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Patients with diffuse large B-cell lymphoma of germinal center origin with BCL2 translocations have poor outcome, irrespective of MYC status: a report from an International DLBCL rituximab-CHOP Consortium Program Study

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ABSTRACT

Diffuse large B-cell lymphoma can be classified by gene expression profiling into germinal center and activated B-cell subtypes with different prognoses after rituximab-CHOP. The importance of previously recognized prognostic markers, such as Bcl-2 protein expression and BCL2 gene abnormalities, has been questioned in the new therapeutic era. We analyzed Bcl-2 protein expression, and BCL2 and MYC gene abnormalities by interphase fluorescence in situ hybridization in 327 patients with de novo disease treated with rituximab-CHOP. Isolated BCL2 and MYC rearrangements were not predictive of outcome in our patients as a whole, but only in those with the germinal center subtype of lymphoma. The prognostic relevance of isolated MYC rearrangements was weaker than that of BCL2 isolated translocations, but was probably limited by the rarity of the rearrangements. Seven of eight patients with double hit lymphoma had the germinal center subtype with poor outcome. The germinal center subtype patients with isolated BCL2 translocations had significantly worse outcome than the patients without BCL2 rearrangements (P=0.0002), and their outcome was similar to that of patients with the activated B-cell subtype (P=0.30), but not as bad as the outcome of patients with double hit lymphoma (P<0.0001). Bcl-2 protein overexpression was associated with inferior outcome in patients with germinal center subtype lymphoma, but multivariable analysis showed that this was dependent on BCL2 translocations. The gene expression profiling of patients with BCL2 rearrangements was unique, showing activation of pathways that were silent in the negative counterpart. BCL2 translocated germinal center subtype patients have worse prognosis after rituximab-CHOP, irrespective of MYC status, but the presence of combined gene breaks significantly overcomes the prognostic relevance of isolated lesions.

Introduction

Diffuse large B-cell lymphoma (DLBCL) is a heterogeneous group of tumors with different clinical, immunophenotypic, and genetic abnormalities as well as highly variable prognosis.1 Identifying distinctive subgroups within the DLBCL category can assist with prognostication and therapeutic strategy. According to gene expression profile (GEP), DLBCL can be divided into germinal center B-cell (GCB), activated B-cell (ABC), and unclassified subtypes,2,4 with different outcomes after treatment with rituximab, cyclophosphamide, doxorubicin, vincristine, and prednisone (R-CHOP).3,5 The t(14;18)(q32;q21) has been identified in 18–20% of patients with de novo DLBCL.6 Rarely, BCL2 is translocated to Ig light chain (IgL, IgK) loci, as a part of t(2;18)(p11;q21.3) or t(18;22)(q21.3;q11), similarly resulting in Bcl-2 overexpression.
BCL2 translocations are more frequently found in the GCB subtype, whereas 18q21 locus amplification is more common in the ABC subtype of DLBCL.12,10

The prognostic significance of BCL2 amplification or translocations in de novo DLBCL in the era of CHOP therapy alone, without rituximab, was controversial.11,20 Some data on the prognostic significance of BCL2 aberrations in patients treated with R-CHOP have recently become available, with two studies reporting no influence of BCL2 gene rearrangements on the survival of DLBCL patients.21,22 On the other hand, the concomitant presence of t(14;18) or variants and MYC rearrangements, referred to as double hit lymphomas, has consistently been associated with adverse outcome in DLBCL patients treated with R-CHOP.23-25

Bcl-2 protein expression seems only partially related to BCL2 gene abnormalities as analyzed by fluorescence in situ hybridization (FISH), as Bcl-2 is expressed in a greater number of DLBCL cases than in those tumors carrying t(14;18)(q23;q21).11,12 Indeed, in the absence of BCL2 translocations, amplification of 18q21 and/or activation of the nuclear factor κB (NF-κB) pathway can cause Bcl-2 protein overexpression.28 The prognostic significance of Bcl-2 expression is also controversial, and comparison between different studies is hampered by the choice of different cut-offs of positive cells, and by the variability of treatments. In patients treated with R-CHOP, Bcl-2 protein did not correlate with outcome,29,30 since the addition of rituximab seemed to improve survival of Bcl-2-positive patients.29,30,31 Apparently eliminating the gap between Bcl-2-positive and Bcl-2-negative patients found in the pre-rituximab era. This result does, however, appear to be contradicted in a very recent study in which Bcl-2 expression in GCB-DLBCL was associated with poorer outcome.22

The goal of this study was to investigate the prognostic value of BCL2 gene aberrations and Bcl-2 expression in a large number of patients with de novo DLBCL, uniformly treated with R-CHOP, for whom MYC and GEP characterization was available.

**Design and Methods**

**Patients**

We studied 327 cases of previously untreated de novo DLBCL, diagnosed between January 2002 and October 2009, and collected as part of the International DLBCL Rituxan-CHOP Consortium Program Study. These cases were analyzed for Bcl-2 protein expression, and BCL2 and MYC gene abnormalities, and gene expression profiling (GEP) was performed. All cases were reviewed by a group of hematopathologists (SMM, MAP, MBM, AT, and KHY), and the diagnoses were confirmed based on World Health Organization classification criteria. Patients with transformation from low grade lymphoma, those with composite follicular lymphoma, primary mediastinal large B-cell lymphoma, primary cutaneous and primary central nervous system DLBCL were excluded from the analysis due to the unique biological features of these types of lymphoma. All patients were adults who were negative for human immunodeficiency virus and had sufficient clinical data and clinical follow-up. Patients in this study were treated with R-CHOP (n=291, 89%) or R-CHOP-like regimens (n=36, 11%; CHOP scheme adopting different anthracyclines i.e. novantrone or epirubicin). All patients with advanced stage disease received six (92%) or eight (8%) cycles, every 21 days, with or without radiotherapy for residual disease or initial bulky disease; localized cases received at least three cycles followed by radiotherapy or six cycles without radiotherapy. The current study was approved by each of the participating centers’ Institutional Review Boards, and the overall collaborative study was approved by the Institutional Review Board at The University of Texas MD Anderson Cancer Center in Houston, Texas, USA.

**Immunohistochemistry for Bcl-2 and cut-off determination**

Bcl-2 protein expression was evaluated in all patients using a monoclonal anti-Bcl-2 antibody (Clone-124, Dako, Carpinteria, CA, USA) and standard immunohistochemical methods. The formalin-fixed, paraffin-embedded tissue slides underwent deparaffinization and heat-induced antigen retrieval techniques. An endogenous biotin-blocking kit (Ventana) was used to decrease background staining. Following antigen retrieval and primary antibody incubation, the reaction was completed in a Ventana ES instrument using a dianaminobenzidine immunoperoxidase detection kit (Ventana). Immunoreactivity was determined without knowledge of the patients’ survival, clinical data, or GEP data. The samples were analyzed independently by a group of four hematopathologists/pathologists in addition to the hematopathologist of each of the contributing centers, and disagreements were resolved by joint review at a multi-headed microscope. An average of 300-400 cells in four to five fields were counted in the tissue microarray cores. A percentage of tumor cell staining ≥50% was considered positive after receptor operating characteristic (ROC) curve analysis was implemented to assess the discriminatory accuracy of Bcl-2 protein in recognizing patients with different overall survival (OS) and progression-free survival (PFS). The 50% value was established from the analysis of the area under the ROC curve (AUROC) and had the maximum specificity and sensibility for OS and PFS discrimination in our patients (AUROC=0.564, P=0.017 for OS and AUROC=0.564, P=0.015 for PFS).31

**Gene expression profiling analysis**

RNA was extracted from 327 formalin-fixed, paraffin-embedded tissue samples using a HighPure Paraffin RNA Extraction Kit (Roche Applied Science). Fifty nanograms of RNA were transcribed into cDNA, linearly amplified using the WT-Ovation™ FFPE System (Nugen), and biotin-labeled using FL-Ovation™ cDNA Biotin Module V2 (Nugen) in all cases. For GeneChip hybridization, 5 μg of WT-Ovation amplified cDNA were applied to HG-U133 Plus 2.0 GeneChips (Affymetrix) and hybridized overnight. GeneChips were washed, stained, and scanned using the Fluidic Station 450 and GeneChip Scanner 3000 (Affymetrix) according to the manufacturer’s recommendations. For data analysis and classification, the microarray DQN (trimmed mean of differences of perfect match and mismatch intensities with quantile normalization) signals were generated and normalized to the quantiles of beta distribution with parameters p=1.2 and q=3 as previously described.32 A Bayesian model was also utilized to determine the class probability. The classification model was built on the 47 paired formalin-fixed, paraffin-embedded tissue sample dataset previously generated with a confidence rate of 90-100% in fresh frozen tissue and 92-100% in formalin-fixed, paraffin-embedded tissue. The same methodology developed during this study has been validated and demonstrated to be applicable by using the LLMPP dataset in the Gene Expression Omnibus (GEO) database GSE#10846 that has 181 CHOP-treated and 233 R-CHOP-treated DLBCL patients with fresh-frozen samples.34

**Fluorescence in situ hybridization for BCL2 and MYC gene rearrangements**

FISH was performed using a locus-specific identifier BCL2 dual-
color, break-apart probe (07J75-001 from Vysis, Downers Grove, IL, USA) on paraffin-embedded tissue sections according to the Vysis protocol. FISH for the MYC gene was performed with a locus-specific identifier IGH/MYC/CEP 8 tri-color, dual fusion probe (DPF, 05J75-001 from Vysis) and, due to shortcomings of the former in identifying alternative (non-IGH) C-MYC rearrangement partners, a locus-specific identifier MYC dual-color, break-apart probe (BP, 05J91-001 from Vysis). Abnormal FISH signals were recorded as percentage of cells showing an abnormality. The cutoff score to consider a case rearranged (“breaks”) was the mean + 3 SD of split nuclei in reference cases (i.e., >3%). A high-level of 18q21 amplification was defined as the presence of either more than ten gene signals or tight clusters of at least five gene signals. Sections of five tonsils were used as controls. To assess reproducibility, the results obtained by two observers were compared in a blinded fashion in 80 cases, showing a perfect agreement for breaks (κ=1) and an excellent agreement for gains (κ=0.91).

Validation set

To validate our observations in predicting survival in an independent series of cases, we analyzed a second group of 120 archival DLBCL cases studied similarly to the first cohort except for MYC analysis that was not available (GCB 49%, ABC 40%, unclassified 11%; BCL2 translocations in 18%; Bcl-2 overexpression in 54%). All these patients had been treated with R-C(1)/HOP and the same selection criteria as those for the first cohort were applied. The clinical characteristics at presentation of the patients in the validation set were not significantly different from those of the patients in the test set.

Statistical analysis

Following pre-defined criteria,33 PFS was measured from the time of diagnosis to the time of progression or death from any cause. OS was measured from the time of diagnosis to last follow-up or death from any cause. Only patients with a follow-up of longer than 12 months were included in the survival analysis. The actuarial probabilities of PFS and OS were determined using the Kaplan–Meier method, and differences were compared using the log-rank test. A Cox proportional-hazards model was used for multivariate analysis. The χ² test or Mann-Whitney test was applied to assess differences between variables. The interobserver agreement for FISH was assessed using the κ statistic; a κ value of >0.75 implied excellent agreement. All statistical calculations, except for ROC and the κ statistic which were performed with SPSS 13.0 (SPSS Inc., Chicago, IL, USA), were conducted using StatView (Abacus Concepts, Berkeley, CA, USA).

Results

Patients’ characteristics and outcome

The median age of the patients at diagnosis was 62 years (range, 18–86). Their clinical characteristics are reported in Table 1. The average follow-up time for survivors was 48 months (median 46; range, 12–113). Only 322 of the 327 patients were included in the survival analysis, since a minimum follow-up of 12 months was required by the study criteria. The 3-year OS rate of the 322 patients from this study cohort was 70%±4%, and the 3-year PFS rate was 58%±5%. Of the common, clinically relevant prognostic variables, International Prognostic Index (IPI) risk group 0-2 versus 3-5 (P<0.0001), and all the single variables included in the IPI were significantly associated with OS and PFS. Patients with the GCB subtype had significantly better 3-year OS and PFS compared to patients with ABC subtype lymphoma (OS: 75%±4% versus 65%±5%, respectively, P=0.003; PFS: 65%±4% versus 52%±4%, respectively, P=0.003).

BCL2 and MYC genes in the subgroups defined by gene expression profiling

Sixty patients (18.3%) had DLBCL with BCL2 gene translocations, and 50 (15.3%) had BCL2 gene amplifications. The presence of BCL2 translocations was not associated with any clinical prognostic variable at diagnosis, except for Ann Arbor Stage (70% versus 49% with stage III-IV, P=0.004), as shown in Table 1. As expected, BCL2 translocations were significantly associated with the GCB subtype (84%, P<0.0001), while gains were present mostly in the ABC subtype (70%, P<0.0001). MYC rearrangements were identified in 27 patients (8%), and eight of them had a concomitant BCL2 translocation, representing double hit lymphomas. Seven of these eight (88%) patients with double hit lymphoma had GCB-DLBCL, and all progressed or relapsed within 12 months from start of therapy (Figure 1A). Patients with MYC breaks were equally distributed among patients with or without BCL2 translocations (P=0.11), but were more frequent (16 cases, 70%) within the GCB subtype group.

The OS and PFS rates of patients with BCL2 translocations were similar to those of patients without BCL2 translocations, irrespectively of MYC status. When we restricted the analysis to the GCB subtype, patients with BCL2 translocations alone, in the absence of MYC breaks, had a significantly worse outcome than GCB patients without BCL2 translocations (3-year PFS of 53% versus 76%, respectively; P=0.0002). The outcome of patients with BCL2 rearranged GCB subtype was similar to that of the patients with the ABC subtype of DLBCL (52%, P=0.30), but still better than that of the patients with double hit lymphomas (P<0.0001, Figure 1A). This finding was confirmed in our validation set of 120 patients, in which BCL2 translocations, while not being predictive in the cohort as a whole (P=0.05 for OS; P=0.11 for PFS), was an adverse variable in the GCB subtype (P=0.01 for both OS and PFS, Figure 1B).

The presence of MYC breaks alone in the 19 patients without concomitant BCL2 translocations was not associated with impaired PFS (P=0.70) or OS (P=0.66) in the whole cohort, but was associated with inferior OS (P=0.05), but not PFS (P=0.22), in patients with GCB-DLBCL (only 9 with isolated MYC breaks). As shown in Figure 1A, BCL2 and MYC rearrangements each contributed with a cumulative pejorative hit to the outcome of GCB-DLBCL patients, while they had no prognostic impact in patients with ABC-DLBCL.

BCL2 gains were not prognostic in any of the subgroups of patients. Particular consideration of high-level amplifications was of no additional prognostic value.

Bcl-2 protein expression, clinical characteristics, fluorescence in situ hybridization and gene expression profiling

None of the common clinical characteristics of our patients at the time of presentation was significantly associated with Bcl-2 protein expression except age, with older patients more often being Bcl-2 positive (≥60 years old, P=0.02). Bcl-2 protein expression in GEP- and FISH-defined subgroups is shown in Figure 2. The number of positive cells in patients with the BCL2 translocation was distinctly higher (range, 10-100%; median 90%) than in
patients without the BCL2 translocation (range, 0-100%; median 60%).

Bcl-2 protein expression was significantly associated with worse PFS (P=0.01) and OS (P=0.02) in the whole cohort, but when patients were divided according to GEP-defined subtypes, we observed that higher Bcl-2 expression was associated with significantly inferior PFS in the GCB subgroup (P=0.04), but not in the ABC subgroup (P=0.57), as shown in Figure 3.

Figure 4 illustrates that Bcl-2 protein expression was not prognostic in patients with or without BCL2 translocations, indicating that Bcl-2 expression cannot be used as a surrogate of t(14;18) and its variants in assessing prognosis (see also multivariate analysis). These curves were obtained after excluding patients with double hit lymphomas from the analysis, since these are associated with Bcl-2 overexpression (Figure 2), and might have represented a confounding variable. When we tested this finding in the validation set of patients, for whom MYC analysis was not available, the prognostic relevance of Bcl-2 protein expression appeared again dependent of BCL2 gene status, even though statistical significance between subgroups was not reached due to low numbers (58 patients with GCB-DLBCL, 20 with BCL2 translocations, only 3 not expressing Bcl-2).

**Multivariate analysis**

Multivariate analysis of all 137 patients with the GCB subtype of DLBCL showed that BCL2 translocations (HR 0.40, 95% CI: 0.18-0.89; P=0.02), but not Bcl-2 expression (HR 1.01, 95% CI: 0.45-2.21; P=0.98), MYC breaks (HR 0.25, 95% CI: 0.10-0.59; P=0.001), and IPI score (HR 0.41, 95% CI: 0.20-0.84; P=0.01), were independently associated with patients’ outcome. Results were not modified after each molecular feature was computed with age as a continuous parameter. However, both BCL2 and MYC rearrangements lost their predictive power when patients with double hit lymphomas were excluded,signifying that the presence of double gene breaks overcomes the significance of the isolated lesions in GCB-DLBCL.

### Table 1. Clinical characteristics and treatment response of 327 DLBCL patients treated with R-CHOP, divided according to the presence of BCL2 gene rearrangements [t(14;18) or its variants].

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>t(14;18) or variants</th>
<th>No translocations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N. (%)</td>
<td>N. (%)</td>
<td>N. (%)</td>
</tr>
<tr>
<td>Patients</td>
<td>327 (100)</td>
<td>60 (100)</td>
<td>267 (100)</td>
</tr>
<tr>
<td>Median age</td>
<td>62</td>
<td>34 (57)</td>
<td>156 (58)</td>
</tr>
<tr>
<td>≥60</td>
<td>190 (58)</td>
<td>32 (53)</td>
<td>108 (41)</td>
</tr>
<tr>
<td>&lt;60</td>
<td>137 (42)</td>
<td>26 (43)</td>
<td>111 (42)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>140 (43)</td>
<td>18 (28)</td>
<td>136 (51)</td>
</tr>
<tr>
<td>Male</td>
<td>187 (57)</td>
<td>47 (72)</td>
<td>119 (49)</td>
</tr>
<tr>
<td>Stage</td>
<td></td>
<td></td>
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<tr>
<td>I-II</td>
<td>154 (47)</td>
<td>18 (28)</td>
<td>136 (51)</td>
</tr>
<tr>
<td>III-IV</td>
<td>173 (53)</td>
<td>42 (63)</td>
<td>131 (49)</td>
</tr>
<tr>
<td>Lactate dehydrogenase</td>
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<tr>
<td>Normal</td>
<td>103 (36)</td>
<td>19 (29)</td>
<td>84 (36)</td>
</tr>
<tr>
<td>Elevated</td>
<td>182 (64)</td>
<td>33 (63)</td>
<td>149 (64)</td>
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<tr>
<td>Extranodal sites*</td>
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<tr>
<td>0-1</td>
<td>243 (79)</td>
<td>43 (63)</td>
<td>200 (79)</td>
</tr>
<tr>
<td>&gt;1</td>
<td>65 (21)</td>
<td>13 (23)</td>
<td>52 (21)</td>
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<tr>
<td>Performance Status</td>
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<td></td>
<td></td>
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<tr>
<td>0-1</td>
<td>204 (68)</td>
<td>37 (56)</td>
<td>167 (86)</td>
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<tr>
<td>&gt;1</td>
<td>34 (14)</td>
<td>5 (8)</td>
<td>29 (14)</td>
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<td>IPI risk group</td>
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<tr>
<td>0-2</td>
<td>176 (64)</td>
<td>33 (57)</td>
<td>143 (64)</td>
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<tr>
<td>3-5</td>
<td>99 (36)</td>
<td>18 (28)</td>
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<tr>
<td>Gene expression profiling</td>
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</tr>
<tr>
<td>GCB</td>
<td>139 (47)</td>
<td>48 (82)</td>
<td>91 (38)</td>
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<tr>
<td>ABC</td>
<td>138 (46)</td>
<td>9 (16)</td>
<td>129 (54)</td>
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<tr>
<td>Unclassified</td>
<td>21 (7)</td>
<td>1 (2)</td>
<td>20 (8)</td>
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<tr>
<td>Bcl-2 protein</td>
<td></td>
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<tr>
<td>Negative</td>
<td>116 (39)</td>
<td>10 (18)</td>
<td>106 (45)</td>
</tr>
<tr>
<td>Positive</td>
<td>178 (61)</td>
<td>47 (82)</td>
<td>131 (55)</td>
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<tr>
<td>MYC gene abnormalities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No break</td>
<td>300 (92)</td>
<td>52 (87)</td>
<td>248 (93)</td>
</tr>
<tr>
<td>Break</td>
<td>27 (8)</td>
<td>8 (13)</td>
<td>19 (7)</td>
</tr>
</tbody>
</table>

Data regarding lactate dehydrogenase (n=285), involvement of extranodal sites (n=308), Performance Status (n=238), IPI risk group (n=275), GEP (n=298), and Bcl-2 protein expression (n=294), were not available for all patients. *Primary nodal DLBCL (no extranodal site involved, 42% of patients) had no significant association with BCL2 translocations compared to patients with one or more extranodal sites involved (P=0.43). **refers to the comparison between GCB and ABC. Clinical and biological characteristics of 327 DLBCL patients treated with R-CHOP. The patients were stratified according to the presence of BCL2 translocations.
BCL2 translocations in diffuse large B-cell lymphoma

Figure 1. Overall survival and progression-free survival of patients with DLBCL according to (A) the presence of BCL2 translocations alone or concomitant MYC breaks stratified by GEP-defined subgroups; (B) BCL2 translocations stratified with GEP subgroups in the validation set. DHL: double hit lymphoma.

Figure 2. Box plot graphs for the distribution of Bcl-2 expression in 327 patients with DLBCL according to GEP and FISH analysis. Reported P values were calculated with the Mann-Whitney test. Only significant differences are reported. SD: standard deviation. (A) Bcl-2 protein expression in GEP-defined subgroups; (B) Bcl-2 protein expression in correlation with BCL2 and MYC gene aberrations in GEP-defined subgroup. UC: unclassified; DHL: double hit lymphoma.

- Reported P values were calculated with the Mann-Whitney test
- Bcl-2 protein expression: mean 57, SD 35, and median 70. SD: standard deviation.
Differential gene expression between patients with germinal center B-cell lymphoma with or without t(14;18)

Four-hundred and forty-four genes were found to be differentially expressed (>1.5 fold and \(P<0.005\)) in DLBCL patients with or without BCL2 translocations including both GCB and ABC subtypes. In the GCB group, however, only 43 genes were differentially expressed among patients with and without BCL2 translocations (Figure 5A). Most of these genes (72%) were informative. As expected, BCL2 was highly expressed in the translocated cases, as was the MME (CD10) gene. BCL11A, an oncogene that is located at 2p16.1 beside the c-REL locus and that functions as a transcriptional repressor, was highly expressed in patients with BCL2 translocated tumors. Neither BCL11A nor c-REL was increased in the ABC subgroup with BCL2 translocations (Figure 5B).

Interestingly, a number of genes overexpressed in the BCL2 translocated group are involved in the control of angiogenesis and the inflammatory response (AIMP1, PPIA, and ALOX), while others are involved in promoting apoptosis or regulating B-cell signaling (STK17A, RAL-GPS2, NCOA3, STRBP, and ZNF117).
Discussion

We addressed the clinical impact of \textit{BCL2} aberrations and their relationship to Bcl-2 protein expression in a large series of patients with DLBCL homogeneously treated with R-CHOP, with known \textit{MYC} gene status and molecularly characterized according to GEP analysis. We were able to establish the role of the \textit{BCL2} gene in different subtypes of DLBCL, irrespectively of concomitant \textit{MYC} aberrations. We found that isolated \textit{BCL2} translocations, in the absence of \textit{MYC} breaks, were associated with a poor outcome in the subset of patients with GCB-DLBCL, and that the prognosis of these patients was similar to that of patients with ABC-DLBCL. The concomitant presence of \textit{MYC} breaks (double hit lymphoma) further worsened the outcome of these patients. The role of Bcl-2 protein expression appeared dependent on its association with \textit{BCL2} translocations, as outlined by multivariate analysis and survival curves (Figure 4). Finally, \textit{BCL2} gains, more common in ABC-DLBCL, did not affect prognosis.

As determined by FISH break apart probe analysis, the overall frequency of \textit{BCL2} translocations in \textit{de novo} DLBCL was 18.3\%. The \textit{BCL2} translocations were almost exclusively associated with GCB-DLBCL, found in 34.5\% of cases (Table 1), similarly to other reports.\textsuperscript{3,4,5,38} Nine cases of ABC-DLBCL harbored \textit{BCL2} translocations (one was a double hit lymphoma), and the presence of \textit{BCL2} translocations in ABC DLBCL did not influence the PFS of these patients. The preferential occurrence of \textit{BCL2} rearrangements in the GCB subgroup, and its impact on survival of this subgroup, suggests that \textit{BCL2} translocations might be an important and initial event in the pathogenesis of GCB DLBCL.

The impact of \textit{BCL2} translocations on survival in our series could not be explained by differences in the clinical features of the patients because there was no association between the presence of \textit{BCL2} translocations and IPI risk groups (\(P=0.90\), Table 1). Patients with GCB-DLBCL and \textit{BCL2} translocations had an outcome that was similar to that of patients with ABC-DLBCL, while the remaining patients with GCB-DLBCL without \textit{BCL2} translocations had a very good PFS (Figure 1). The prognostic role of \textit{BCL2} translocations appeared independent of the concomitant presence of \textit{MYC} aberrations, being present also when patients with double hit lymphoma were excluded from the analysis (Figure 1A). However, the presence of double gene breaks (double hit lymphoma) conferred a significant further worsening to the outcome of patients

![Figure 5. Gene expression profile and representative FISH analysis of DLBCL patients. (A). Gene expression profile of 139 GCB-DLBCL patients stratified according to the presence or absence of \textit{BCL2} translocations; (B). Gene expression profile of 80 DLBCL patients with \textit{BCL2} translocations stratified between GCB-DLBCL (n=78) and ABC-DLBCL (n=12); (C). Representative FISH of \textit{BCL2} amplification (upper image) and translocation (lower image) using a locus-specific identifier \textit{BCL2} dual-color break-apart probe.](image-url)
with isolated BCL2 or MYC lesions. Confirming previous findings,23,24 we were able to show in our series the synergistic clinical effect of combined activation of MYC (promoting cellular proliferation) and BCL2 (blocking cellular death), which was associated with the GCB subtype, and was the strongest prognostic variable together with IPI risk group in this subgroup of patients, as outlined by our multivariate analysis and shown in Figure 1A.

In this series, Bcl-2 protein was overexpressed in half of the patients with GCB-DLBCL and in 72% of patients with ABC-DLBCL (Figure 2), consistent with other series.18,39 However, Bcl-2 overexpression had prognostic value only in the GCB subtype, as already observed by others in the era of R-CHOP therapy.45,46 In the present study we have shown that the prognostic effect of Bcl-2 expression within the GCB subgroup is related to the concomitant presence of BCL2 translocations. No impact of Bcl-2 protein expression was present in patients with or without BCL2 translocations (Figure 4), a finding obtained after excluding patients with double hit lymphoma.

Iqbal et al.22 recently published a similar analysis to our study in patients classified by GEP analysis, confirming that the prognostic significance of Bcl-2 protein is observed in the GCB subset rather than in ABC-DLBCL. Differently from our findings, in their study BCL2 translocations were not adverse in the GCB subset. We believe that several factors may have contributed to the different prognostic impact of BCL2 translocations in our study compared to Iqbal’s study. First, the number of patients with GCB-DLBCL and BCL2 rearrangements in Iqbal’s study was apparently low to drive conclusions on the prognostic impact of BCL2 expression within the GCB subgroup as already observed by others in the era of R-CHOP therapy.45,46 In the present study we have shown that the prognostic effect of Bcl-2 expression within the GCB subgroup is related to the concomitant presence of BCL2 translocations. No impact of Bcl-2 protein expression was present in patients with or without BCL2 translocations (Figure 4), a finding obtained after excluding patients with double hit lymphoma.

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Our GEP analysis revealed that patients with BCL2 translocations substantially differed with respect to important recurrent oncogenic events, which may contribute to the adverse outcome of the subgroup of GCB-DLBCL patients with BCL2 translocations. Up-regulation of the BCL11A gene occurred exclusively in the group of patients with BCL2 translocations (Figure 5). BCL11A cooperates with c-REL in B-cell lymphomas,25,41 and amplification of the c-REL locus has already been reported to be more common in the GCB-DLBCL subtype, in which it was found in 16% of cases,3 but without further characterization. These cases might correspond to our subgroup of GCB-DLBCL with BCL2 translocations overexpressing BCL11A.

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