CA-125 KELIM as a Potential Complementary Tool for Predicting Veliparib Benefit: An Exploratory Analysis From the VELIA/GOG-3005 Study

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PURPOSE In VELIA trial, veliparib combined with carboplatin-paclitaxel, followed by maintenance (veliparib-throughout) was associated with improved progression-free survival (PFS) compared with carboplatin-paclitaxel alone in patients with high-grade ovarian carcinomas. We explored the prognostic value of the modeled cancer antigen (CA)-125 elimination rate constant K (KELIM), which is known to be an indicator of the intrinsic tumor chemosensitivity (the faster the rate of CA-125 decline, the higher the KELIM and the higher the chemosensitivity), and its association with benefit from veliparib.

PATIENTS AND METHODS Individual KELIM values were estimated from longitudinal CA-125 kinetics. Patients were categorized as having favorable ($\geq$ median) or unfavorable ($<$ median) KELIM. The prognostic value of KELIM for veliparib-related PFS benefit was explored in cohorts treated with primary or interval debulking surgery, according to the surgery completeness, the disease progression risk group, and the homologous recombination (HR) status (*BRCA* mutation, HR deficiency [HRD], or HR proficiency [HRP]).

RESULTS The data from 854 of 1,140 enrolled patients were analyzed (primary debulking surgery, n = 700; interval debulking surgery, n = 154). Increasing KELIM values were associated with higher benefit from veliparib in HRD cancer, as were decreasing KELIM values in HRP cancer. The highest PFS benefit from veliparib was observed in patients with both favorable KELIM and *BRCA* mutation (hazard ratio, 0.28; 95% CI, 0.13 to 0.61) or *BRCA* wild-type HRD cancer (hazard ratio, 0.43; 95% CI, 0.26 to 0.70), consistent with the association between poly (adenosine diphosphate-ribose) polymerase inhibitor efficacy and platinum sensitivity. In contrast, seventy-four percent of patients with a *BRCA* mutation and unfavorable KELIM progressed within 18 months while on veliparib. The patients with HRP cancer and unfavorable KELIM might have benefited from the veliparib chemosensitizing effect.

CONCLUSION In addition to HRD/*BRCA* status, the tumor primary chemosensitivity observed during the first-line chemotherapy might be another complementary determinant of poly (adenosine diphosphate-ribose) polymerase inhibitor efficacy.

INTRODUCTION

Platinum-based chemotherapy followed by maintenance treatment with bevacizumab and/or poly (adenosine diphosphate-ribose) polymerase inhibitors (PARPis) is the standard first-line systemic treatment for patients with high-grade carcinomas of the ovary, fallopian tube, or peritoneum (high-grade ovarian carcinomas [HGOC]).[1-6] Which patients truly benefit from PARPi maintenance remains controversial. Although *BRCA* mutation and, to a lesser extent, other measures of homologous recombination deficiency (HRD) are undoubtedly associated with PARPi activity,[7-10] data

suggest that the efficacy of these drugs cannot be unequivocally explained by these biomarkers, and there are still knowledge gaps in the understanding of determinants of PARPi efficacy. Among potential predictive biomarkers, sensitivity to platinum-based chemotherapy is very relevant. Strong relationships between platinum sensitivity and PARPi efficacy have been reported in several studies in patients treated in first-line or recurrent settings.[10-12]

Recent publications on more than 12,000 patients enrolled in five randomized trials, along with The Netherlands Cancer Registry and the Gynecology

CONTEXT

Key Objective

To understand the role of the tumor primary chemosensitivity (assessed by the modeled cancer antigen-125 kinetic parameter elimination rate constant K, KELIM) regarding the efficacy of the maintenance with the poly (adenosine diphosphate-ribose) polymerase inhibitor veliparib, with respect to the homologous recombination (HR) status, in patients with advanced ovarian carcinoma.

Knowledge Generated

The analysis of VELIA trial revealed that higher tumor chemosensitivity was associated with higher efficacy of veliparib in terms of progression-free survival in patients with HR-deficient cancer (with/without *BRCA* mutation). Conversely, poor chemosensitivity was associated with limited efficacy of veliparib in patients with *BRCA* mutation or *BRCA* wild-type HR deficiency disease. In patients with HR-proficient cancer characterized by poor chemosensitivity, veliparib might have induced the chemosensitizing effect.

Relevance

The tumor primary chemosensitivity, assessable by elimination rate constant K score (KELIM calculable online), may be a complementary parameter to integrate with *BRCA* mutation and HR status for understanding the prognosis and the benefit to expect from maintenance with the poly (adenosine diphosphate-ribose) polymerase inhibitor veliparib.

Cancer InterGroup meta-analysis data set, have indicated that cancer antigen (CA)-125 elimination rate constant K (KELIM), a modeled kinetic parameter on the basis of CA-125 measurements during the first 100 days of adjuvant or neoadjuvant chemotherapy, represents a reproducible indicator of tumor-intrinsic chemosensitivity in the first-line setting.[13,14] KELIM exhibited a strong prognostic and predictive value for response to neoadjuvant chemotherapy, completeness of interval debulking surgery (IDS), risk of subsequent platinum-resistant relapse, progression-free survival (PFS), benefit from bevacizumab in the ICON-7 trial, and long-term survival in HGOC.[15-18] These data suggest that the longitudinal kinetics of CA-125 during the first three cycles of chemotherapy, as captured by KELIM, may reflect an intrinsic property of cancer cells related to their sensitivity to chemotherapy, which is independent of the regimen received. Indeed, the analyses performed on ICON-7, AGO-OVAR 9, and CHIVA trials showed that the addition of third drug (chemotherapy or antiangiogenic drugs) to carboplatin-paclitaxel did not alter CA-125 KELIM values and that KELIM was prognostic and strongly related to overall survival regardless of whether patients received doublet or triplet regimens. Of note, KELIM was shown to be more accurate than the CA-125 Gynecology Cancer InterGroup response criterion for characterizing chemotherapy efficacy in the first-line setting.[15,17,19-21]

Veliparib is an oral PARPi that inhibits poly (adenosine diphosphate-ribose) polymerase (PARP) activity without substantial trapping of PARP onto DNA damage repair intermediates,[22,23] thereby making veliparib more suitable for administration in combination with platinum-based chemotherapy.[24] The efficacy of veliparib was assessed in combination with standard frontline platinum-based chemotherapy (concomitant-veliparib arm; dose reduced during combination therapy) or in the same regimen followed by veliparib continued as a monotherapy in the maintenance phase (veliparib-throughout arm) in the VELIA phase III trial.[7] Compared with the chemotherapy-only (placebo) arm, the veliparib-throughout arm was associated with significantly improved PFS in patients with *BRCA* mutations, in those with high genomic instability score (GIS, considered a reflection of tumor HRD), and in the intent-to-treat population.[7,25] Patients enrolled in VELIA trial were not selected on the basis of their response to platinum-based chemotherapy, thereby making it possible to investigate the association between the tumor chemosensitivity and the efficacy of this PARPi beyond homologous recombination (HR) status.

The present exploratory post hoc study was meant to confirm the prognostic value of KELIM as an indicator of intrinsic chemosensitivity and test it as a predictive marker in relation to veliparib efficacy.

PATIENTS AND METHODS

Patients and Treatments

The VELIA study is a three-arm phase III trial in which patients with newly diagnosed HGOC were randomly assigned in a 1:1:1 ratio to the control arm (arm 1: chemotherapy plus placebo, followed by placebo maintenance), veliparib-combination-only arm (arm 2: chemotherapy plus veliparib, followed by placebo maintenance), or veliparib-throughout arm (arm 3: chemotherapy plus veliparib, followed by veliparib maintenance) in women with newly diagnosed stage III or IV HGOC.[7] The trial design mandated that CA-125 values would be measured at every cycle for assessing the prognostic/predictive value of CA-125 kinetics.

To be included in the present analysis, patients had to have at least three available values of CA-125 during the first 100 days of adjuvant chemotherapy after primary debulking surgery (PDS) or before the date of IDS. The following data were collected: age, somatic or germline *BRCA* mutation status (*BRCA* mutation or *BRCA* wild-type), HR status as determined by the Myriad BRACAnalysis CDx or myChoice HRD CDx assay (HRD: *BRCA*-mutated or GIS ≥ 33; or HR-proficient (HRP): *BRCA* wild-type and GIS < 33), disease stage (III or IV), completeness of surgery on the basis of postoperative lesions assessed by the surgeon (complete surgery with no residual lesions or incomplete surgery with microscopic residual lesions between 0 and 1 cm or with macroscopic residual lesions > 1 cm).

Estimation of KELIM for Patients Enrolled in the VELIA Trial

In a collaboration with the Lyon University team (EA 3738, CICLY, France), the development of the KELIM model was conducted by the AbbVie team based on previous publications,[15,17] with the following modifications: patients in the VELIA study were initially pooled together to model individual KELIM values, on the basis of the CA-125 kinetics during the first 100 days of chemotherapy (starting on cycle 1 day 1). The patients were then separated into two subgroups according to timing of surgery (PDS or IDS). The median values of KELIM for each subgroup were then calculated to categorize the patient as having a high tumor primary chemosensitivity (favorable KELIM value ≥ median) or an poor tumor primary chemosensitivity (unfavorable KELIM value < median).

Statistical Analysis

The prognostic value of KELIM for PFS, along with the association between KELIM and veliparib efficacy, was assessed in patients treated in the veliparib-throughout arm (arm 3) and in the placebo arm (arm 1), using the Kaplan-Meier method and univariate and multivariate Cox proportional hazards models.

Patients were analyzed all together (whole population) and then separately in the PDS and IDS cohorts as a way of accounting for their different prognosis. In addition to KELIM, the other prognostic factors assessed in univariate and multivariate analyses were as follows: treatment arm (3 *v* 1), disease stage (III *v* IV), surgery outcome on the basis of postoperative lesions (no residual lesion, *v* microscopic residual lesion, *v* any other residual lesion), and HR status (*BRCA* mutation, *BRCA* wild-type HRD, and HRP). The final Cox survival models were obtained using backward selection.

Additional analyses were performed to further assess the interactions between KELIM and treatment arms regarding veliparib-related PFS benefit, along with the association between KELIM and veliparib activity across important prognostic subgroups: disease stage (stage III or stage IV), completeness of surgery on the basis of postoperative residual lesions; disease progression risk groups

(low-risk disease: stage III disease with no or microscopic residual lesions after surgery; high-risk diseases: stage III disease with postoperative macroscopic residual lesions or stage IV diseases),[26] and HRD/HRP/*BRCA* mutation status.

All survival analyses were implemented with a landmark time point set at 100 days after the start of neoadjuvant chemotherapy. As CA-125 was modeled from days 0 to 100, the patients who progressed during the first 100 days were excluded to avoid bias related to the links between early progression and CA-125 kinetics or radiological tumor responses.[27]

The hazard ratios were computed using the Cox proportional hazard model and with the 95% CI.

All analyses were performed using R program (Lucent technology, Murray Hill, NJ).[28]

RESULTS

Patient Characteristics

One thousand one hundred forty patients were enrolled in the VELIA study. Among 854 patients with ≥ 3 available measurements of CA-125 during the first three cycles of neoadjuvant or adjuvant chemotherapy, 700 patients (81.9%) received PDS and 154 patients (18.1%) received IDS (Data Supplement, online only and Table 1). The distribution of patients treated with the 3-weekly or the weekly carboplatin-paclitaxel regimens was well balanced between patients with favorable or unfavorable KELIM. The median number of CA-125 measurements per patient was four in the PDS cohort and three in the IDS cohort. Key demographic and clinical characteristics of the 854 patients are given in Table 1.

Model Adjustment and Qualification

Typical parameter estimates, along with the qualification analyses from the final semimechanistic model, are presented in Appendix 1 (online only; Appendix Table A1, online only; and Data Supplement).

Characterization of KELIM in VELIA Trial

The median KELIM was 0.023 for all 854 patients, 0.017 for the IDS cohort, and 0.024 for the PDS cohort. Patients in the IDS cohort tended to have a less favorable KELIM than those in the PDS cohort, which was expected since these patients still had tumor in place. The distributions of KELIM values across treatment arms in the PDS and IDS are shown in the Data Supplement. Consistent with previous publications, KELIM did not differ significantly across treatment arms, confirming that KELIM could be assessed as an indicator of the primary tumor chemosensitivity. As expected, the percentages of *BRCA* mutations and HRD tumors tended to be higher in favorable KELIM groups, compared with those in unfavorable KELIM groups, regardless of the treatment arms and surgery types (Table 1 and Data Supplement).

TABLE 1. Characteristics of Assessed Patients

	PDS Cohort				IDS Cohort			
	Veliparib-Throughout Arm		Control Arm		Veliparib-Throughout Arm		Control Arm	
Characteristic	Favorable KELIM (n = 120)	Unfavorable KELIM (n = 116)	Favorable KELIM (n = 117)	Unfavorable KELIM (n = 121)	Favorable KELIM (n = 31)	Unfavorable KELIM (n = 14)	Favorable KELIM (n = 26)	Unfavorable KELIM (n = 31)
Age, years								
Median, years (range)	57 (33-82)	63 (30-84)	55 (33-79)	64 (39-79)	62 (43-78)	62 (53-81)	62 (39-73)	64 (44-77)
BRCA mutational status, No. (%)								
BRCA wild-type	76 (60.0)	76 (65.5)	78 (66.7)	87 (71.9)	17 (54.8)	11 (78.6)	16 (61.5)	19 (61.3)
BRCA 1/2 mutations	41 (34.2)	36 (31.00)	34 (29.1)	28 (23.1)	9 (29.0)	2 (14.3)	9 (34.6)	6 (19.4)
Missing	7 (5.8)	4 (3.4)	5 (4.3)	6 (5.0)	5 (16.1)	1 (7.1)	1 (3.8)	6 (19.4)
HR status, No. (%)								
HRP	34 (28.3)	36 (31.0)	32 (27.4)	44 (36.4)	6 (19.4)	8 (57.1)	7 (26.9)	13 (41.9)
HRD	78 (65.0)	74 (63.8)	75 (64.1)	66 (54.5)	16 (51.6)	3 (21.4)	18 (69.2)	11 (35.5)
Missing	8 (6.7)	6 (5.2)	10 (8.5)	11 (9.1)	9 (29.0)	3 (21.4)	1 (3.8)	7 (22.6)
Disease stage, No. (%)								
Stage III	102 (85.0)	90 (77.6)	102 (87.2)	99 (81.8)	21 (67.7)	9 (64.3)	17 (65.4)	20 (65.5)
Stage IV	18 (5.0)	26 (22.4)	15 (12.8)	22 (18.2)	10 (32.3)	5 (35.7)	9 (34.6)	11 (35.5)
ECOG PS, No. (%)								
≥ 1	42 (35.0)	51 (44.0)	43 (36.8)	42 (34.7)	8 (25.8)	5 (35.7)	7 (26.9)	16 (51.6)
0	78 (65.0)	65 (56.0)	74 (63.2)	79 (65.3)	23 (74.2)	9 (64.3)	19 (73.1)	15 (48.4)
Chemotherapy dosing schedule with carboplatin-paclitaxel, No. (%)								
Three-weekly dosing regimen	68 (56.7)	45 (38.8)	61 (52.1)	49 (40.5)	15 (48.4)	7 (50.0)	14 (53.8)	18 (58.1)
Weekly dosing regimen	52 (43.3)	71 (61.2)	56 (47.9)	72 (59.5)	16 (51.6)	7 (50.0)	12 (46.2)	13 (41.9)
Postoperative lesions, No. (%)								
Any macroscopic residual disease	43 (35.8)	30 (25.9)	37 (31.6)	36 (29.8)	7 (22.6)	5 (35.7)	3 (11.5)	12 (38.7)
Microscopic residual disease	21 (17.5)	25 (21.6)	24 (20.5)	30 (24.8)	9 (29.0)	3 (21.4)	6 (23.1)	8 (25.8)
No residual disease	56 (46.7)	61 (52.6)	56 (47.9)	55 (45.5)	15 (48.4)	6 (42.9)	17 (65.4)	11 (35.5)

Abbreviations: ECOG PS, Eastern Cooperative Oncology Group performance status; HR, homologous recombination; HRD, homologous recombination deficiency; HRP, homologous recombination proficiency; IDS, interval debulking surgery; KELIM, elimination rate constant K; PDS, primary debulking surgery.

Associations Between KELIM and PFS

Prognostic value of KELIM. The median follow-up times were 28.6 and 28.2 months for the veliparib-throughout arm and the control arm, respectively.

In the whole population, KELIM status was a significant prognostic covariate in univariate (hazard ratio, 0.63; 95% CI, 0.51 to 0.79) and multivariate survival analyses (hazard ratio, 0.68; 95% CI, 0.56 to 0.85), together with the treatment arm and HR status (Data Supplement).

In the PDS cohort, the median PFS was longer in patients with favorable KELIM compared with those with unfavorable KELIM in both treatment arms, consistent with the previously reported prognostic value of KELIM (Fig 1). For example, the median PFS of patients treated in the
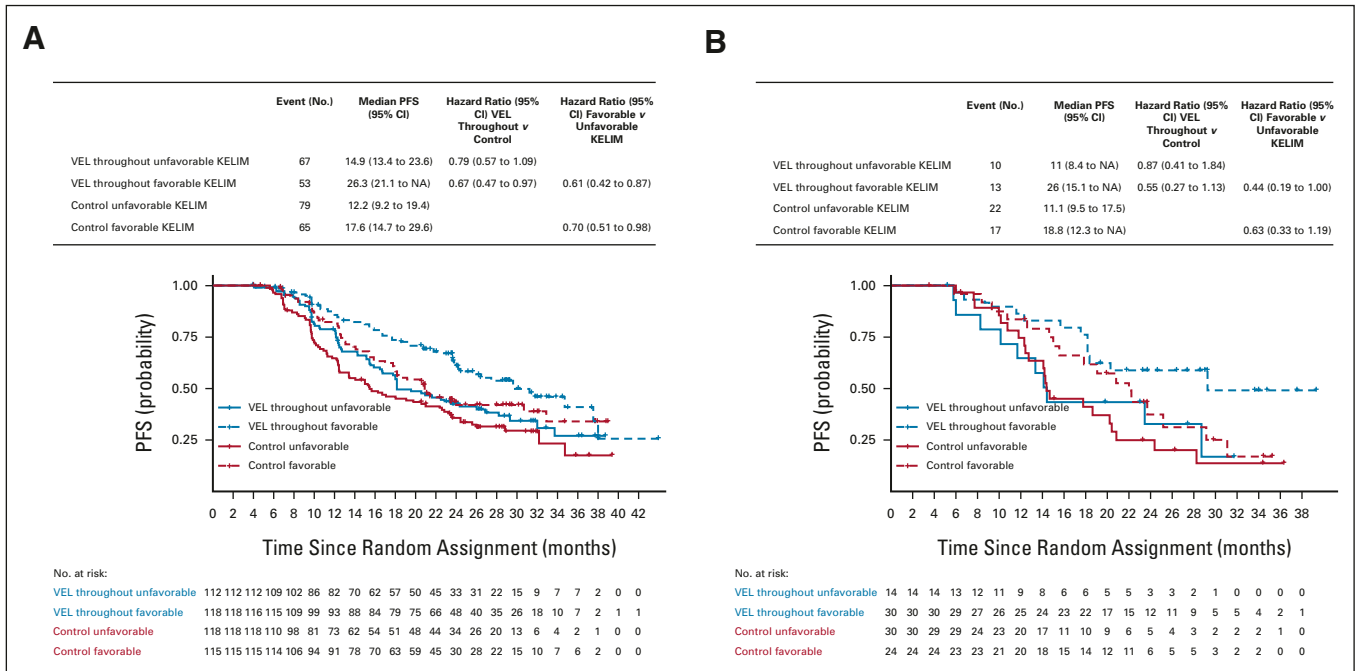
A

	Event (No.)	Median PFS (95% CI)	Hazard Ratio (95% CI) VEL Throughout v Control	Hazard Ratio (95% CI) Favorable v Unfavorable KELIM
VEL throughout unfavorable KELIM	67	14.9 (13.4 to 23.6)	0.79 (0.57 to 1.09)	
VEL throughout favorable KELIM	53	26.3 (21.1 to NA)	0.67 (0.47 to 0.97)	0.61 (0.42 to 0.87)
Control unfavorable KELIM	79	12.2 (9.2 to 19.4)		
Control favorable KELIM	65	17.6 (14.7 to 29.6)		0.70 (0.51 to 0.98)

No. at risk:
VEL throughout unfavorable	112	112	112	109	102	86	82	70	62	57	50	45	33	31	22	15	9	7	7	2	0	0
VEL throughout favorable	118	118	116	115	109	99	93	88	84	79	75	66	48	40	35	26	18	10	7	2	1	1
Control unfavorable	118	118	118	110	98	81	73	62	54	51	48	44	34	26	20	13	6	4	2	1	0	0
Control favorable	115	115	115	114	106	94	91	78	70	63	59	45	30	28	22	15	10	7	6	2	0	0

B

	Event (No.)	Median PFS (95% CI)	Hazard Ratio (95% CI) VEL Throughout v Control	Hazard Ratio (95% CI) Favorable v Unfavorable KELIM
VEL throughout unfavorable KELIM	10	11 (8.4 to NA)	0.87 (0.41 to 1.84)	
VEL throughout favorable KELIM	13	26 (15.1 to NA)	0.55 (0.27 to 1.13)	0.44 (0.19 to 1.00)
Control unfavorable KELIM	22	11.1 (9.5 to 17.5)		
Control favorable KELIM	17	18.8 (12.3 to NA)		0.63 (0.33 to 1.19)

No. at risk:
VEL throughout unfavorable	14	14	14	13	12	11	9	8	6	6	5	5	3	3	2	1	0	0	0	0
VEL throughout favorable	30	30	30	29	27	26	25	24	23	22	17	15	12	11	9	5	5	4	2	1
Control unfavorable	30	30	29	29	24	23	20	17	11	10	9	6	5	4	3	2	2	2	1	0
Control favorable	24	24	24	23	23	21	20	18	15	14	12	11	6	5	5	3	2	2	0	0

FIG 1. PFS according to treatment arms (VEL-throughout v placebo [control]) and KELIM (favorable or unfavorable) in cohort of patients operated with (A) PDS and (B) neoadjuvant chemotherapy and IDS. IDS, interval debulking surgery; KELIM, elimination rate constant K; NA, not available; PDS, primary debulking surgery; PFS, progression-free survival; VEL, veliparib.

veliparib-throughout arm was 29.6 months for those who had favorable KELIM and 18.2 months for those who had unfavorable KELIM (hazard ratio, 0.61; 95% CI, 0.42 to 0.87). In the control arm, the median PFS was 20.9 months for patients with favorable KELIM and 15.4 months for patients with unfavorable KELIM (hazard ratio, 0.69; 95% CI, 0.49 to 0.95; Fig 1). In multivariate analysis, KELIM status was a significant independent prognostic covariate (hazard ratio, 0.67; 95% CI, 0.52 to 0.85), along with the treatment arm, surgery outcomes on the basis of postoperative lesions, and HR status (Data Supplement).

Similar data of the prognostic value of KELIM were observed in the IDS cohort, with larger CIs because of the lower number of patients (Fig 1 and Data Supplement).

Association between KELIM and benefit from veliparib. The magnitude of the PFS difference between patients treated in the veliparib-throughout arm or in the placebo arm was
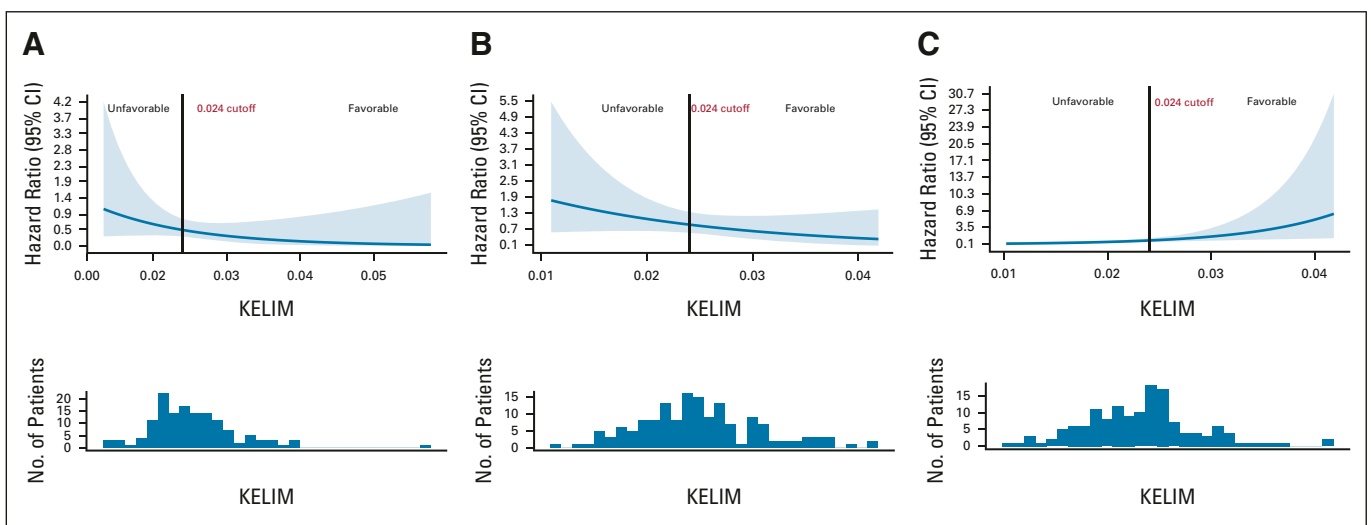
FIG 2. Generalized additive model with Cox proportional hazard ratios of PFS benefit in veliparib-throughout arm 3 versus placebo arm 1 according to KELIM in (A) patients with *BRCA* mutation, (B) *BRCA* wild-type HRD cancer, and (C) HRP cancer. The cutoff at 0.024 was the KELIM median value. HRD, homologous recombination deficiency; HRP, homologous recombination proficiency; KELIM, elimination rate constant K; PFS, progression-free survival.
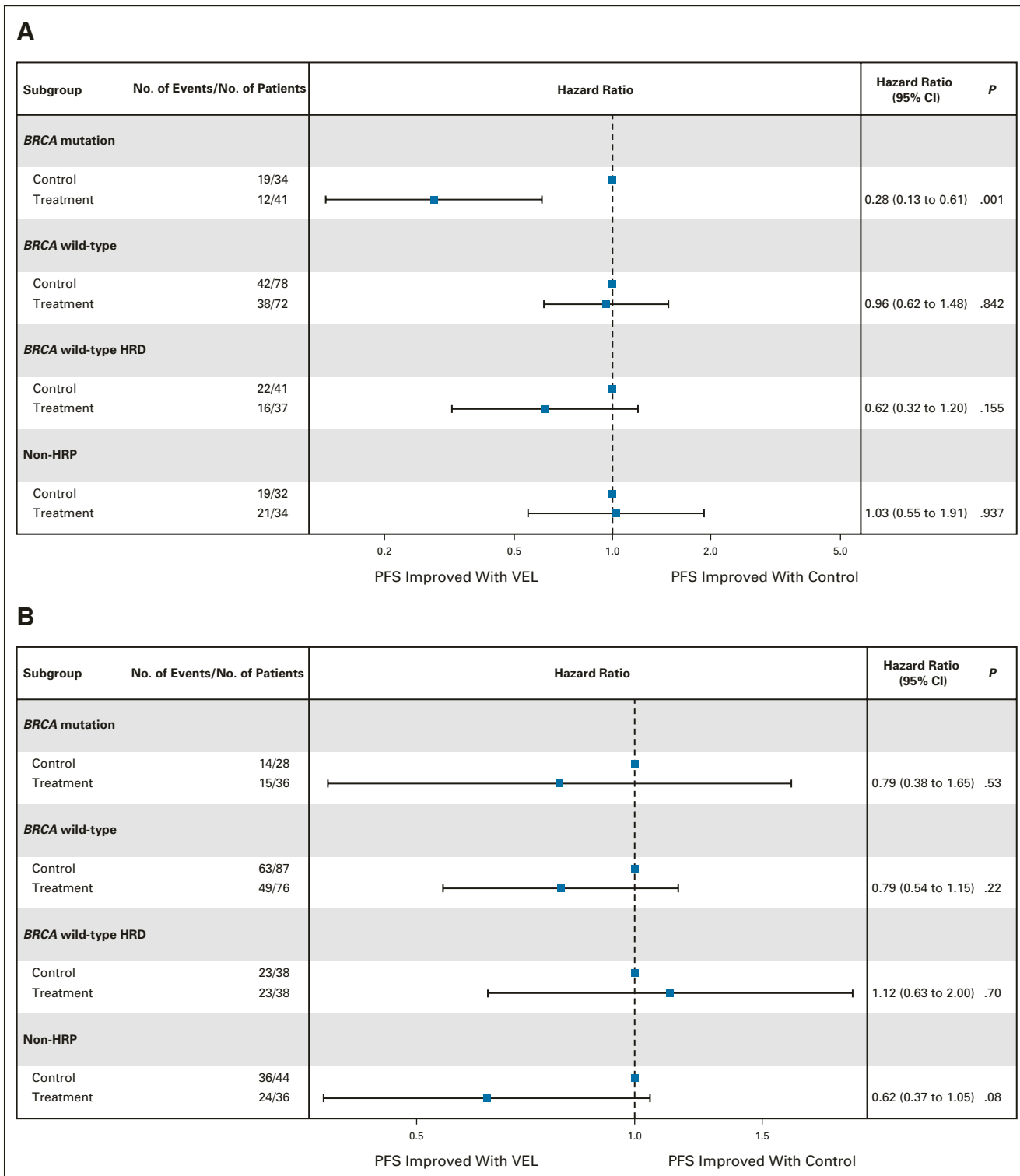
A

Subgroup	No. of Events/No. of Patients	Hazard Ratio	Hazard Ratio (95% CI)	P
BRCA mutation				
Control	19/34			
Treatment	12/41		0.28 (0.13 to 0.61)	.001
BRCA wild-type				
Control	42/78			
Treatment	38/72		0.96 (0.62 to 1.48)	.842
BRCA wild-type HRD				
Control	22/41			
Treatment	16/37		0.62 (0.32 to 1.20)	.155
Non-HRP				
Control	19/32			
Treatment	21/34		1.03 (0.55 to 1.91)	.937

0.2   0.5   1.0   2.0   5.0

PFS Improved With VEL   PFS Improved With Control

B

Subgroup	No. of Events/No. of Patients	Hazard Ratio	Hazard Ratio (95% CI)	P
BRCA mutation				
Control	14/28			
Treatment	15/36		0.79 (0.38 to 1.65)	.53
BRCA wild-type				
Control	63/87			
Treatment	49/76		0.79 (0.54 to 1.15)	.22
BRCA wild-type HRD				
Control	23/38			
Treatment	23/38		1.12 (0.63 to 2.00)	.70
Non-HRP				
Control	36/44			
Treatment	24/36		0.62 (0.37 to 1.05)	.08

0.5   1.0   1.5

PFS Improved With VEL   PFS Improved With Control

FIG 3. Forest plots of benefit from veliparib-throughout versus placebo arms regarding PFS according to homologous recombination (HR) status in patients with (A) favorable KELIM or (B) unfavorable KELIM treated with primary debulking surgery. HRD, homologous recombination deficiency; HRP, homologous recombination proficiency; KELIM, elimination rate constant K; PFS, progression-free survival; VEL, veliparib.

higher in patients who had favorable KELIM compared with those who had unfavorable KELIM, thereby suggesting a potential predictive value of KELIM regarding the benefit from veliparib. In the PDS cohort, the PFS hazard ratio was 0.67 (95% CI, 0.47 to 0.97) for patients with favorable KELIM and 0.77 (95% CI, 0.56 to 1.06) for patients with

unfavorable KELIM (Fig 1). Moreover, in the IDS cohort, the veliparib-throughout arm was associated with longer median PFS for patients with favorable KELIM only (29.3 v 20.8 months; hazard ratio, 0.54; 95% CI, 0.27 to 1.07; Fig 1). These data suggest a potential association between veliparib benefit and KELIM value.

Association between veliparib activity and KELIM, according to the completeness of surgery and disease progression risk group. The outcomes of the analyses are presented in Appendix 1. A strong association was found between KELIM estimated during neoadjuvant chemotherapy before surgery and the completeness of subsequent IDS (Data Supplement and Table 1). Higher benefit from veliparib in patients with favorable KELIM compared with those with unfavorable KELIM was observed, regardless of the completeness of surgery or disease risk group (Data Supplement).
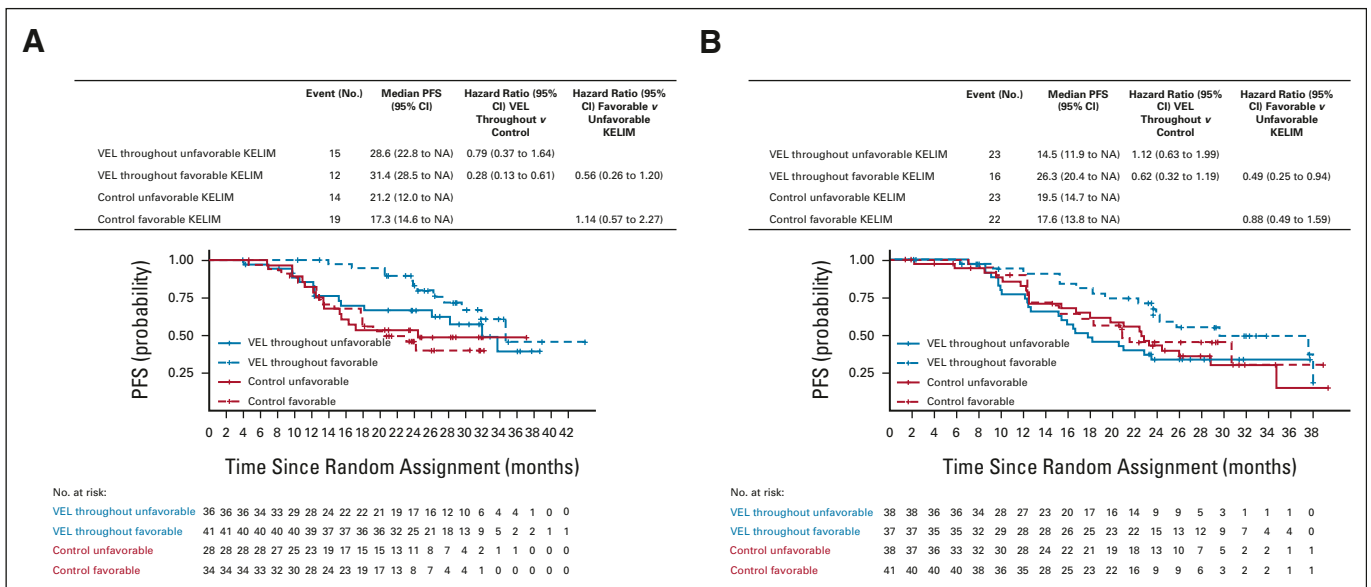
Association between veliparib activity and KELIM according to HR status. The BRCA mutation and tumor HR status were available in 794 (93%) and 763 (89%) patients.

The generalized additive model with Cox proportional hazard ratios suggested different interactions between KELIM value and benefit from veliparib, depending on the HR status. In patients with BRCA mutation and BRCA wild-type HRD cancers, increasing KELIM value was associated with higher benefit from veliparib. However, in patients with HRP cancers, decreasing KELIM value seemed to be associated with higher benefit from veliparib (Fig 2).

In patients treated with PDS, the subgroup of patients who derived the highest benefit from veliparib, in comparison with the placebo arm, were those with both favorable KELIM and either BRCA mutation (hazard ratio, 0.28; 95% CI,

0.13 to 0.61) or BRCA wild-type HRD cancers (hazard ratio, 0.43; 95% CI, 0.26 to 0.7), whereas those with HRP tumors had no PFS improvement (Figs 3A and 4). The interaction tests between the treatment arm and KELIM status were consistent with higher benefit from veliparib in patients with HRD cancer exhibiting favorable KELIM: BRCA mutation (n = 139 patients), hazard ratio, 0.45; 95% CI, 0.16 to 1.26; BRCA wild-type HRD cancer (n = 147 patients), hazard ratio, 0.54; 95% CI, 0.23 to 1.30; and HRD cancer (n = 286 patients), hazard ratio, 0.50; 95% CI, 0.26 to 0.96. By contrast, the patients with unfavorable KELIM derived no benefit from veliparib whether they were carrying BRCA mutation or had HRD cancer (Fig 3B). For example, 74% of patients with BRCA mutation and unfavorable KELIM treated with veliparib had short PFS < 18 months. The discriminative accuracy (receiver operating characteristic curve area under the curve) of KELIM (unfavorable v favorable) for identifying the patients likely to experience early progression < 18 months was 0.75 (95% CI, 0.63 to 0.86; sensitivity, 0.62 and specificity, 0.74 for a KELIM cutoff at 0.024; Data Supplement).

Consistent with the generalized additive model curve analysis (Fig 2), a nonsignificant PFS benefit with veliparib was observed in patients with HRP cancer characterized by unfavorable KELIM. Compared with patients treated with placebo arm 1, this PFS gain was temporary in patients treated with the concomitant-veliparib arm 2 (median PFS, 10.2 v 6.7 months; hazard ratio, 0.79; 95% CI, 0.49 to 1.30; Fig 5A) and maintained in patients treated with the veliparib-throughout arm (arm 3; median PFS, 14.7 v 6.7 months; hazard ratio, 0.62; 95% CI, 0.37 to 1.05; Figs 3B and 5B).
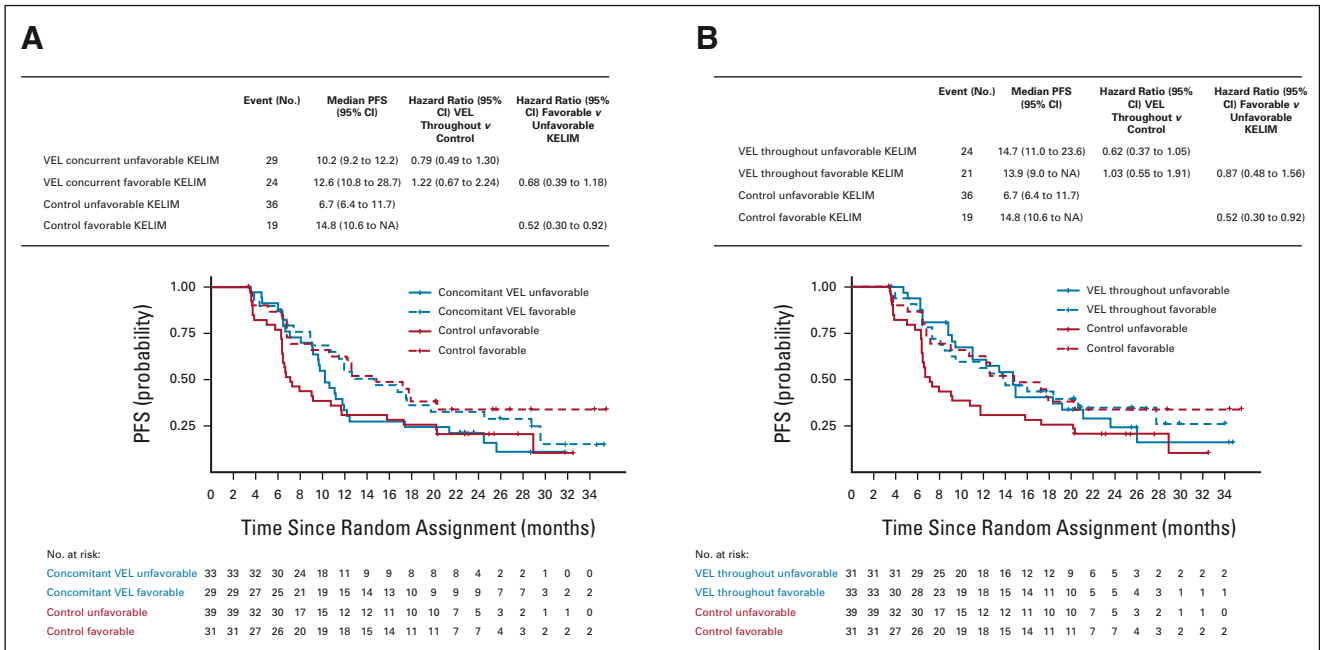

FIG 4. PFS according to KELIM (favorable or unfavorable) and treatment arms (VEL-throughout arm three v placebo [control] arms) in patients operated with PDS carrying tumors associated with (A) BRCA mutation or (B) BRCA wild-type HRD. HRD, homologous recombination deficiency; KELIM, elimination rate constant K; NA, not available; PDS, primary debulking surgery; PFS, progression-free survival; VEL, veliparib.

A

	Event (No.)	Median PFS (95% CI)	Hazard Ratio (95% CI) VEL Throughout v Control	Hazard Ratio (95% CI) Favorable v Unfavorable KELIM
VEL concurrent unfavorable KELIM	29	10.2 (9.2 to 12.2)	0.79 (0.49 to 1.30)	
VEL concurrent favorable KELIM	24	12.6 (10.8 to 28.7)	1.22 (0.67 to 2.24)	0.68 (0.39 to 1.18)
Control unfavorable KELIM	36	6.7 (6.4 to 11.7)		
Control favorable KELIM	19	14.8 (10.6 to NA)		0.52 (0.30 to 0.92)

Legend:
- Concomitant VEL unfavorable
- Concomitant VEL favorable
- Control unfavorable
- Control favorable

Y-axis: PFS (probability) — 1.00, 0.75, 0.50, 0.25
X-axis: Time Since Random Assignment (months) — 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34

No. at risk:
Concomitant VEL unfavorable	33	33	32	30	24	18	11	9	9	8	8	4	2	2	1	0	0	
Concomitant VEL favorable	29	29	27	25	21	19	15	14	13	10	9	9	7	7	3	2	2	
Control unfavorable	39	39	32	30	17	15	12	11	10	10	7	5	3	2	1	1	0	
Control favorable	31	31	27	26	20	19	18	15	14	11	11	7	7	4	3	2	2	

B

	Event (No.)	Median PFS (95% CI)	Hazard Ratio (95% CI) VEL Throughout v Control	Hazard Ratio (95% CI) Favorable v Unfavorable KELIM
VEL throughout unfavorable KELIM	24	14.7 (11.0 to 23.6)	0.62 (0.37 to 1.05)	
VEL throughout favorable KELIM	21	13.9 (9.0 to NA)	1.03 (0.55 to 1.91)	0.87 (0.48 to 1.56)
Control unfavorable KELIM	36	6.7 (6.4 to 11.7)		
Control favorable KELIM	19	14.8 (10.6 to NA)		0.52 (0.30 to 0.92)

Legend:
- VEL throughout unfavorable
- VEL throughout favorable
- Control unfavorable
- Control favorable

Y-axis: PFS (probability) — 1.00, 0.75, 0.50, 0.25
X-axis: Time Since Random Assignment (months) — 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34

No. at risk:
VEL throughout unfavorable	31	31	31	29	25	20	18	16	12	12	9	6	5	3	2	2	2	2
VEL throughout favorable	33	33	30	28	23	19	18	15	14	11	10	6	5	4	3	1	1	1
Control unfavorable	39	39	32	30	17	15	12	11	10	10	7	5	3	2	1	1	0	
Control favorable	31	31	27	26	20	19	18	15	14	11	11	7	7	4	3	2	2	

FIG 5. PFS according to KELIM (favorable or unfavorable) and treatment arms ([A] VEL-concurrent arm 2 v placebo [control] arm 1 and [B] VEL-throughout arm 3 v placebo [control] arm 1) in patients operated with PDS carrying tumors associated with HRP. HRP, homologous recombination proficiency; KELIM, elimination rate constant K; NA, not available; PDS, primary debulking surgery; PFS, progression-free survival; VEL, veliparib.

In the IDS cohort, the low numbers of patients in the *BRCA*-mutated and HRD cancer subgroups did not allow us to perform meaningful analyses.

DISCUSSION

To our knowledge, this is the first study to explore the role of the tumor primary chemosensitivity, assessed by the modeled CA-125 kinetic parameter KELIM, in PARPi efficacy in newly diagnosed advanced HGOC.

The data confirmed our previous findings about the prognostic role of KELIM in both PDS and IDS cohorts, regardless of treatment arms. Consistent with the role of KELIM as an indicator of chemosensitivity, we found that favorable KELIM was associated with higher likelihood of complete surgery in the IDS cohort, suggesting that it could be factored into algorithms designed to optimize the timing of IDS.

We also found that favorable KELIM was associated with veliparib benefit in patients with *BRCA* mutation or *BRCA* wild-type HRD cancer. These outcomes suggesting a higher benefit from veliparib in patients with platinum-sensitive diseases are consistent with the literature, as shown with other PARPis.[9-12] In contrast to SOLO-1, PAOLA-1, ATHENA, and PRIMA trials, where patients were selected on the basis of their platinum sensitivity, VELIA enrolled patients without prior assessment of their sensitivity to chemotherapy. The present study suggests that the PFS benefit from veliparib might have been higher if patients with HRD cancer had been selected for their

platinum sensitivity. For example, the PFS relative benefit in the veliparib-throughout arm compared with the placebo arm in patients carrying *BRCA* mutation and favorable KELIM (hazard ratio, 0.28; 95% CI, 0.13 to 0.61) appears to be higher than those reported in patients who were not selected on KELIM in VELIA trial (hazard ratio, 0.44; 95% CI, 0.28 to 0.68). Conversely, lower benefit from veliparib was found in patients carrying *BRCA* mutation or with HRD tumor characterized by unfavorable KELIM. The large majority of patients with *BRCA* mutation and unfavorable KELIM experienced short PFS < 18 months, confirming that HR status is not the only determinant of veliparib efficacy. It indirectly suggests the complementary predictive role of the tumor chemosensitivity in addition to HR status and justifies the selection of patients on the basis of their response to platinum-based chemotherapy in the other phase III trials.

In patients with HRP cancer, a favorable KELIM was not associated with a higher benefit from veliparib. However, some patients carrying HRP cancer characterized by poor chemosensitivity (unfavorable KELIM) might have derived a temporary nonsignificant PFS benefit from the addition of veliparib to chemotherapy (arm 2) and a more sustained PFS benefit from veliparib-throughout (arm 3), potentially as a result of a chemosensitizing effect of veliparib. This hypothesis needs to be explored.

There are several limitations in the present study that should be considered. As all analyses were performed retrospectively, these findings could conceivably be confounded by unaccounted biases. Moreover, subgroup analyses were

hindered by the low number of patients in each subgroup. For example, there were only 45 patients in the veliparib-throughout arm in the IDS cohort. Among them, a disproportionate of 31 (69%) patients were classified as having a favorable KELIM, whereas only 14 patients (31%) as unfavorable KELIM. If the *BRCA* mutation status of patients at the time of data collection had to be documented (mutated or wild-type), the differential *BRCA1* or *BRCA2* mutation status was not used for random assignment, thereby limiting the possibility of additional analyses.

Despite these limitations, the present exploratory study supports the concept that intrinsic chemosensitivity, assessed by KELIM, is a relevant complementary parameter to integrate with *BRCA* mutation status and HRD status for understanding the patient prognosis in the first-line setting and for identifying the patients who would receive maximum benefit from veliparib. For example, KELIM could be assessed in patients with the CA-125 values observed during the first three to four cycles of adjuvant/neoadjuvant chemotherapy, and veliparib would be associated with chemotherapy and then given as a maintenance treatment in patients with favorable KELIM and *BRCA* mutation or HRD cancer. Of note, KELIM of patients is easily calculable online (for both neoadjuvant chemotherapy[29] and adjuvant chemotherapy[30]). In addition, KELIM might be of interest for identifying the patients who are more likely to benefit from other PARPis. KELIM is being prospectively assessed in the phase III trial NIVARNA-1 comparing the efficacy of niraparib with/without bevacizumab in patients operated with complete PDS (ClinicalTrials.gov identifier: NCT05183984).

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AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

CA-125 KELIM as a Potential Complementary Tool for Predicting Veliparib Benefit: An Exploratory Analysis From the VELIA/GOG-3005 Study

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APPENDIX 1.

Structure of the Semimechanistic Model of Elimination Rate Constant K

Treatment kinetics were described by a two-compartment model: central compartment (C1) receiving chemotherapy dosing (doses set to 1) and a transit compartment (C2) to describe the treatment lag-time effect. The cancer antigen (CA)-125 production inhibition induced by the treatment is expressed by an indirect effect model using an E_{max} (E50) relationship

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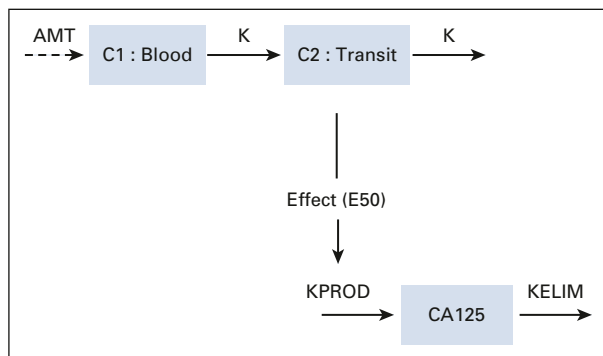
where K is the treatment kinetic rate constant ($days^{-1}$), KPROD is the CA-125 tumor production rate ($days^{-1}$), E50 is the concentration producing 50% of the maximum effect (AU), and elimination rate constant K (KELIM) is the CA-125 elimination rate ($days^{-1}$).

Association Between Veliparib Activity and KELIM, According to the Completeness of Surgery and Disease Progression Risk Group

In the primary debulking surgery cohort, as expected, complete surgery was associated with better progression-free survival outcomes compared with incomplete surgery. The positive discriminatory impact of a favorable KELIM regarding the benefit from veliparib was especially marked in patients operated with complete primary debulking surgery (favorable KELIM: 34.7 in the veliparib-throughout arm v 32.9 months in the standard arm; hazard ratio, 0.83; 95% CI, 0.46 to 1.46; unfavorable KELIM: 19.5 months in the veliparib-throughout arm v 23.3 months in the standard arm; hazard ratio, 1.23; 95% CI, 0.76 to 2.00; Data Supplement). The same analyses were performed in the interval debulking surgery cohort, but the low number of patients reduced the power of the analyses. Nevertheless, a trend for higher benefit with veliparib was observed only among patients with favorable KELIM (Data Supplement).

Similar outcomes were found when patients were categorized according to the disease risk groups, with a trend for higher benefit from veliparib among patients with favorable KELIM compared with those with unfavorable KELIM (Data Supplement).

TABLE A1. Parameter Estimates From the Final Semimechanistic Model

n = 854	Estimate	RSE[a] on Estimate, %	IIV[b], % CV	Shrinkage[c], %
K, d^{-1}	0.9230	25.00	13.34	99.8
KPROD, $IU \cdot mL^{-1} \cdot d^{-1}$	0.0547	3.93	16.70	86.8
E50, AU	0.5730	31.40	15.65	99.8
KELIM, D^{-1} (covariate = 0)	0.0235	1.61	29.24	23.6
KELIM, D^{-1} (covariate = 1)	0.0167	2.99	29.24	23.6
CA_0, $IU \cdot mL^{-1}$	4.9400	3.75	38.85	71.5

NOTE. RSE was computed using boostrapping of 500 samples. Covariate: 0 = primary debulking surgery; 1 = interval debulking surgery. CA_0 = estimated CA-125 basal concentration.

Abbreviations: CA, cancer antigen; CV, coefficient of variation; IIV, interindividual coefficient of variation; KELIM, elimination rate constant K; KPROD, modeled CA-125 production rate constant K; RSE, relative standard error.

[a]RSE calculated as (SE/estimated parameter) × 100.

[b]IIV calculated as square root (variance of random effect) × 100.

[c]Percentage on the standard deviation scale.