Research Article

Programmed Cell Death Ligand 1 Expression in Osteosarcoma

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Abstract

Programmed cell death ligand 1 (PDL1, also known as B7H1) is a cell-surface protein that suppresses the cytotoxic CD8+ T-cell-mediated immune response. PDL1 expression and its clinical relevance in sarcomas are not well understood. Therefore, we sought to measure RNA expression levels for PDL1 in 38 clinically annotated osteosarcoma tumor samples and aimed to determine if PDL1 expression correlates with clinical features and tumor-infiltrating lymphocytes (TIL). Quantitative real-time RT-PCR for PDL1 was optimized in 18 cell lines, of which 5 were osteosarcoma derived. qRT-PCR results were validated via flow cytometry and immunohistochemistry (IHC) in select cell lines. Total RNA was isolated from 38 human osteosarcoma samples for qRT-PCR analysis. Clinical data were sorted, and significance was determined by the Student t test. TILs were examined in patient samples by tissue microarray hematoxylin–eosin staining. We confirmed the constitutive PDL1 mRNA expression in cell lines by qRT-PCR, flow cytometry, and IHC. Across human osteosarcoma samples, PDL1 mRNA gene expression ranged over 4 log (>5,000-fold difference). Relative expression levels were evaluated against clinical factors such as age/gender, metastasis, recurrence, chemotherapy, percentage of necrosis, and survival; no significant associations were identified. The presence of TILs was associated with high PDL1 expression \( R^2 = 0.37; P = 0.01 \). In summary, we developed an RNA-based assay to determine PDL1 expression levels, and we show, for the first time, that high levels of PDL1 are expressed in a subset of osteosarcoma, and PDL1 expression is positively correlated with TILs. Multiple agents targeting PD1/PDL1 are in clinical development, and this may be a novel immunotherapeutic strategy for osteosarcoma clinical trials. Cancer Immunol Res 2(7): 690–8. ©2014 AACR.

Introduction

Osteosarcoma is an aggressive malignant tumor of the bone thought to arise from mesenchymal stem cells (1). Though it is a rare tumor, osteosarcoma is the most common primary malignancy of the bone and the eighth most common form of childhood cancer (2, 3). With modern multimodality therapies, the 5-year survival rate has increased to 70% (4). However, progress has slowed over the past 30 years, and efforts to improve outcomes with intensifying regimens or adding novel agents have brought disappointing results (5–9). Moreover, for patients with metastatic osteosarcoma at diagnosis and for those with relapsed disease, outcomes are remarkably poor with 4- to 5-year overall survival rate at less than 20% (10, 11). Therefore, development of novel therapeutic strategies is critical for this patient population.

There is growing interest in the oncology community in the immunoregulatory receptor PD1 and the corresponding B7 family of ligands as a potential mechanism of tumor immune tolerance and escape. In the normal physiologic state, a T-cell response is a complex sequence of events involving clonal T-cell selection, activation, proliferation, and trafficking to antigen sites to ultimately deliver immune effector functions (12). This is initiated through the T-cell receptor followed by a series of highly regulated signals to either stimulate or inhibit the T-cell response. These inhibitory signals are critical to maintaining self-tolerance and protecting neighboring tissues during the immune response (12). PD1 is a cell-surface receptor expressed on subsets of T and B lymphocytes, as well as other immune cells. In the inflammatory microenvironment, stimuli such as IFNγ (13–15) may upregulate programmed cell death ligand 1 (PDL1) expression in peripheral tissues and immune cells to suppress the immune response.

Interestingly, many different malignancies can co-opt this checkpoint system by upregulating PDL1 constitutively or in response to inflammation. Examples include melanoma, lung cancer, renal cell carcinoma, ovarian cancer, and colorectal

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samples. Given the clinical activity of anti-PD1/PDL1 therapies across a range of tumor histologies, these data may have predictive value across a range of malignancy subtypes, including non–small cell lung cancer (NSCLC), a histology not typically associated with immune responses. In these previously heavily treated patients, the response rates ranged from 18% to 28%, depending on the tumor histology, and importantly the responses were durable.

At the moment, no clear biomarker exists to predict anti-PD1/PDL1 tumor responsiveness. Recent data suggest that PDL1 expression, determined by immunohistochemistry (IHC), may be an important biomarker (14, 23–26) perhaps also when combined with T-cell activation signals (17, 27, 28). Despite these results, diagnostics for PDL1 are limited by the lack of reliable protein-based assays, and the literature remains controversial. Previous studies have shown a correlation between PDL1 mRNA and protein expression (29, 30). To this end, we sought to develop an RNA-based PDL1 assay to circumvent the technical issues constraining the IHC-based strategies.

In summary, we have developed an RNA-based assay to detect PDL1 expression levels, which we used to demonstrate the expression of PDL1 in 32 of 38 human osteosarcoma tumor samples. Given the clinical activity of anti-PD1/PDL1–based therapies across a range of tumor histologies, these data may lead to a promising target for novel immunotherapy strategies.

Materials and Methods

Institutional Review Board approval was obtained to study all osteosarcoma samples from the Partners Human Research Office (2007P-002464). Written informed consent was obtained from all patients whose specimens and clinical information were used for this research study.

Osteosarcoma Patient Surgical Specimens

The study consisted of 38 fresh-frozen tumor tissue samples of histologically confirmed osteosarcomas from 37 patients (15 female and 22 male) with an age range of 6 to 75 (median 29) years. Nine samples were from biopsy, 13 from primary tumor, 14 from metastases, and 2 from recurrent tumors. Two samples, P516 and P661 (clinical data are presented in Table 1), were metastases from the same patient, and therefore P661 was excluded from statistical analyses. Fourteen of 37 patients were treated with preoperative chemotherapy. Twenty-six patients died, with a median survival of 36 months (range, 1–200 months).

Cell Lines, Cell Culture, and Antibodies

The human osteoblast cell line HOB-c was purchased from PromoCell GmbH, the human osteoblast cell line NHO52 from ATCC, and the human osteoblast cell line hFOB from Lonza Walkersville, Inc. The human stem cell line MCS was obtained from Invitrogen. Two human muscle cell RNAs were purchased from Ambion and Stratagene. The human osteosarcoma cell line SaOS was obtained from ATCC. The multidrug-resistant human osteosarcoma cell line U-20ST R was established in our laboratory from human osteosarcoma cell line U-20S, also purchased from ATCC. U-20ST R was selected from U-20S by stepwise increases in paclitaxel concentrations from 0.0001 to 0.1 μmol/L. The human osteosarcoma cell lines KHO S and KHOSR2 were provided by Dr. Ef stathios Donohue (Institute of Biological Research and Biotechnology, Athens, Greece). The human chondrosarcoma cell line Cs-1 was established in our laboratory from a surgically resected human high-grade chondrosarcoma removed from a 62-year-old male with metastatic chondrosarcoma. The human Ewing sarcoma TC-7 and the trabeccdinin-resistant TC-ET cell lines were donated by Dr. Katia Scand lini (Rizzoli Orthopaedic Institute, Bologna, Italy). The human ovarian cancer cell line SKOV3 was purchased from ATCC; the human ovarian cancer cell lines A2780 and OVCARB were obtained from Dr. Thomas Hamilton (Fox Chase Cancer Center, Philadelphia, PA) and from Dr. Patricia Donahue (Massachusetts General Hospital, Boston, MA), respectively. Cell lines were grown in DMEM (Invitrogen) supplemented with 10% FBS, 100 U/mL penicillin, and 100 μg/mL streptomycin (Invitrogen). All cell lines were tested and validated to be mycoplasma-free. No other authentications were performed. U-20S cells were treated with IFNγ, as previously described (31). Briefly, 3 × 10⁵ cells were incubated at 37°C for 48 hours in 8 mL medium supplemented with 100 U/mL IFNγ.

To detect PDL1 by flow cytometry and IHC, six antibodies were screened: four noncommercial mouse mAbs (CST1, CST2, XW, and LC), a mouse mAb from ebioscience (clone MIH1), and a rabbit polyclonal from ProSci (cat. no. 4059).

Quantitative Real-Time RT-PCR

To determine the expression of PDL1 mRNA in cell lines (n = 18) and osteosarcoma surgical specimens (n = 38), total RNA was extracted using TRIzol Reagent (Life Technologies) according to the manufacturer’s protocol. RNA samples were quantified using the ultraviolet spectrophotometer at 260 nm (Beckman DU-640; Beckman Instruments). Equal amounts of RNA were reverse transcribed using a High-Capacity cDNA Reverse Transcription Kit (Applied Biosystems). cDNAs were then amplified by real-time PCR using TaqMan gene expression assays (Applied Biosystems) for PDL1 (product ID Hs01125301_m1; probe sequence: 5'-ggtatatacattggaggagagatccagctactgatcttcagcagggatttcacactgtgggtgtagggtagctcg-3') and according to the manufacturer’s protocol. PCR was performed with TaqMan gene expression master mix (Applied Biosystems) using 2 μL of cDNA in a 20-μL final reaction volume. The amplification cycles were performed by the Applied Biosystems StepOne-Plus System (Applied Biosystems) as follows: 50°C for 2 minutes, 95°C for 10 minutes, followed by 40 cycles of 95°C for 15 seconds, and finally 60°C for 1 minute. The housekeeping gene β-actin (product ID Hs01060665_g1; probe sequence: 5'– ggtgagtttgaggttggctctgtagggcagaggctgatgctggggag-3') expression level was used as an internal control to evaluate the integrity of each sample. The
relative expression level of mRNA of PDL1 was calculated as follows: 2(\text{threshold cycle of } b\text{-actin} – \text{threshold cycle of PDL1}). Relative expression was scored on a log10 scale (0–4).

**Flow cytometry**

Selected cell lines were examined by flow cytometry to validate a correlation of PDL1 mRNA and protein expression. MCF7 and SKOV3 cells were collected in 1 mmol/L EDTA/PBS and then washed with PBS. Cells (2 × 10^5) of each were blocked in 2% BSA/PBS for 30 minutes at 4°C. The cells were then probed with 1 μg of the primary antibody (eBioscience, XW, or Prosci) for 30 minutes at 4°C, washed, and then incubated at 1:100 with the secondary antibody (R-Phycocerythrin-AffiniPure F(ab′)2 Frag Goat Anti-Mouse IgG, Fcγ Fc constant fragment-specific (min X Hu, Bov, Hrs Sr Prot), Jackson Immunoresearch; or Alexa Fluor 488 Goat Anti-Rabbit IgG (H+L) Antibody, Invitrogen). After washing and fixation in 2% PFA/PBS, cells were sorted using the BD FACSCalibur flow cytometer.

**Table 1. Clinical data of RNA samples from osteosarcoma tissues**

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<tr>
<th>Sample</th>
<th>Age at diagnosis (median = 29)</th>
<th>Gender (female = 15; male = 23)</th>
<th>Preoperative chemotherapy</th>
<th>Percentage of necrosis</th>
<th>Metastasis, origin (lung = 22; other = 8)</th>
<th>Local relapse</th>
<th>Disease status</th>
<th>Follow-up (months; median = 36)</th>
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<td>Yes</td>
<td>Yes</td>
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Abbreviations: AWED, alive with evidence of disease; DOD, dead of disease; n/a, not available; NED, no evidence of disease. aNo TIL data. Note that P516 and P661 are metastatic tumors from the same patient.
Tissue microarray construction

Representative areas of 100 paraffin-embedded osteosarcoma tumor specimens for each case were selected and prepared as previously described (32). Briefly, three areas of tumor parts per case were selected for assembling the recipient master block to ensure accurate representation of the selected cores. Each target area on the selected block was punched to form a 0.5-mm diameter tissue core and was placed consecutively on the recipient master block. The osteosarcoma tissue microarray (TMA) was constructed by the Tissue Microarray and Imaging Core at the Dana-Farber/Harvard Cancer Center (http://genepath.med.harvard.edu:8080/pathcore/).

PDL1 detection by IHC

TMA slides were stained using the Cell and Tissue Staining Kit (R&D Systems) with slight modifications. Briefly, slides were dewaxed and rehydrated in xylene and graded ethanol solutions for antigen retrieval. Slides were then blocked with 3% H2O2, goat serum, avidin solution, and biotin solution. Primary antibody (eBioscience; CST1, CST2, and LC) was added and then probed with biotinylated goat anti-mouse secondary antibody (Vector Laboratories) and high-sensitivity streptavidin–HRP conjugate. To visualize staining, slides were incubated in 3,3′-diaminobenzidine in 0.1% H2O2 in Tris–HCl buffer, and subsequently counterstained with Hematoxylin QS (Vector Laboratories). PDL1-positive samples were defined as

Figure 1. PDL1 expression in cancer and noncancer cell lines. A, relative expression of PDL1 from total RNA isolated from cell lines. B, representative PDL1 protein expression levels in corresponding high- and low-expressing cell lines by IHC. C, representative PDL1 protein expression levels in corresponding high- and low-expressing cell lines by flow cytometry.
those showing membrane and cytoplasmic staining pattern of tumor tissue. PD-L1 staining intensity was graded into four groups: no staining (0), weak staining (1+), moderate staining (2+), and intense staining (3+). The immunostained slide was evaluated under the microscope. The staining intensity of cells showing positive membrane and cytoplasmic staining for PD-L1 was calculated by reviewing the entire spot.

**Detection of immune infiltrates**

The tumor-infiltrating lymphocytes (TIL) were examined on a hematoxylin and eosin–stained osteosarcoma TMA slide. TMA was evaluated for the presence of TILs at ×400 magnification and scored semiquantitatively as follows: score 0, no TILs; 1, rare/few TILs; 2, brisk/prominent TILs.

**Statistical analysis**

Statistical analysis was done using GraphPad Prism 4 software. The 75th percentile was used as cutoff for high or low PD-L1 mRNA expression, as previous studies have suggested that high-expression patients represented approximately 25% in other cancers (33, 34). For comparison between PD-L1 expression and clinical and pathologic variables, a two-sided Student t test was used. The overall cancer-specific follow-up time was calculated in months from the date of surgery to the date of death due to osteosarcoma or the last follow-up date. Survival analysis was performed using the Kaplan–Meier method, and significance was determined by the log-rank test. For comparison between PD-L1 expression and immune infiltrates, a one-way ANOVA analysis was used. A P value of <0.05 was considered as statistically significant.

**Results**

**PD-L1 expression in cell lines**

PD-L1 gene expression was quantitatively confirmed in all 18 cell lines. Absolute PD-L1 expression was normalized to that of the housekeeping gene β-actin. Breast cancer cell line MCF7 has been shown previously to have relatively low PD-L1 expression (35). Drug-resistant osteosarcoma cell line KHOSR2 and virally derived osteoblast cell line hFOB had high (3 log) PD-L1 gene expression, and osteosarcoma cell line SaOS and breast cancer cell line MCF7 had low (<1 log) expression. Other cell lines, including stem cell (MCs), osteoblast (Obs; NHOS2), ovarian cancer (SKOV3, OVCAR8, and A2780), Ewing sarcoma (TC-7 and TC-ET), chondrosarcoma (Cs-1), and osteosarcoma (U-2OS, U-2OSTR, and KHOS), ranged from intermediate (1 log) to high (2 log) expression of PD-L1 (Fig. 1A). Each tumor cell type generally demonstrated varying PD-L1 expression. In nonmalignant cell lines such as muscle, stem cells, and osteoblasts, PD-L1 gene expression ranged from moderate to high. Osteosarcoma cell lines ranged from low to high PD-L1 expression, with slightly higher expression from drug-resistant variants (KHOSR2 and U-2OSTR) than their parental cell lines (KHOS and U-2OS). Ewing sarcoma cell lines expressed moderate levels of PD-L1, and ovarian cancer cell lines demonstrated moderate PD-L1 expression as well. The one chondrosarcoma cell line showed high PD-L1 levels, and one breast cancer cell line exhibited low PD-L1 expression; however, conclusions on the expression of PD-L1 on these two tumor types cannot be drawn from one cell line. PD-L1 gene expression was induced 5-fold by IFNγ treatment in osteosarcoma cell line U-2OS (data not shown).

To validate the RT-PCR data, IHC and flow cytometry assays were performed on selected cell lines. Consistent with the RT-PCR data, there was low-level staining in the negative control MCF7 cells and intense staining in the positive control KHOSR2 cells by IHC using mouse mAb LC (Fig. 1B). This staining was both membranous and cytoplasmic. Flow cytometry of negative control MCF7 and positive control SKOV3 cells using the eBioscience clone MIH1 also showed consistent patterns of expression between RNA and protein (Fig. 1C). Unfortunately, the ProSci rabbit polyclonal failed to detect PD-L1 on the positive control cell line SKOV3, and the XW mouse mAb exhibited unspecific binding on the negative control cell line MCF7 (Supplementary Fig. S1). Although the eBioscience mouse mAb demonstrated the expected results by flow cytometry, it produced weak staining by IHC TMA. The CST1, CST2, and LC antibodies also failed to show sufficient specificity for PD-L1 by IHC TMA.

**PD-L1 expression in osteosarcoma tumor tissue**

The PD-L1 RT-PCR assay was performed on total RNA isolated from 38 osteosarcoma human tumor samples (Fig. 2). Absolute expression was normalized to that of housekeeping gene expression, and osteosarcoma cell line SaOS and breast cancer cell line MCF7 had low (<1 log) expression. Other cell lines, including stem cell (MCs), osteoblast (Obs; NHOS2), ovarian cancer (SKOV3, OVCAR8, and A2780), Ewing sarcoma (TC-7 and TC-ET), chondrosarcoma (Cs-1), and osteosarcoma (U-2OS, U-2OSTR, and KHOS), ranged from intermediate (1 log) to high (2 log) expression of PD-L1 (Fig. 1A). Each tumor cell type generally demonstrated varying PD-L1 expression. In nonmalignant cell lines such as muscle, stem cells, and osteoblasts, PD-L1 gene expression ranged from moderate to high. Osteosarcoma cell lines ranged from low to high PD-L1 expression, with slightly higher expression from drug-resistant variants (KHOSR2 and U-2OSTR) than their parental cell lines (KHOS and U-2OS). Ewing sarcoma cell lines expressed moderate levels of PD-L1, and ovarian cancer cell lines demonstrated moderate PD-L1 expression as well. The one chondrosarcoma cell line showed high PD-L1 levels, and one breast cancer cell line exhibited low PD-L1 expression; however, conclusions on the expression of PD-L1 on these two tumor types cannot be drawn from one cell line. PD-L1 gene expression was induced 5-fold by IFNγ treatment in osteosarcoma cell line U-2OS (data not shown).

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gene β-actin and categorized by log-transcript detection: low, 1 log; intermediate, 2 log; and high, 3 and 4 log. We found 9 samples with high-level expression (24%). There were 19 samples (50.0%) with intermediate expression, 4 (10.5%) with low-level expression, and 6 (15.8%) were negative.

**Prognostic value of PDL1 expression**

We evaluated the clinicopathologic features of the human tumor samples and found no significant relationship between PDL1 gene expression and age at surgery, gender, neoadjuvant chemotherapy treatment, percentage of necrosis, metastatic status, relapse status, or survival. The median overall survival for PDL1-low patients was 89 months compared with 28 months for PDL1-high patients, which showed a trend but was not statistically significant (P = 0.0544).

**Correlation between PDL1 and tumor-infiltrating T lymphocytes**

IHC identified TILs in 28 of 38 tumor samples on the TMA. The TIL patterns were diffused within the 0.5-mm TMA punches of the osteosarcoma tissues. Semiquantitative scoring of the degree of TILs was determined by a pathologist, who was blinded to the PDL1 results. There was a positive correlation between PDL1 mRNA expression and TILs (R² = 0.37; P = 0.01; Fig. 4).

**Characterization of origin of metastases**

Thirty osteosarcoma tissue samples were derived from metastatic lesions (23 pulmonary and 7 nonpulmonary). Non-pulmonary metastases included the pelvis, humerus, ilium, flank, and anterior mediastinum. The mean PDL1 expression for pulmonary metastases (2.6 ± 0.21 log) was significantly higher than the mean PDL1 expression for nonpulmonary metastases (1.1 ± 0.40 log; P = 0.0024; Fig. 5A). Furthermore, the origin of the metastasis (pulmonary vs. nonpulmonary) correlated with TILs (P = 0.044; Fig. 5B).

**Discussion**

The field of immunotherapeutics is rapidly evolving, with the recent successful early clinical studies targeting the PD1–PDL1 axis. There is much interest to see if these agents could be applied to other tumor subtypes. It has been suggested that tumor PDL1 expression may be an adequate biomarker to predict responsiveness to these therapies. One limiting factor, however, has been a lack of reliable, and widely available, anti-PDL1 antibodies for this important diagnostic step. In the first part of this study, our objective was to develop an RNA-based assay to circumvent this issue.
"normal" tissue to establish a baseline level of PDL1 expression. With this approach, we found 24% of patients had very high levels of PDL1 transcript (3 log or more). This finding perhaps suggests that there is a subset of patients for whom PDL1-directed therapies could be relevant.

In our analyses, there was no correlation of PDL1 expression with clinicopathologic features, such as age at surgery, gender, neoadjuvant chemotherapy, percentage of necrosis, metastatic status, relapse status, or disease status at the time of biopsy. There was a slight trend for poorer overall survival for patients with osteosarcoma with high PDL1 expression. These data are likely confounded by the small, heterogeneous sample size, and larger studies with similar osteosarcoma patient samples are required. Several previous studies have demonstrated conflicting results varying from positive correlation of tumor aggressiveness in renal cell carcinoma (33, 36), to observing no correlation with clinicopathologic variables (24), to an inverse relationship in which high PDL1 expression was associated with increased survival in colorectal cancer, melanoma, and NSCLC (15, 30, 37). In addition, the role that TILs play in the mechanisms of PDL1 expression and survival for patients with osteosarcoma is not yet known.

In anti-PDL1 clinical trial samples, emerging data suggest that PDL1 expression plus a T-cell activation gene signature, including CD8 and IFNγ, may be associated with treatment response (17). We found a correlation between TILs and PDL1 expression in our tumor samples. In future studies, we will examine the subtypes of lymphocyte present in biopsies, including B and T cells (CD20 and CD3), CD4/CD8 T-cell response, and macrophages (CD163 or CD68), as well as evidence for T-cell activation.

We found higher levels of expression of PDL1 and TILs in metastases that originated in the lung versus other sites, including the pelvis, humerus, ilium, flank, and anterior mediastinum. The significance of this finding remains unclear, but it could be related to the lung microenvironment or perhaps the prior treatments (e.g., lung metastases are typically an early event in osteosarcoma). Future studies with larger patient samples will be needed to explore this further.

In summary, we have developed a sensitive quantitative RNA assay to detect PDL1 expression. We showed PDL1 expression in over 80% of osteosarcoma patient samples, with high levels in 24%, and that PDL1 expression correlated with the presence of TILs. This study sets up an important framework to design anti-PD1 or anti-PDL1 immune-checkpoint therapies in patients with osteosarcoma.

Disclosure of Potential Conflicts of Interest
E. Choy is a consultant/advisory board member for Amgen and Pfizer. No potential conflicts of interest were disclosed by the other authors.

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Development of methodology: J.K. Shen, G.M. Cote, P. Yang, F.J. Hornicek, Z. Duan
Acquisition of data (provided animals, acquired and managed patients, provided facilities, etc.): J.K. Shen, D. Harmon, F.J. Hornicek, Z. Duan

Figure 5. Characterization of the origins of metastases. A, PDL1 expression is significantly higher in metastatic osteosarcoma tumors that originate from lung than from other locations (P = 0.0024). B, TILs also exhibit a positive correlation with pulmonary osteosarcoma metastasis compared with nonpulmonary metastasis (P = 0.0443).
Analysis and interpretation of data (e.g., statistical analysis, bios-statistics, computational analysis): J.K. Shen, G.M. Cote, E. Choy, P. Yang, I. Chebib, F.J. Hornicek, Z. Duan.

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References

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