	62.9	27.2	59.0	22.6	0.566
Carbohydrate intake (g)	329.5	78.3	325.2	85.6	315.2	74.6	0.255
Fiber intake (g)	5.3	1.9	5.2	2.0	4.6	1.8	0.004
Calcium intake (mg)	740.8	292.2	738.3	337.6	620.9	274.2	0.001
Retinol intake (μg)	284.6	219.1	302.4	176.9	331.2	624.7	0.597
Carotene intake (μg)	4,943.5	2,439.7	4,856.3	2,532.1	3,866.8	2,083.5	0.000
Vitamin A intake (IU)	3,430.6	1,587.5	3,424.3	1,546.9	2,954.2	2,197.4	0.049
Vitamin C intake (mg)	134.0	65.6	133.3	65.9	113.4	56.4	0.008
Vitamin D intake (IU)	76.4	48.8	69.3	40.6	66.9	53.7	0.213
Vitamin E intake (mg)	8.4	2.8	8.3	3.2	7.5	2.7	0.021
Salt intake (g)	13.5	4.1	13.7	4.8	12.8	4.5	0.291
Cholesterol intake (mg)	323.7	122.6	322.9	160.2	304.7	137.5	0.412

Analysis of variance was used to examine the differences in the mean values of factors among groups

SD standard deviation

Table 2 Relationship between serum micronutrients and tobacco smoking status

	Non-smoker ($N = 190$)		Past smoker ($N = 56$)		Current smoker ($N = 142$)		P value
	Adjusted mean	95 % CI	Adjusted mean	95 % CI	Adjusted mean	95 % CI	
Serum retinol (μg/dL)	59.23	56.42–62.04	59.70	54.59–64.81	60.88	57.24–64.51	0.695
Serum α-carotene (μg/dL)	9.70	8.58–10.82	7.47	5.43–9.51	7.23	5.78–8.68	0.003
Serum β-carotene (μg/dL)	58.05	50.77–65.33	46.61	33.36–59.85	41.02	31.60–50.44	0.003
Serum zeaxanthin/lutein (μg/dL)	54.93	50.77–59.09	54.06	46.50–61.62	49.88	44.50–55.26	0.205
Serum cryptoxanthin (μg/dL)	31.19	25.61–36.76	23.61	13.46–33.76	21.27	14.05–28.49	0.03
Serum lycopene (μg/dL)	30.00	26.76–33.22	34.68	28.80–40.55	27.23	23.04–31.41	0.06
Serum α-tocopherol (μg/dL)	881.68	817.51–945.84	953.15	836.40–1,069.91	873.56	790.50–956.63	0.414

Analysis of covariance was used to examine the differences in the mean concentrations of the serum levels of micronutrients that are related to the effect of the smoking status. The data were adjusted for age (20–29, 30–39, or 40–54 years), BMI and alcohol intake frequency (0, 1–6, 7/week)

(HR 0.68, 95 % CI 0.49–0.95) as compared with women in the lower tertiles, but the linear trend was not statistically significant ($p = 0.882$). From the questionnaire, high-load intake of retinol significantly inhibited the regression (adjusted model: HR 0.59, 95 % CI 0.40–0.89) but the linear trend was not significant (Table 3).

Because serum levels of most carotenoids were low and carotene intake was small in smokers, the regression group was sub-analyzed stratifying by smoking status (never or current smokers) as shown in Tables 4 and 5. In non-smokers (Table 4), regression was observed in women in the upper tertiles of serum zeaxanthin/lutein (HR 1.25, 95 % CI 0.78–2.01) as compared with women in the lower and middle tertiles, and the linear trend was statistically significant ($p = 0.024$). In current smokers, this was statistically abolished as shown in Table 5. In current smokers, a significant inhibition of regression was observed in women in the middle tertiles for serum alpha-tocopherol (HR 0.53, 95 % CI 0.27–0.94) as compared with women in the lower tertiles, and the linear trend was significant ($p = 0.042$) in the adjusted model (Table 5).

Effect of serum micronutrients and nutrient intake in progression subjects

In Table 6, a significant inverse relationship was observed in subjects with a medium level of serum beta-carotene (HR 0.28, 95 % CI 0.11–0.71, $p = 0.007$), although these

Table 3 HR of regression from entire CIN1/2 according to the serum micronutrients and nutrient intake questionnaire

	n	Person-months	Events	Cumulative 2-year rate (95 % CI)	Hazard ratio for regression (95 % CI)			
					Unadjusted	*p* value	Adjusted model	*p* value
Serum retinol							*p* for trend	0.812
Low (<55.2)	128	1,715.6	74	62.5 (53.6–71.4)	1		1	
Medium (55.2–67.9)	132	1,689.8	77	63.2 (54.4–72.0)	1.06 (0.77–1.46)	0.709	1.19 (0.86–1.65)	0.301
High (>67.9)	131	1,763.5	67	57.8 (48.6–67.4)	0.87 (0.62–1.21)	0.399	0.87 (0.62–1.22)	0.423
Serum α-carotene							*p* for trend	0.472
Low (<5.1)	127	1,654.9	71	60.9 (51.9–70.0)	1.00		1.00	
Medium (5.1–9.7)	133	1,750.0	68	57.3 (48.2–66.8)	0.91 (0.65–1.27)	0.574	1.00 (0.71–1.41)	0.984
High (>9.7)	131	1,764.0	79	65.2 (56.5–73.9)	1.04 (0.75–1.43)	0.828	1.26 (0.89–1.80)	0.19
Serum β-carotene							*p* for trend	0.095
Low (<28.3)	129	1,679.7	66	56.7 (47.7–66.2)	1.00		1.00	
Medium (28.3–57.6)	131	1,755.9	75	62.7 (53.8–71.6)	1.10 (0.79–1.53)	0.581	1.17 (0.83–1.66)	0.364
High (>57.6)	131	1,733.3	77	64.0 (55.2–72.9)	1.12 (0.80–1.56)	0.511	1.34 (0.93–1.93)	0.115
Serum zeaxanthin/lutein							*p* for trend	0.235
Low (<42.9)	130	1,645.9	76	62.7 (53.8–71.6)	1.00		1.00	
Medium (42.9–57.3)	130	1,803.1	70	58.1 (49.2–67.2)	0.85 (0.62–1.18)	0.341	0.97 (0.69–1.36)	0.868
High (>57.3)	131	1,719.9	72	63.5 (54.2–72.7)	0.89 (0.65–1.23)	0.488	1.05 (0.75–1.48)	0.768
Serum cryptoxanthin							*p* for trend	0.215
Low (<11.2)	129	1,659.5	74	63.9 (54.8–73.0)	1.00		1.00	
Medium (11.2–22.1)	130	1,754.7	67	56.8 (47.8–66.2)	0.87 (0.62–1.21)	0.406	0.91 (0.65–1.28)	0.592
High (>22.1)	132	1,754.7	77	63.1 (54.3–71.9)	0.99 (0.72–1.37)	0.974	1.07 (0.76–1.51)	0.694
Serum lycopene							*p* for trend	0.638
Low (<19.8)	129	1,713.7	69	58.6 (49.7–67.9)	1.00		1.00	
Medium (19.8–35.8)	131	1,780.3	79	66.3 (57.4–75.0)	1.07 (0.78–1.48)	0.67	1.07 (0.76–1.49)	0.705
High (>35.8)	131	1,674.9	70	58.5 (49.4–67.8)	1.02 (0.73–1.42)	0.914	1.08 (0.77–1.52)	0.662
Serum α-tocopherol							*p* for trend	0.882
Low (<753.0)	128	1,535.8	82	67.3 (58.7–75.6)	1.00		1.00	
Medium (753.0–983.9)	132	1,896.8	66	54.7 (45.9–64.0)	0.66 (0.48–0.91)	0.011	0.68 (0.49–0.95)	0.025
High (>983.9)	131	1,736.3	70	62.8 (53.2–72.3)	0.74 (0.54–1.01)	0.062	0.78 (0.56–1.09)	0.142
Retinol intake							*p* for trend	0.322
Low (<190.2)	130	1,555.8	74	62.8 (53.6–72.0)	1.00		1.00	
Medium (190.2–313.1)	130	1,755.6	74	63.3 (54.0–72.0)	0.89 (0.65–1.23)	0.484	0.76 (0.54–1.07)	0.12
High (>313.1)	131	1,857.5	70	57.8 (49.0–66.9)	0.80 (0.57–1.10)	0.172	0.59 (0.40–0.89)	0.011
Carotene intake							*p* for trend	0.325
Low (<3,281.4)	130	1,639.3	70	59.8 (50.6–69.1)	1.00		1.00	
Medium (3,281.4–5,042.8)	131	1,812.8	72	61.6 (52.5–64.7)	0.92 (0.66–1.28)	0.637	0.90 (0.63–1.28)	0.557
High (>5,042.8)	130	1,716.8	76	62.2 (53.5–71.0)	1.03 (0.74–1.42)	0.869	0.97 (0.65–1.46)	0.89
Vitamin A intake							*p* for trend	0.546
Low (<2,398.8)	130	1,601.8	70	61.5 (62.5–74.6)	1.00		1.00	
Medium (2,398.8–3,466.7)	131	1,834.7	72	59.7 (51.7–64.7)	0.90 (0.65–1.25)	0.541	0.91 (0.64–1.29)	0.599
High (>3,466.7)	130	1,732.4	76	62.6 (53.9–71.4)	1.01 (0.73–1.40)	0.948	0.93 (0.61–1.42)	0.727
Vitamin E intake							*p* for trend	0.147
Low (<6.7)	130	1,610.2	68	57.4 (48.3–66.7)	1.00		1.00	
Medium (6.7–8.7)	130	1,897.1	71	59.4 (50.5–68.5)	0.90 (0.64–1.25)	0.521	0.95 (0.66–1.39)	0.807
High (>8.7)	131	1,661.6	79	65.9 (57.1–74.6)	1.11 (0.80–1.54)	0.519	0.88 (0.54–1.43)	0.601

Cox's proportional hazard model showing the hazard ratio for regression in a cumulative 24-month period. The adjusted model was calculated by CIN grade (initial biopsy results; CIN1 or CIN2), HPV genotypes (HPV16/18/31/33/35/42/52/59, other high-risk types, low-risk types, or HPV negative) [17, 18], age, total calorie intake and smoking status (Brinkman index >100). The units of micronutrients are expressed as μg/dL