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Vaccination with ALVAC and AIDSVAX to Prevent HIV-1 Infection in Thailand

Supachai Rerks-Ngarm, M.D., Punnee Pitisuttithum, M.D., D.T.M.H., Sorachai Nitayaphan, M.D., Ph.D., Jaranit Kaewkungwal, Ph.D., Joseph Chiu, M.D., Robert Paris, M.D., Nakorn Premisri, M.D., Chawetsan Namwat, M.D., Mark de Souza, Ph.D., Elizabeth Adams, M.D., Michael Benenson, M.D., Sanjay Gurunathan, M.D., Jim Tartaglia, Ph.D., John G. McNeil, M.D., Donald P. Francis, M.D., D.Sc., Donald Stablein, Ph.D., Deborah L. Birx, M.D., Supamit Chunsuttiwat, M.D., Chirasak Khamboonruang, M.D., Prasert Thongcharoen, M.D., Ph.D., Merlin L. Robb, M.D., Nelson L. Michael, M.D., Ph.D., Prayura Kunasol, M.D., and Jerome H. Kim, M.D.,
for the MOPH-TAVEG Investigators*

ABSTRACT

BACKGROUND

The development of a safe and effective vaccine against the human immunodeficiency virus type 1 (HIV-1) is critical to pandemic control.

METHODS

In a community-based, randomized, multicenter, double-blind, placebo-controlled efficacy trial, we evaluated four priming injections of a recombinant canarypox vector vaccine (ALVAC-HIV [vCP1521]) plus two booster injections of a recombinant glycoprotein 120 subunit vaccine (AIDSVAX B/E). The vaccine and placebo injections were administered to 16,402 healthy men and women between the ages of 18 and 30 years in Rayong and Chon Buri provinces in Thailand. The volunteers, primarily at heterosexual risk for HIV infection, were monitored for the coprimary end points: HIV-1 infection and early HIV-1 viremia, at the end of the 6-month vaccination series and every 6 months thereafter for 3 years.

RESULTS

In the intention-to-treat analysis involving 16,402 subjects, there was a trend toward the prevention of HIV-1 infection among the vaccine recipients, with a vaccine efficacy of 26.4% (95% confidence interval [CI], -4.0 to 47.9; $P=0.08$). In the per-protocol analysis involving 12,542 subjects, the vaccine efficacy was 26.2% (95% CI, -13.3 to 51.9; $P=0.16$). In the modified intention-to-treat analysis involving 16,395 subjects (with the exclusion of 7 subjects who were found to have had HIV-1 infection at baseline), the vaccine efficacy was 31.2% (95% CI, 1.1 to 52.1; $P=0.04$). Vaccination did not affect the degree of viremia or the CD4+ T-cell count in subjects in whom HIV-1 infection was subsequently diagnosed.

CONCLUSIONS

This ALVAC-HIV and AIDSVAX B/E vaccine regimen may reduce the risk of HIV infection in a community-based population with largely heterosexual risk. Vaccination did not affect the viral load or CD4+ count in subjects with HIV infection. Although the results show only a modest benefit, they offer insight for future research. (ClinicalTrials.gov number, NCT00223080.)

From the Department of Disease Control, Ministry of Public Health, Nonthaburi (S.R.-N., R.P., C.N., S.C., C.K., P.T., P.K.); Vaccine Trials Center (P.P.) and Data Management Unit (J.K.), Faculty of Tropical Medicine, Mahidol University, Bangkok; Thai Component (S.N.) and U.S. Army Medical Component (J.C., R.P., M.S., M.B.), Armed Forces Research Institute of Medical Sciences, Bangkok — all in Thailand; the Division of AIDS, National Institutes of Allergy and Infectious Diseases, National Institutes of Health, Bethesda, MD (E.A.); Sanofi Pasteur, Swiftwater, PA (S.G., J.T., J.G.M.); Global Solutions for Infectious Diseases, South San Francisco, CA (D.P.F.); the Emmes Corporation, Rockville, MD (D.S.); the Global AIDS Program, Centers for Disease Control and Prevention, Atlanta (D.L.B.); U.S. Military HIV Research Program, Walter Reed Army Institute of Research, Rockville, MD (M.L.R., N.L.M., J.H.K.); and U.S. Army Medical Materiel Development Activity, Ft. Detrick, MD (J.H.K.). Address reprint requests to Dr. Kim at the U.S. Military HIV Research Program, Walter Reed Army Institute of Research, 1600 E. Gude Dr., Rockville, MD 20850, or at jkim@hivresearch.org.

*The names and affiliations of the Ministry of Public Health–Thai AIDS Vaccine Evaluation Group (MOPH-TAVEG) investigators are listed in the Appendix.

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IN THE LATE 1980S IN THAILAND, THERE was a dramatic increase in the prevalence of infection with the human immunodeficiency virus type 1 (HIV-1) in sentinel surveillance cohorts.¹⁻³ Initially, these groups consisted of injection-drug users and commercial sex workers; they were subsequently expanded to include persons in the general population. By 1995, the overall seroprevalence of HIV-1 reached a peak of 3.7% among conscripts in the Royal Thai Army and of 12.5% among conscripts from Northern Thailand.^{2,4,5} The Thai Ministry of Public Health responded with an effective HIV-prevention campaign, and the number of new HIV-1 infections per year decreased from an estimated 143,000 in 1990 to 14,000 in 2007.^{2,4,6-9} The persistence of new infection despite these measures led public health officials to conclude that an HIV vaccine, within the context of a broader HIV-prevention program, was needed for better control of the epidemic.

A number of trials of various subtype B canarypox-HIV vector primes and boosters containing subunit glycoprotein 120 or 160 (gp120 or gp160) established the prime-boost concept as a candidate for advanced testing.¹⁰⁻¹³ Canarypox-based prime-boost regimens induced both cellular and humoral responses, but CD8+ responses on enzyme-linked immunosorbent spot (ELISPOT) assay were low,¹² and the presence of primary isolate neutralizing antibody was not consistently detected.¹⁴⁻¹⁸

A series of phase 1 and 2 trials of HIV vaccines involving more than 1000 Thai volunteers was undertaken, with products matching the circulating HIV-1 subtypes B and CRF01_AE.^{8,17-22} Although a phase 3 trial of VaxGen bivalent gp120 AIDSVAX B/E vaccine alone involving injection-drug users showed no effect on HIV-1 acquisition,²¹ a phase 2 trial of an ALVAC-HIV (vCP1521) prime with an AIDSVAX B/E boost showed induction of prespecified cellular and humoral immune responses and was consistent with criteria for advancement to a large test-of-concept study.¹⁷ In October 2003, our study was initiated in a population at community risk for HIV infection.⁸

METHODS

STUDY DESIGN AND POPULATION

This study was a community-based, randomized, multicenter, double-blind, placebo-controlled efficacy trial of the prime-boost combination of

vaccines containing ALVAC-HIV (vCP1521) (Sanofi Pasteur) and AIDSVAX B/E (Global Solutions for Infectious Diseases). For details regarding the vaccines and placebo, see the Supplementary Appendix, available with the full text of this article at NEJM.org. The study was designed to evaluate two coprimary end points: the prevention of HIV-1 infection and the effect of vaccination on the early viral load after infection. The trial was conducted through facilities of the Thai Ministry of Public Health in Rayong and Chon Buri provinces. From September 2003 through December 2005, a total of 16,402 volunteers were enrolled.

Thai men and women who were between the ages of 18 and 30 years and who were not infected with HIV were recruited from the community without regard to HIV risk (i.e., community risk). Written informed consent was obtained from all volunteers, who were required to pass a written test of understanding. Women were counseled to practice effective contraception until 3 months after the last vaccination; pregnant and breast-feeding women were excluded.

STUDY OVERSIGHT

The protocol was reviewed by the ethics committees of the Ministry of Public Health, the Royal Thai Army, Mahidol University, and the Human Subjects Research Review Board of the U.S. Army Medical Research and Materiel Command. It was also independently reviewed and endorsed by the World Health Organization and the Joint United Nations Program on HIV/AIDS and by the AIDS Vaccine Research Working Group of the National Institute of Allergy and Infectious Diseases at the National Institutes of Health. The manufacturers were full trial collaborators and were a part of the phase 3 trial steering committee.

STUDY PROCEDURES

The study vaccines were administered at baseline (day 0), 4 weeks (prespecified range, 3 to 7), 12 weeks (range, 10 to 15), and 24 weeks (range, 21 to 28). The ALVAC-HIV (vCP1521) vaccine was administered at each of the four visits. Boosting with AIDSVAX B/E occurred at weeks 12 and 24. For 3 days after each dose of vaccine, subjects reported local and systemic vaccine reactions on a diary card. All other adverse and serious adverse events were documented at each visit and were graded on a scale that is used for rating adverse events associated with vaccines, as recommended by the Division of Acquired Immunodeficiency

Syndrome of the National Institute of Allergy and Infectious Diseases (<http://rcc.tech-res.com/safetyandpharmacovigilance>). All subjects who underwent randomization were included in the safety analysis.

Women underwent urine testing for pregnancy throughout the vaccination phase. Pregnant volunteers did not receive further vaccinations. All volunteers were followed with the use of HIV testing at day 0, at 24 and 26 weeks, and every 6 months during the 3-year follow-up phase. Peripheral-blood mononuclear cells were isolated and archived in liquid nitrogen at 0, 6, 12, and 42 months. Assessment of behavior associated with an increased risk of HIV infection occurred at baseline, at week 26, and at each 6-month follow-up visit. HIV-prevention counseling was provided during each vaccination and post-test counseling visit.

PRIMARY END POINTS

We established the presence of HIV infection on the basis of repeated positive results on enzyme immunoassay and Western blotting, with two confirmatory HIV nucleic acid tests: the Amplicor HIV Monitor (version 1.5) assay (Roche) in Thailand and the Procleix HIV discriminatory assay (Novartis) in the United States. We performed three measurements of HIV-1 RNA within 6 weeks after serodiagnosis to determine the mean postinfection viral load. Infection time was defined as the midpoint between the last negative result and the first positive result of testing. An independent endpoints monitoring committee whose members were unaware of study-group assignments verified the accuracy of all diagnoses.

ASSESSMENT OF RISK

We assessed subjects' risk of HIV infection using a self-administered behavioral questionnaire at baseline and every 6 months thereafter. First, volunteers categorized themselves as being at high, moderate, or low risk for HIV infection. A second approach categorized subjects as being at high risk if they reported being at high risk or reported any high-risk behavior (e.g., needle sharing, multiple sex partners, commercial sex work, and symptoms of sexually transmitted disease). Volunteers were considered to be at low risk if they perceived their risk as low; if they reported that in the previous 6 months they had had no more than one sex partner and no sexual contact with a commercial sex worker, a partner of the same

sex, an HIV-infected partner, a partner who used injection drugs, or a partner who had multiple partners; and if they reported having had no symptoms of a sexually transmitted disease or incarceration within 6 months before study entry. Moderate-risk subjects were considered to be at neither low nor high risk.

IMMUNOGENICITY ANALYSES

We analyzed plasma and cells from volunteers who did not have HIV infection at various time points after vaccination to evaluate immunogenicity. After removal of a small subgroup of samples for future matched case-control studies, we identified random samples and provided them in a blinded fashion to the Armed Forces Research Institute of Medical Sciences laboratory at a ratio of samples from the vaccine group to samples from the placebo group of approximately 4:1. The immunogenicity of the vaccine regimen was measured with the use of the following validated assays: interferon- γ ELISPOT and CD4+ and CD8+ intracellular cytokine staining for interferon- γ and interleukin-2 to Gag and Env; binding antibody to gp120 in the MN strain, gp120 in the A244 strain (CM244), and p24 Gag; and lymphoproliferation to gp120 MN, gp120 A244, and p24 (for details, see the Supplementary Appendix).^{17,18,22-25}

STATISTICAL ANALYSIS

According to the study protocol, we conducted both intention-to-treat and per-protocol analyses. The intention-to-treat analysis included all subjects who underwent randomization. Because of the time between screening and vaccination and the possibility of acquiring HIV-1 infection during this interval, the protocol specified look-back testing of baseline plasma for HIV-1 RNA if the sample that was collected on the day of the fourth vaccination was HIV-seropositive. Seven persons who were enrolled and vaccinated were found to be positive for HIV-1 RNA at baseline. The per-protocol analysis included a subgroup of subjects in the intention-to-treat analysis who received the entire series of vaccinations within the defined time period, who remained eligible to participate in the study, and who did not have HIV infection at the time of the fourth vaccination. A separate subgroup analysis, called the modified intention-to-treat analysis, excluded the seven volunteers who were found to have HIV infection at baseline. This was used as the primary analysis

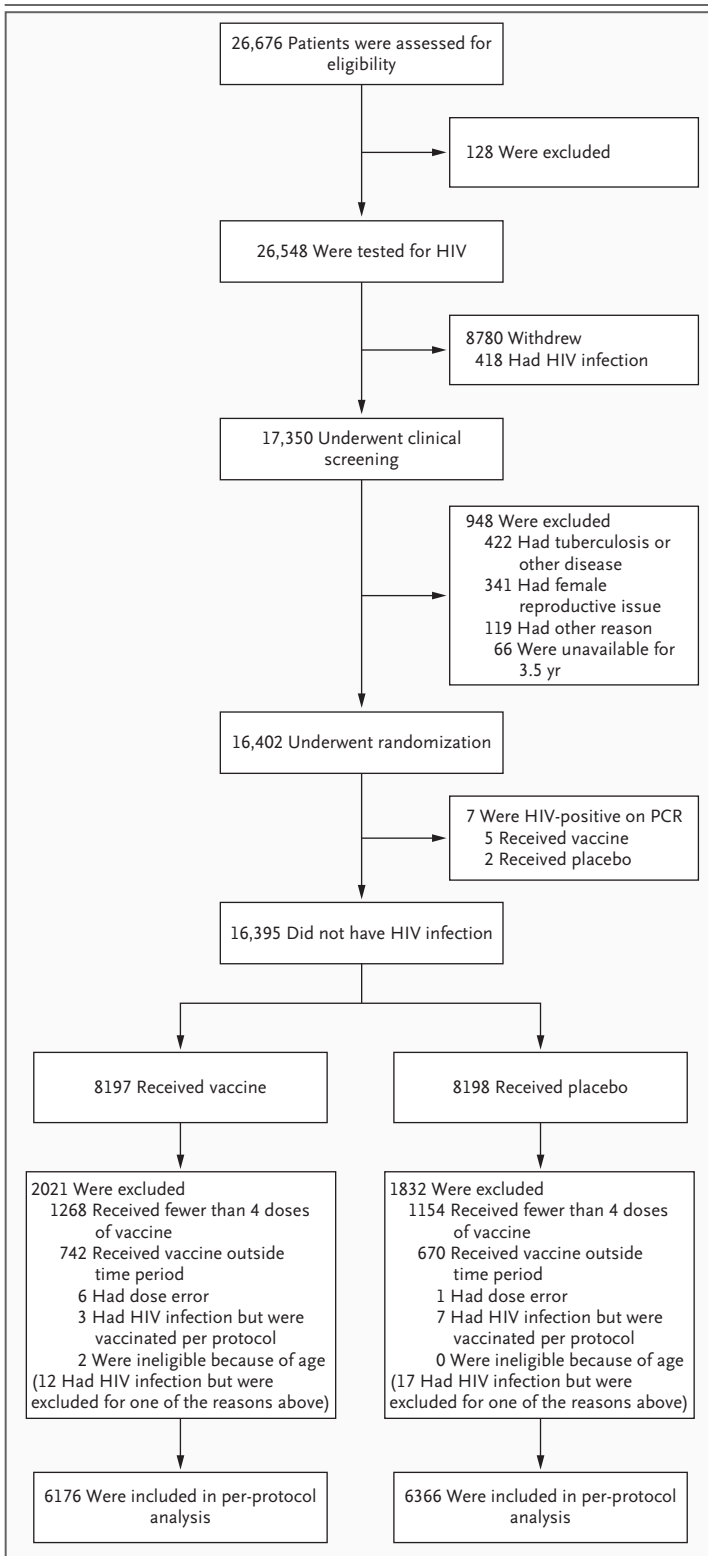


Figure 1. Enrollment and Outcomes.

During the course of the study, there were 15 HIV-1 infections in the vaccine group and 24 in the placebo group that were excluded from the final analysis. This left 12,542 volunteers (6176 in the vaccine group and 6366 in the placebo group) who received all four doses of vaccine within the prespecified time period, who were not excluded for the other reasons, and who did not have HIV-1 infection at visit 7 (per-protocol population).

at the time of the interim and final analyses and was prespecified in the final data-analysis plan that was approved 5 months before the unblinding of the study. (For details regarding the sample size calculation, randomization procedures, and calculation of vaccine efficacy, see the Supplementary Appendix.)

After the initiation of the trial, the effect of vaccination on early viral load was included as a coprimary end point, and the mean postinfection viral load was compared between vaccine and placebo recipients at the 1% level with the Wilcoxon statistic. The effect of selection bias was considered.²⁶

The trial was monitored by an independent, international data and safety monitoring board, which met every 6 to 12 months (eight times during the trial) and reviewed the trial for safety and futility. At the interim analysis, the trial was reviewed for efficacy, safety, and futility. Statistical futility for the acquisition end point was examined with a trigger for early termination if the conditional power was less than 10%. All reported P values are two-tailed and have not been adjusted for multiple testing. A P value of less than 0.05 was considered to indicate statistical significance.

RESULTS

STUDY POPULATION

A total of 26,676 volunteers were screened and 16,402 were enrolled (intention-to-treat group) (Fig. 1). The 12,542 subjects who completed all vaccination visits on schedule and were not found to have HIV-1 infection after receiving the full vaccination regimen were included in the per-protocol analysis. Seven volunteers who were found to

Table 1. Baseline Characteristics of the Subjects (Modified Intention-to-Treat Population).

| Variable | Vaccine (N = 8197) | Placebo (N = 8198) <i>number (percent)</i> | All Subjects (N = 16,395) |
|--|-----------------------|--|------------------------------|
| Sex | | | |
| Male | 5033 (61.4) | 5031 (61.4) | 10,064 (61.4) |
| Female | 3164 (38.6) | 3167 (38.6) | 6,331 (38.6) |
| Age group | | | |
| ≤20 yr | 2297 (28.0) | 2246 (27.4) | 4,543 (27.7) |
| 21–25 yr | 3633 (44.3) | 3708 (45.2) | 7,341 (44.8) |
| ≥26 yr | 2267 (27.7) | 2244 (27.4) | 4,511 (27.5) |
| Province | | | |
| Chon Buri | 4107 (50.1) | 4107 (50.1) | 8,214 (50.1) |
| Rayong | 4090 (49.9) | 4091 (49.9) | 8,181 (49.9) |
| Marital status | | | |
| Single | 3353 (40.9) | 3338 (40.7) | 6,691 (40.8) |
| Married | 4110 (50.1) | 4169 (50.9) | 8,279 (50.5) |
| Divorced | 602 (7.3) | 541 (6.6) | 1,143 (7.0) |
| Widowed | 50 (0.6) | 64 (0.8) | 114 (0.7) |
| Separated | 82 (1.0) | 86 (1.0) | 168 (1.0) |
| No. of sex partners | | | |
| 0 | 1864 (22.7) | 1801 (22.0) | 3,665 (22.4) |
| 1 | 5428 (66.2) | 5495 (67.0) | 10,923 (66.6) |
| >1 | 619 (7.6) | 620 (7.6) | 1,239 (7.6) |
| Did not answer | 280 (3.4) | 273 (3.3) | 553 (3.4) |
| Missing data | 6 (0.1) | 9 (0.1) | 15 (0.1) |
| Risk group | | | |
| Low | 3865 (47.2) | 3924 (47.9) | 7,789 (47.5) |
| Medium | 2369 (28.9) | 2292 (28.0) | 4,661 (28.4) |
| High | 1963 (23.9) | 1982 (24.2) | 3,945 (24.1) |
| Behavioral risk | | | |
| Needle sharing | 68 (0.8) | 65 (0.8) | 133 (0.8) |
| No condom use | | | |
| With casual partner | 497 (6.1) | 439 (5.4) | 936 (5.7) |
| With commercial sex worker | 33 (0.4) | 29 (0.4) | 62 (0.4) |
| With same-sex partner | 79 (1.0) | 90 (1.1) | 169 (1.0) |
| With HIV-infected partner | 16 (0.2) | 13 (0.2) | 29 (0.2) |
| With partner who injects drugs | 12 (0.1) | 6 (0.1) | 18 (0.1) |
| With multiple sex partners | 128 (1.6) | 130 (1.6) | 258 (1.6) |
| Condom use with HIV-infected partner | 113 (1.4) | 114 (1.4) | 227 (1.4) |
| Symptoms of an STD within past 6 mo* | 246 (3.0) | 233 (2.8) | 479 (2.9) |
| Drug injection in jail | 23 (0.3) | 15 (0.2) | 38 (0.2) |
| Occupation as a commercial sex worker | 42 (0.5) | 44 (0.5) | 86 (0.5) |
| Occupation in the entertainment business | 233 (2.8) | 237 (2.9) | 470 (2.9) |

* STD denotes sexually transmitted disease.

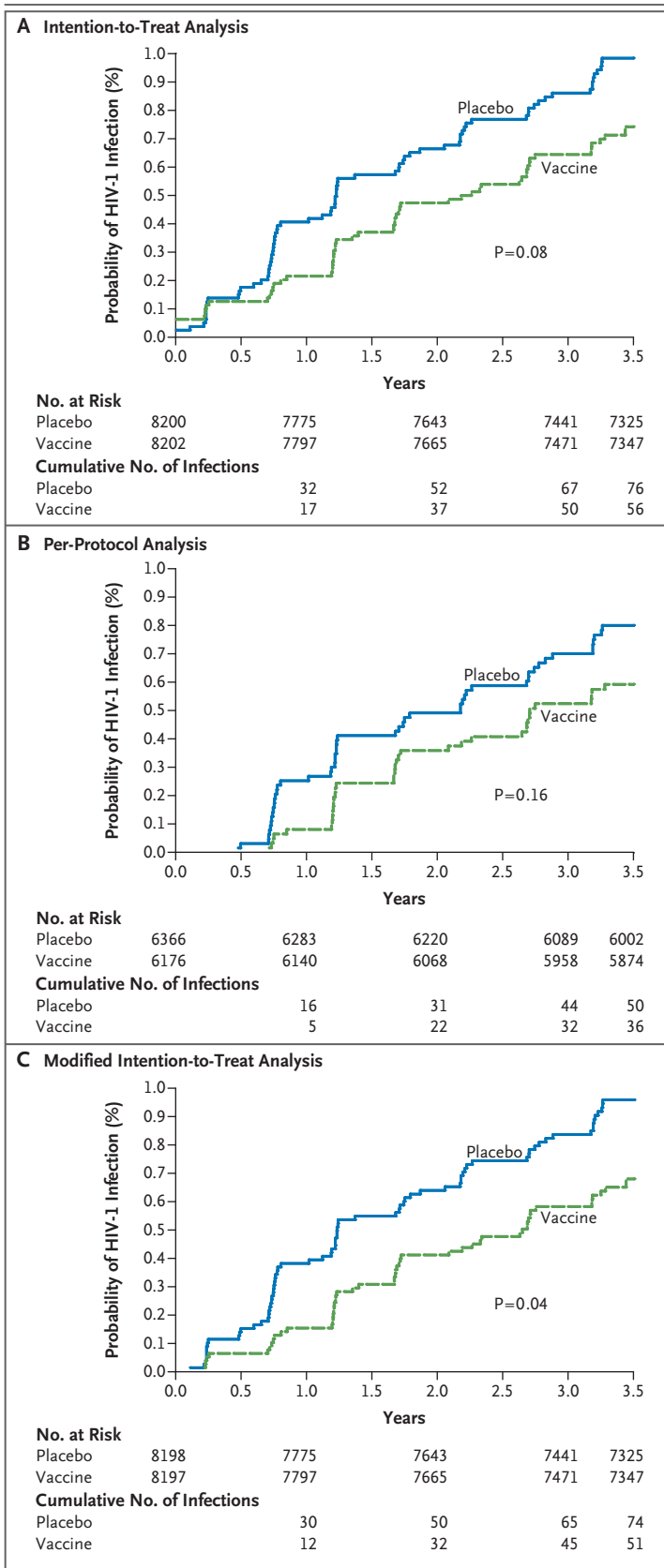


Figure 2. Kaplan–Meier Cumulative Rates of Infection, According to Type of Analysis.

The vaccination regimen was completed approximately 6 months after the first dose was administered. In the intention-to-treat analysis involving 16,402 subjects, the vaccine efficacy was 26.4% (95% confidence interval [CI], -4.0 to 47.9; $P=0.08$) (Panel A). In the per-protocol analysis involving 12,542 subjects, the vaccine efficacy was 26.2% (95% CI, -13.3 to 51.9; $P=0.16$) (Panel B). In the modified intention-to-treat analysis involving 16,395 subjects (excluding 7 subjects who were found to have had HIV infection at baseline), the vaccine efficacy was 31.2% (95% CI, 1.1 to 51.2; $P=0.04$) (Panel C).

be seropositive for HIV-1 on the first test after vaccination were determined by RNA testing to have been infected at enrollment and were not included in the modified intention-to-treat analysis, leaving 16,395 volunteers: 8197 in the vaccine group and 8198 in the placebo group. This group consisted of 10,064 men (61.4% of the subjects) and 6331 women (38.6%). Baseline characteristics were similar for selected variables, and there was no imbalance between the two groups in self-described risk behavior (Table 1).

There were no substantive changes in serial self-reports of risk behavior during the trial. No data were collected on the status of male circumcision or on serologic analyses for adenovirus type 5 or herpes simplex virus type 2.

There were 52,985 person-years of follow-up (15% more than planned). At 42 months, 14,672 of the volunteers (89.5%) had completed the trial and were HIV-seronegative.

ADVERSE EVENTS

Most local and systemic reactions to the vaccine were mild to moderate and reflected the findings of studies on the safety of these products that have been reported previously^{12,17,27-29} (Fig. 1 in the Supplementary Appendix). Most reactions were mild to moderate and resolved within 3 days after vaccination. At least one adverse event was reported in 69.4% of subjects in the two study groups. The number of deaths and the frequency and severity of adverse events and serious adverse events were similar in the two groups (Table 1 in the Supplementary Appendix).

PRIMARY END POINTS

HIV-1 Infection

HIV-1 infection was diagnosed in 132 subjects (56 in the vaccine group and 76 in the placebo

Table 2. Rate of HIV Infection and Vaccine Efficacy, According to Selected Baseline Variables (Modified Intention-to-Treat Population).

| Variable | Vaccine (N=8197) | | | | Placebo (N=8198) | | | | Vaccine Efficacy % (95% CI) |
|---------------------|------------------|--------------------|---------------------|-----------------------|------------------|--------------------|---------------------|-----------------------|--------------------------------|
| | No. Evaluated | No. with Infection | No. of Person-Years | Rate no./person-yr | No. Evaluated | No. with Infection | No. of Person-Years | Rate no./person-yr | |
| All subjects | 7960 | 51 | 26,507 | 0.192 | 7988 | 74 | 26,478 | 0.279 | 31.2 (1.7 to 51.8) |
| Sex | | | | | | | | | |
| Male | 4875 | 32 | 16,221 | 0.197 | 4885 | 43 | 16,179 | 0.266 | 25.8 (-17.3 to 53.0) |
| Female | 3085 | 19 | 10,286 | 0.185 | 3103 | 31 | 10,300 | 0.301 | 38.6 (-8.6 to 65.3) |
| Age group | | | | | | | | | |
| ≤20 yr | 2228 | 12 | 7,358 | 0.163 | 2185 | 11 | 7,216 | 0.152 | 7.1 (-143.0 to 52.7) |
| 21–25 yr | 3517 | 20 | 11,713 | 0.171 | 3610 | 40 | 11,946 | 0.335 | 49 (12.8 to 70.2) |
| ≥26 yr | 2215 | 19 | 7,437 | 0.255 | 2193 | 23 | 7,316 | 0.314 | 18.7 (-49.3 to 55.7) |
| Living with partner | | | | | | | | | |
| Yes | 4017 | 19 | 13,466 | 0.141 | 4083 | 34 | 13,612 | 0.25 | 43.5 (1.0 to 67.8) |
| No | 3943 | 32 | 13,041 | 0.245 | 3905 | 40 | 12,866 | 0.311 | 21 (-25.7 to 50.4) |
| Risk group | | | | | | | | | |
| Low | 3767 | 17 | 12,565 | 0.135 | 3837 | 29 | 12,798 | 0.227 | 40.4 (-8.5 to 67.2) |
| Medium | 2297 | 12 | 7,642 | 0.157 | 2222 | 22 | 7,353 | 0.299 | 47.6 (-6.0 to 74.0) |
| High | 1896 | 22 | 6,300 | 0.349 | 1929 | 23 | 6,327 | 0.364 | 3.7 (-72.7 to 46.3) |

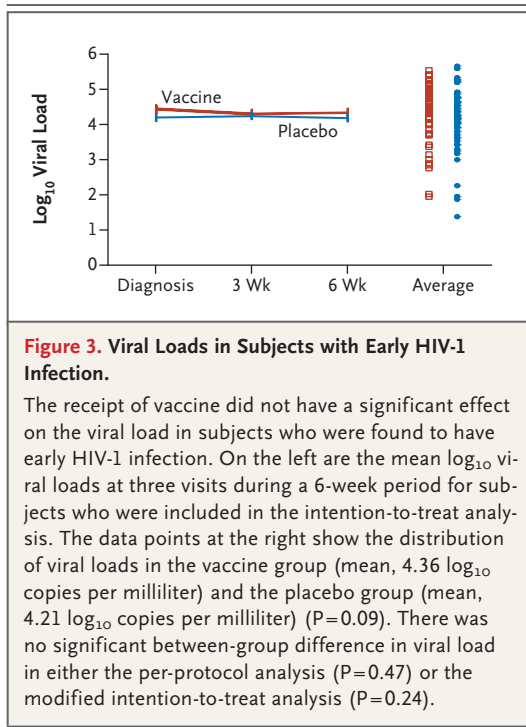
group) during 52,985 person-years of follow-up in the intention-to-treat analysis, in 86 subjects (36 in the vaccine group and 50 in the placebo group) during 36,720 person-years of follow-up in the per-protocol analysis, and in 125 subjects (51 in the vaccine group and 74 in the placebo group) during 52,985 person-years of follow-up in the modified intention-to-treat analysis. One subject in the placebo group who was identified by hospital record as being seropositive for HIV after dying from *Pneumocystis jirovecii* pneumonia was included in the analysis before the unblinding of the study. This diagnosis of HIV-1 infection was the only one that occurred outside planned procedures.

With the use of the Cox proportional-hazards method, the observed vaccine efficacy was 26.4% (95% confidence interval [CI], -4.0 to 47.9; $P=0.08$) in the intention-to-treat analysis (Fig. 2A); 26.2% (95% CI, -13.3 to 51.9; $P=0.16$) in the per-protocol analysis (Fig. 2B); and 31.2% (95% CI, 1.1 to 52.1; $P=0.04$ by the O'Brien-Fleming method) in the modified intention-to-treat analysis (Fig. 2C). Because HIV testing was done at week 24, it is not possible to discern which dose of vaccine might have been associated with an early effect. The overall observed

effect in the modified intention-to-treat analysis was evaluated with the use of several different analyses: event rates by Barnard's test ($P=0.04$), the log-rank test ($P=0.04$), the Wilcoxon test ($P=0.03$), modification of the time-to-seroconversion end point ($P=0.04$), exclusion of the in-hospital diagnosed case ($P=0.05$), and analysis of interval-censored data ($P=0.04$).

Covariates were analyzed for the populations with similar results. Simultaneous adjustment for sex, age, living with a partner, and baseline risk factors did not affect estimates of vaccine efficacy, even though between-group differences in age, living with a partner, and baseline risk factors were significant. Subgroup analyses revealed no significant heterogeneity in vaccine efficacy according to baseline variables (Table 2).

There were 86 HIV-1 infections in the per-protocol population and 125 infections in the modified intention-to-treat population. There were three categories into which the 39 subjects with HIV-1 infection who were excluded from the per-protocol population could be organized: 10 subjects (3 in the vaccine group and 7 in the placebo group) were infected during the vaccination phase and received all vaccinations on schedule; 10 subjects (3 in the vaccine group and 7 in



the placebo group) were infected after the vaccination phase and received all vaccinations, but one or more vaccinations were not administered during the prespecified window; and 19 subjects (9 in the vaccine group and 10 in the placebo group) were infected after the vaccination phase but did not receive all vaccinations.

Postinfection Viral Load and CD4+ T-Cell Count

There was no significant difference in the mean viral load among subjects who were found to have HIV infection in the vaccine group, as compared with those in the placebo group. The mean viral-load values were 4.36 \log_{10} copies per milliliter in the vaccine group and 4.21 \log_{10} copies per milliliter in the placebo group ($P=0.09$ by the Wilcoxon test) in the intention-to-treat analysis (Fig. 3). The viral-load values were 4.24 \log_{10} copies per milliliter in the vaccine group and 4.19 \log_{10} copies per milliliter in the placebo group in the per-protocol analysis ($P=0.47$) and 4.30 \log_{10} copies per milliliter and 4.20 \log_{10} copies per milliliter, respectively, in the modified intention-to-treat analysis ($P=0.24$).

In all three analyses, there were no significant between-group differences in postinfection CD4+ T-cell counts. The mean early postinfection CD4+ T-cell count was 541 cells per microliter in the vaccine group and 568 cells per microliter in the

placebo group in the intention-to-treat analysis ($P=0.47$ by the Wilcoxon test), 572 cells per microliter in the vaccine group and 532 cells per microliter in the placebo group in the per-protocol analysis ($P=0.72$), and 555 cells per microliter in the vaccine group and 568 cells per microliter in the placebo group in the modified intention-to-treat analysis ($P=0.76$).

IMMUNOGENICITY

Vaccination induced an HIV-specific response, as measured by the production of interferon- γ by T cells when exposed to either Env or Gag antigen on ELISPOT assay, in 19.7% of volunteers 6 months after the final dose of vaccine was administered (Table 3 and the Supplementary Appendix). This result was similar to the rate of 17% in the phase 2 trial (de Souza MS: personal communication). Response rates for CD4+ Env-specific intracellular cytokine staining were higher in the vaccine group than in the placebo group. Rates of positivity in the gp120 and p24 binding-antibody assays and the lymphoproliferation assay were similar to those in the phase 2 study.¹⁷ Binding antibody for Env was nearly uniformly present, with the reciprocal of the geometric mean titer (GMT⁻¹) of 31,207 for the MN strain and 14,558 for the A244 strain, whereas p24 responses were less frequent (GMT⁻¹, 138) (for details, see the Supplementary Appendix). The median lymphocyte stimulation index (LSI) was 2 for all subjects at baseline and subsequently in placebo recipients. The LSI was significantly higher in vaccine recipients (median LSI, 24 for gp120 MN, 32 for A244, and 4 for p24).

DISCUSSION

In this clinical trial, we evaluated the efficacy of ALVAC-HIV priming and AIDSVAX B/E boosting for the prevention of HIV-1 infection in more than 16,000 young Thai adults at community risk for such infection. In the intention-to-treat group (which included seven subjects who were found to have had HIV-1 infection at baseline), there was a trend toward prevention of infection with the vaccine regimen. In the per-protocol analysis, which excluded 30% of the end points and person-years of follow-up, the results were not significant. However, after the exclusion of the subjects who were infected with HIV-1 before vaccination, the modified intention-to-treat analysis showed a significant, though modest, reduc-

Table 3. Immunogenicity Analyses at Baseline and 12 Months.*

| Assay and Antigen | Baseline | | 12 Months | |
|---------------------------------|----------------------------|--|---------------------------------------|---------------------------------------|
| | no. positive/total no. (%) | | Vaccine no. positive/total no. (%) | Placebo no. positive/total no. (%) |
| ELISPOT | | | | |
| Gag | 7/194 (3.6) | | 13/156 (8.3) | 3/41 (7.3) |
| Env | 7/198 (3.5) | | 25/157 (15.9) | 3/41 (7.3) |
| Gag or Env | 8/198 (4.0) | | 31/157 (19.7) | 3/41 (7.3) |
| Intracellular cytokine staining | | | | |
| CD8 Gag | 11/200 (5.5) | | 11/144 (7.6) | 4/56 (7.1) |
| CD8 Env | 15/200 (7.5) | | 16/144 (11.1) | 8/56 (14.3) |
| CD4 Gag | 0/200 | | 2/144 (1.4) | 0/56 |
| CD4 Env | 4/200 (2.0) | | 49/144 (34.0)† | 2/56 (3.6) |
| Binding antibody‡ | | | | |
| gp120 MN | 8/200 (4.0) | | 140/142 (98.6)† | 0/58 |
| gp120 A244 | 1/200 (0.5) | | 140/142 (98.6)† | 0/58 |
| p24 | 2/200 (1.0) | | 74/142 (52.1)† | 0/58 |
| Lymphoproliferation‡§ | | | | |
| gp120 MN | 23/96 (24.0) | | 62/71 (87.3)† | 5/25 (20.0) |
| gp120 A244 | 12/96 (12.5) | | 64/71 (90.1)† | 4/25 (16.0) |
| p24 | 19/96 (19.8) | | 35/71 (49.3)¶ | 4/25 (16.0) |

* All analyses were performed on samples collected at baseline (visit 1) and at 12 months (visit 9), unless otherwise specified.

† P<0.001 for the between-group comparison.

‡ These analyses were performed at 6.5 months (visit 8), 2 weeks after the administration of the fourth dose of vaccine.

§ Lymphoproliferation was measured with the use of the lymphocyte stimulation index (LSI). Values are for subjects who had an LSI of 5 or more.

¶ P=0.001 for the between-group comparison.

tion in the rate of HIV-1 infection, as compared with placebo.

Taken together, these data are consistent with a modest protective effect of vaccine in this study. However, there was no significant difference in the HIV-1 viral load or the postinfection CD4+ count between the two study groups. A simple, combined analysis of phase 1 and 2 ALVAC-HIV and gp120 prime–boost studies showed a rate of HIV-1 infection of 0.59 per 100 person-years in the vaccine group and 1.2 per 100 person-years in the placebo group, for a vaccine efficacy of 50% (95% CI, –39 to 80), a difference that was not significant; the results also showed no effect on viral load.³⁰ In nonhuman primates, ALVAC-SIV appeared to protect neonatal macaques against infection from milk containing a low dose of simian immunodeficiency virus (SIV).³¹ However, ALVAC-SIV did not prevent infection from a more intense challenge exposure, although it did reduce the viral load and delay disease progression.^{32,33}

Our trial did not have sufficient power to determine whether there was an effect of risk stratification on either disease acquisition or vaccine efficacy, and none of the observed heterogeneity achieved significance. Previous efficacy trials of HIV vaccines in higher-risk populations have not shown an effect on disease acquisition. Bivalent subtype B AIDSVAX B/B gp120 did not protect high-risk men who have sex with men,^{34–36} and AIDSVAX B/E did not protect Thai injection-drug users²¹ from infection with HIV-1. The Step trial of Merck recombinant adenovirus type 5 (rAd5) HIV-1 vaccine containing subtype B *gag*, *pol*, and *nef* in high-risk men who have sex with men was stopped because of futility and possibly higher rates of infection in vaccine recipients.³⁷

An immunologic correlate with protection from HIV-1 infection has not been determined at this time. Though early studies of canarypox–gp120 subunit prime–boost regimens were promising,^{10–13} advanced-phase testing of subtype B ALVAC-HIV (vCP1452) and AIDSVAX B/B was can-

celed because CD8+ reactivity on ELISPOT was too low.¹² The vaccines that were used in our trial showed a level of immunogenicity that was similar to levels reported previously.¹⁷ Additional studies with the use of more recently developed immunogenicity assays are planned in order to determine their suitability for correlates analyses.³⁸⁻⁴¹ Further insight may be gained through molecular-sieve analysis of breakthrough infections with the use of single-genome amplification.⁴²

Although our study provided preliminary evidence that an HIV vaccine regimen has the potential to prevent infection, it did not have the power to address two intriguing considerations: vaccine efficacy may have decreased over the first year after vaccination, and vaccine efficacy may have been greater in persons at lower risk for infection (Fig. 2 and Table 2). These issues deserve greater attention in future studies. We do not understand the immune mechanisms mediating the results that we observed. The ALVAC-HIV and AIDSVAX B/E prime-boost regimen induces a broad constellation of immune responses against HIV-1, including T-cell-line adapted neutralizing antibody (71% with response), antibody-directed, cell-mediated cytotoxicity, CD4+ lymphoproliferation (61% with response to gp20 MN, 63% with response to gp120 CM244), and CD8+ T cells (24% with response to ⁵¹Cr-release cytotoxic T-cell assay; 17% with positive response on ELISPOT),^{17,33,43} but these may not be the relevant responses. Understanding the potential immunologic correlates of protection will be a principal research focus. The data also do not answer the related question

of whether it was a single vaccine or the combination of vaccines that induced a potentially protective immune response. Previous studies have suggested that prime-boost combinations induce qualitative or quantitative protective immune responses that are not seen with either vaccine alone, but the current data do not address this question.^{28,44}

Finally, our study supports the possibility that immunologic mechanisms mediating protection against HIV may be different from those mediating early postinfection control of viral replication.^{45,46} Taken together, these considerations underscore the opportunities afforded by the efficacy testing of HIV vaccines in human subjects in providing an objective context for review of existing methods of vaccine design, immunogenicity testing, and animal models.

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Drs. Gurunathan, Tartaglia, and McNeil report being employees of Sanofi Pasteur, and Dr. Tartaglia reports having an equity interest in the company. No other potential conflict of interest relevant to this article was reported.

The opinions expressed in this article are those of the authors and do not represent the official views of the Department of Health and Human Services, the National Institute of Allergy and Infectious Diseases, the Centers for Disease Control and Prevention, the Department of Defense, or Department of the Army.

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APPENDIX

The following investigators and institutions participated in the MOPH-TAVEG study: **Ministry of Public Health, Thailand:** S. Rerks-Ngarm, S. Chunsuttiwat, N. Prensri, C. Namwat, P. Kunasol, P. Thongcharoen, C. Khamboonruang; **Vaccine Trials Center, Mahidol University:** P. Pititsuttithum, V. Bussaratid, W. Maek-a-nantawat, J. Dhitavat, P. Suntharasamai, S. Pungpak, S. Vanijanonta; **Data Management Unit, Mahidol University:** J. Kaewkunwal, A. Khamsiriwatchara, P. Jarujareet; **Royal Thai Army, Armed Forces Research Institute of Medical Sciences:** S. Nitayaphan, C. Easmila, S. Tabprasit; **U.S. Army Component, Armed Forces Research Institute of Medical Sciences:** J. Chiu, R. Paris, M. Benenson, A. Brown, P. Morgan, M. de Souza, R. Trichavaroj, A. Schuetz, N. Thaitawat; **Sanofi Pasteur:** S. Gurunathan, J. Tartaglia, J.G. McNeil, R. Harkness, C. Meric, R. El Habib, L. Baglyos; **Global Solutions in Infectious Diseases:** D. Francis, C. Lee; **National Institute of Allergy and Infectious Diseases:** E. Adams; **U.S. Military HIV Research Program, Walter Reed Army Institute of Research and U.S. Army Medical Materiel Development Agency, U.S. Army Medical Research and Materiel Command:** J.H. Kim, M.L. Robb, N.L. Michael, M. Milazzo, A. Bolen, B. Wessner, S.R. Kim, M. Marovich, J. Currier; **Global AIDS Program, Centers for Disease Control and Prevention:** D.L. Birx; **Emmes Corporation:** D. Stablein, T. Germanson, L. Dally; **SHI Consulting:** R. Wiley; **International AIDS Vaccine Initiative:** Dr. J.-L. Excler; **Tripler Army Medical Center:** Dr. J. Berenberg.

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