Association of Polymerase ε–Mutated and Microsatellite-Instable Endometrial Cancers With Neoantigen Load, Number of Tumor-Infiltrating Lymphocytes, and Expression of PD-1 and PD-L1

The Harvard community has made this article openly available. Please share how this access benefits you. Your story matters.

Citation

Published Version
doi:10.1001/jamaoncol.2015.2151

Citable link
http://nrs.harvard.edu/urn-3:HUL.InstRepos:32705577

Terms of Use
This article was downloaded from Harvard University’s DASH repository, and is made available under the terms and conditions applicable to Other Posted Material, as set forth at http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#LAA
Association of Polymerase e–Mutated and Microsatellite-Instable Endometrial Cancers With Neoantigen Load, Number of Tumor-Infiltrating Lymphocytes, and Expression of PD-1 and PD-L1

Brooke E. Howitt, MD; Sachet A. Shukla, PhD; Lynette M. Sholl, MD; Lauren L. Ritterhouse, MD; Jaclyn C. Watkins, MD; Scott Rodig, MD, PhD; Elizabeth Stover, MD, PhD; Kyle C. Strickland, MD, PhD; Alan D. D’Andrea, MD; Catherine J. Wu, MD; Ursula A. Matulonis, MD; Panagiotis A. Konstantinopoulos, MD, PhD

The Cancer Genome Atlas project identified 2 groups of endometrioid endometrial cancers (ECs) with high mutation frequency: an ultramutated group (7% of all tumors) that harbored mutations in the exonuclease domain of polymerase e (POLE), and a hypermutated group (28% of tumors) with microsatellite instability (MSI), the majority of which harbored MLH1 promoter methylation. The predicted median (range) neoantigen load (predicted neoepitopes per sample) was proportional to the mutational load: highest in ultramutated polymerase e (POLE) tumors (8342 [628-20,440]), less in hypermutated MSI (541 [146-8063]; $P < .001$), and lowest in microsatellite-stable tumors (70.5 [7-1877]; $P < .001$). The POLE and MSI ECs exhibited higher numbers of CD3+ (44.5 vs 21.8; $P = .001$) and CD8+ (32.8 vs 13.5; $P < .001$) TILs compared with microsatellite-stable tumors. PD-1 was overexpressed in TILs (81% vs 28%; $P < .001$) and peritumoral lymphocytes (90% vs 28%; $P < .001$) of POLE and MSI tumors. PD-L1 expression was infrequently noted in tumor cells but was common in intraepithelial immune cells and more frequent in POLE and MSI tumors (39% vs 13%; $P = .02$).

CONCLUSIONS AND RELEVANCE
Polymerase e–mutated and MSI ECs are associated with high neoantigen loads and number of TILs, which is counterbalanced by overexpression of PD-1 and PD-L1. Polymerase e–mutated and MSI EC tumors may be excellent candidates for PD-1-targeted immunotherapies.

IMPORTANTCE
Immune checkpoint inhibitor therapy has shown benefit in various cancers, but their potential in endometrial cancer (EC) is unknown.

OBSERVATIONS
Prediction of neoantigen load was performed using sequencing data from the Cancer Genome Atlas data set. Evaluation of tumor-infiltrating lymphocytes (TILs) and PD-1 and PD-L1 expression was performed in 63 patients with EC referred to our institution. The predicted median (range) neoantigen load (predicted neoepitopes per sample) was proportional to the mutational load: highest in ultramutated polymerase e (POLE) tumors (8342 [628-20,440]), less in hypermutated MSI (541 [146-8063]; $P < .001$), and lowest in microsatellite-stable tumors (70.5 [7-1877]; $P < .001$). The POLE and MSI ECs exhibited higher numbers of CD3+ (44.5 vs 21.8; $P = .001$) and CD8+ (32.8 vs 13.5; $P < .001$) TILs compared with microsatellite-stable tumors. PD-1 was overexpressed in TILs (81% vs 28%; $P < .001$) and peritumoral lymphocytes (90% vs 28%; $P < .001$) of POLE and MSI tumors. PD-L1 expression was infrequently noted in tumor cells but was common in intraepithelial immune cells and more frequent in POLE and MSI tumors (39% vs 13%; $P = .02$).

CONCLUSIONS AND RELEVANCE
Polymerase e–mutated and MSI ECs are associated with high neoantigen loads and number of TILs, which is counterbalanced by overexpression of PD-1 and PD-L1. Polymerase e–mutated and MSI EC tumors may be excellent candidates for PD-1-targeted immunotherapies.
Table. Clinical and Pathologic Characteristics of the Study Cohort

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>MSI and POLE Mutated (n = 31)</th>
<th>MSS (n = 32)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient age, mean (range), y</td>
<td>62 (38-87)</td>
<td>62 (27-87)</td>
</tr>
<tr>
<td>Patient race, No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>25 (81)</td>
<td>20 (63)</td>
</tr>
<tr>
<td>Black</td>
<td>3 (10)</td>
<td>0</td>
</tr>
<tr>
<td>Hispanic</td>
<td>1 (3)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Asian</td>
<td>0</td>
<td>1 (3)</td>
</tr>
<tr>
<td>No data</td>
<td>2 (6)</td>
<td>10 (31)</td>
</tr>
<tr>
<td>Tumor histotype and grade, No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endometrioid grade 1</td>
<td>16 (52)</td>
<td>28 (88)</td>
</tr>
<tr>
<td>Endometrioid grade 2</td>
<td>8 (26)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Endometrioid grade 3</td>
<td>6 (19)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (3)a</td>
<td>2 (6)a</td>
</tr>
<tr>
<td>Lymphovascular invasion, No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>6 (19)</td>
<td>4 (12)</td>
</tr>
<tr>
<td>Absent</td>
<td>25 (81)</td>
<td>28 (88)</td>
</tr>
<tr>
<td>Depth of invasion, No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No myoinvasion</td>
<td>9 (29)</td>
<td>11 (34)</td>
</tr>
<tr>
<td>&lt;50% myometrial thickness</td>
<td>15 (48)</td>
<td>12 (38)</td>
</tr>
<tr>
<td>≥50% myometrial thickness</td>
<td>7 (23)</td>
<td>9 (28)</td>
</tr>
<tr>
<td>FIGO stage, No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A</td>
<td>25 (81)</td>
<td>23 (72)</td>
</tr>
<tr>
<td>1B</td>
<td>5 (16)</td>
<td>5 (16)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>2 (6)</td>
</tr>
<tr>
<td>3-4</td>
<td>1 (3)</td>
<td>2 (6)</td>
</tr>
</tbody>
</table>

Abbreviations: FIGO, Fédération Internationale de Gynécologie et d’Obstétrique; MSI, microsatellite instable; MSS, microsatellite stable; POLE, polymerase e.

* Biphasic grade 1/3.

**Serous.

Tumor Samples
This study included 63 cases (Table) retrieved from the archives of Brigham and Women's Hospital under an institutional review board-approved protocol; a waiver of consent was granted due to the retrospective nature of the study. The POLE-mutated cases were identified by means of Sanger sequencing of 2 mutational hot spots (exons 9 and 13). Microsatellite instability status was determined using mismatch DNA repair immunohistochemical analysis (eTable 1 in the Supplement).

Immunohistochemical Analysis and Evaluation of Tumor-Associated Lymphocytes
Immunohistochemical analysis was performed for CD3, CD4, CD8, CD20, PD-1, and PD-L1 on formalin-fixed paraffin-embedded tissue samples using standard protocols (eMethods in the Supplement).

Statistical Analyses
Staining results were compared using the t test (all P values were 2 sided), as well as the Fisher exact test.

At a Glance
- Objective was to assess whether hypermutated polymerase e (POLE) and microsatellite instable (MSI) endometrial cancers (ECs) harbor more neoantigens and tumor-infiltrating lymphocytes (TILs) than the comparatively hypomutated microsatellite-stable ECs.
- The POLE-mutated tumors had an almost 15-fold higher median number of predicted neoepitopes per sample compared with MSI tumors (P < .001) and MSI tumors almost 7-fold higher compared with microsatellite-stable (MSS) tumors (P < .001).
- The POLE and MSI tumors exhibited a statistically significantly higher number of CD3+ (P = .001) and CD8+ TILs (P < .001) compared with MSS tumors but no difference in CD4+ or CD20+ TILs.
- PD-L1 was overexpressed in TILs and peritumoral lymphocytes of POLE and MSI tumors.
- PD-L1 expression was infrequent in tumor cells but common in intraepithelial immune cells and more frequent in POLE and MSI tumors.

Results

Neoantigen Load of POLE, MSI, and MSS ECs
We accessed whole-exome sequencing data from the 17 POLE-mutated, 65 MSI, and 90 MSS ECs included in the Cancer Genome Atlas EC data set. We performed HLA typing using POLYSOLVER, which was recently reported to infer HLA alleles with 97% accuracy and with a 100% rate of homozygous locus inference calls based on a validation set of 253 HapMap samples. Of these EC cases, 43% (74 of 172) were found to be HLA-A2 positive. Taking into account the 8 most frequent class I major histocompatibility complex (MHC) alleles in whites (ie, A*02:01, C*07:01, A*01:01, A*03:01, C*07:02, C*04:01, B*07:02, C*06:02), 151 of 172 (88%) subjects had at least 1 of these alleles. The neoantigen load for each sample was determined using a pipeline based on the NetMHCpan tool9 (version 2.4) that predicts MHC class I binding peptides. For each mutation capable of generating a potential neoantigen (missense and readthrough mutations, as well as in- and out-of-frame insertions and deletions in the coding sequence), binding affinities were predicted for all possible mutation-bearing 9- and 10-mer peptides in the immediate vicinity of the somatic change site. The total number of peptides predicted to have at least a weak binding (<500 nM) with any of the sample’s inferred HLA alleles was determined using mismatch DNA repair immunohistochemical analysis (eTable 1 in the Supplement).

Tumor-Associated Lymphocytes in POLE, MSI, and MSS ECs
Three POLE-mutated (P286R), 28 MSI, and 32 MSS primary ECs from previously untreated patients were evaluated (Table).
POLE and MSI tumors were grouped together as the hypermutated group compared with the hypomutated MSS cancers. The POLE and MSI tumors exhibited a statistically significantly higher mean number of CD3+(44.5 vs 21.8; \( P = .001 \)) and CD8+ TILs(32.8 vs 13.5; \( P < .001 \)) compared with MSS tumors (Figures 1B, 1C, and 1D) but no difference in CD4+ or CD20+ TILs. Furthermore, we did not detect differences in CD3+ (44.1 vs 47.3; \( P = .86 \)) and CD8+ (48.0 vs 31.2; \( P = .29 \)) TILs between POLE and MSI tumors, respectively. Finally, we observed a statistically significantly higher incidence of presence (ie, 1+, 2+, 3+ staining) of peritumoral CD3+ T cells in the stroma surrounding the epithelial component of POLE and MSI tumors compared with MSS tumors (77% of POLE and MSI vs 34% of MSS tumors, respectively; \( P < .001 \)) (eFigure 1 in the Supplement).

PD-1 and PD-L1 Expression in POLE, MSI, and MSS ECs

Expression of PD-1 in intraepithelial and peritumoral lymphocytes (presence vs total absence) was significantly more frequent in POLE and MSI compared with MSS ECs (\( P < .001 \) in both cases) (Figure 2A). PD-L1 expression (presence vs total absence) in intraepithelial immune cells was significantly more frequent in POLE and MSI compared with MSS tumors (\( P = .02 \)) (Figure 2B). PD-L1 expression in at least 10% of peritumoral immune cells was also more frequent in POLE and MSI tumors (84% vs 56%, \( P = .03 \)). However, PD-L1 expression in tumor cells was not different between POLE and MSI and MSS tumors (Figure 2B); PD-L1 expression in tumor cells followed 3 patterns (Figure 2C): a nonspecific blush pattern consistent with negative PD-L1 expression (83% of cases), focal membranous positivity (15% of the cases), and extensive membranous positivity (seen in 1 POLE tumor).

Discussion

To our knowledge, we report for the first time that POLE and MSI ECs are associated with significantly increased predicted neoepitopes and numbers of CD3+ and CD8+ TILs compared with MSS tumors. These observations support the hypothesis that hypermutated tumors also harbor higher neoantigen loads and are associated with increased tumor infiltration by cytotoxic T lymphocytes. PD-1 and PD-L1 were also significantly overexpressed in TILs and peritumoral lymphocytes of POLE and MSI compared with MSS ECs.
Unlike melanoma, renal cell, and lung cancer,\textsuperscript{10} we noted infrequent expression of PD-L1 in tumor cells (with the notable exception of 1 POLE tumor). Instead, PD-L1 expression was noted in intraepithelial immune cells and was significantly more frequent in POLE and MSI tumors. Of note, response to anti-PD-L1 antibody MPDL3280A has been shown to correlate with expression of PD-L1 in tumor-infiltrating immune cells but not in tumor cells.\textsuperscript{11} Collectively, our findings suggest that POLE and MSI tumors may be excellent candidates for immunotherapies targeting the PD-1 pathway. Of note, there are no prior studies of immunotherapy performed specifically for patients with EC but there is 1 ongoing clinical trial of the PD-1 antibody nivolumab in all MSI cancers (NCT01876511).

We acknowledge that the number of POLE-mutated cases included in our study was small. However, all POLE cases exhibited consistent results with increased number of TILs and PD-1 and PD-L1 overexpression. It is possible that POLE-mutated tumors may harbor more CD8+ TILs, which would be consistent with their higher neoantigen load. However, to formally test this hypothesis, a large number of POLE and MSI cases would be required given that both exhibit high numbers of TILs.

Conclusions

Our findings are in keeping with the hypothesis that high mutational loads are associated with high neoantigen loads and an elevated number of TILs, which is counterbalanced by overexpression of immune checkpoints.\textsuperscript{3,12,13} Besides PD-1 and PD-L1, other immune checkpoints such as CTLA-4, LAG-3, and IDO may also be upregulated in POLE and MSI ECs.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

REFERENCES


Drafting of the manuscript: Howitt, Shukla, Wu, Konstantinopoulos.
Critical revision of the manuscript for important intellectual content: Howitt, Sholl, Ritterhouse, Watkins, Rodig, Stover, Strickland, D'Andrea, Matulonis, Konstantinopoulos.
Statistical analysis: Shukla, Wu, Konstantinopoulos.
Obtained funding: D'Andrea, Konstantinopoulos.
Administrative, technical, or material support: Howitt, Ritterhouse, Watkins, Rodig, Strickland, Matulonis, Konstantinopoulos.
Study supervision: Howitt, Wu, Konstantinopoulos.
Conflict of Interest Disclosures: Dr Sholl has served as a member of the scientific advisory board for Genentech. Dr Rodig has received research funding from Bristol-Myers Squibb and Roche-ventana. No other disclosures are reported.
Funding/Support: Dr Wu acknowledges support from the Blavatnik Family Foundation and National Institutes of Health/National Cancer Institute (R01CA155010-04) for management and analysis of this study. Dr Konstantinopoulos acknowledges support from the Susan Smith Center for Women's Cancers and the Department of Defense Ovarian Cancer Academy Award W81XWH-10-1-0585 for management and analysis of this study. This work was supported, in part, by the Center for Immunology at the Dana-Farber Cancer Institute.


---

**CORRECTION**

**Data Errors in Table:** In the Original Investigation titled "Risk Adjusting Survival Outcomes in Hospitals That Treat Patients With Cancer Without Information on Cancer Stage," published online October 8, 2015, erroneous κ values were reported in 8 of the 12 categories of Table 2. The correct values also exceed the thresholds for high levels of agreement and thus do not alter the article’s conclusions. For 3- and 5-year mortality in the specified cancer types, the correct respective κ values are as follows: lung/bronchus, 0.84 and 0.84; prostate, 0.93 and 0.91; breast, 0.94 and 0.92; and colorectal, 0.89 and 0.90. This article was corrected online.