Short Communication

Hematogones Detection in Hematological Malignancies and Bone Marrow Transplantation

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Abstract

Hematogones (HGs, normal B-lymphocyte precursors) were first described in 1937 by Peter Vogel as “lymphoid-appearing cells” in bone marrow aspirates from children. HGs in Latin mean “blood-maker”. The function and significance of these cells remained unclear till the 1970s when flow cytometry was used to identify them. HGs may be particularly prominent in the regeneration phase following chemotherapy or bone marrow transplantation. Moreover, increased HGs may cause misinterpreted because they share morphologic features with neoplastic lymphoblasts. In this review, we tried to focus on current morphologic and immunophenotypical characterization of HGs and their clinical significance as diagnostic and prognostic tool in predicting patient outcomes. We have examined several studies to evaluate risk ratio of HGs level at certain cut off limit which has been proposed in majority of studies. Out of 21 studies which included 1150 patients with different hematological malignancies and bone marrow failure syndromes and 590 post transplantation patients. We report how HGs detection would help in diagnosis and predict outcome in bone marrow transplantation patients.

ABBREVIATIONS

HG: Hematogones; AIDS: Acquired Immunodeficiency Syndrome; aHSCT: Allogeneic Hematopoietic Stem Cell Transplantation; ALL: Acute Lymphoblastic Leukemia; CML: Chronic Myeloid Leukemia; MDS: Myelodysplastic Syndrome; AA: Aplastic Anemia; MRD: Minimal Residual Disease; GVHD: Graft Versus Host Disease; AML: Acute Myeloid Leukemia; NHL: Non-Hodgkin lymphoma; MM: Multiple Myeloma; SAA: Severe Aplastic Anemia; ATCL: Adult T-Cell Leukemia/Lymphoma; BMT: Bone Marrow Transplantation; CBT: Cord Blood Transplantation; LFS: Leukemia Free Survival; ITP: Immune Thrombocytopenic Purpura; LPD: Lymphoproliferative Disorder; FL: Follicular Lymphoma

INTRODUCTION

Hematogenes (HG), B-lymphocyte precursors, primarily recognized by their morphologic features in bone marrow [1,2]. Total HGs may be classified into early, intermediate or late developmental stages. Reports showed HGs may increase in healthy infants and children as well as in several diseases of children and adults, known as reactive HGs [3,4]. While HGs, identified as regenerative, may be particularly noticeable after chemotherapy or bone marrow transplantation and in some diseases such as autoimmune, congenital cytopenias, neoplasms, and acquired immunodeficiency syndrome (AIDS) [3,5-7]. Recently, several studies have demonstrated a role of HGs level in predicting outcomes after conventional chemotherapy [8-10] or allogeneic hematopoietic stem cell transplantation (HSCT) [11-14]. In this review, we discussed HGs potential role in certain diseases as a biomarker for either diagnostic and prognostics purposes, especially blood disorders and other malignancies. Our strategy in searching current literature using these specific keywords such as normal B precursor, HGs in disease diagnosis, post transplantation prognosis, HGs levels in relation to post chemotherapy prognosis, and HGs used to be misinterpreted and lead to miss diagnosis. We have applied few filters such as reports human studies reported in English, Chinese studies were translated into English through Google translate. We aimed to examine HGs detection throughout literature to-date and discussed pros and cons with spotlight on certain precautions for HGs assessment. Moreover, we have tried to find HGs predictive
values in clinical lab and its clinical significance for cancer patients.

Characterization

Morphologic: The most immature HGs have common cytological features with lymphoblasts and even in some cases they may be indistinguishable from neoplastic lymphoblasts in acute lymphoblastic leukemia (ALL) (Figure 1). Early HGs have round nuclei with indentations, scant cytoplasm, and inconspicuous homogeneous chromatin with indistinct or at times variably prominent nucleoli. Presence of one or more nucleoli reflects HGs immaturity, cytoplasm is moderately to deeply basophilic and lacks inclusions, granules or vacuoles [15]. The most mature HGs resemble mature B-lymphocytes with condensed chromatin (Figure 1). Late HGs typically exhibit highly condensed, uniform nuclear chromatin and scant cytoplasm. The nucleoli are absent or indistinct (Figure 1). HGs are usually not present in a peripheral blood smear, except for samples from neonates [16] or umbilical cord blood [2,17].

Immunophenotypic: The earliest recognizable B-lineage precursors expressed the progenitor cell marker CD34 in combination with CD38, CD19, high levels (bright) of CD10, and low levels of CD22 while lacking CD20. These progressed to the next stages by down-regulating CD34 completely and CD10 partially, prior to progressive up-regulation of CD20. CD22 levels also increased slightly as CD20 was up-regulated. Finally, CD10 was down-regulated completely, CD38 partially, and CD22 upgraded to high intensity. Late stage, in which CD10 is completely down-regulated, is considered a mature stage of B-cell development. TdT expression parallels CD34 in the B-cell maturation sequence. Surface Ig is variable among individual cells in each case, occurring shortly before to after acquisition of a high level of CD20 expression. Asynchronous expression of the earliest and latest antigens, e.g., concurrent CD34 and CD20, and aberrant over- or under-expression of antigens was not observed in HGs populations [18]. However, after chemotherapy or stem cell transplant for hematological disorders, early HGs may coexpress CD20 (dim) and CD34 because of alteration of the maturation pathways of benign B-cell precursors. All stages of HGs express CD19, CD22, CD38 and CD10 [4,19-21]. Studies on cytoplasmic IgM expression in HGs have shown that cytoplasmic IgM expression occurred during HG maturation along with increasing CD19 expression, decreasing CD10 expression and loss of TdT/CD34. Cytoplasmic IgM is acquired early during the Stage 1 to Stage 2 transition in HG development (Figure 1) [20,22-32]. HGs are mainly detected by 4-color flow cytometry assay; where single cell suspensions from tissue, marrow aspirate or whole blood stained with fluorochrome-conjugated monoclonal antibodies against CD10, CD34, CD45 and IgM. HGs may be sub classified into (a): immature – CD34$^{high}$, IgM$^{neg}$, CD10$^{high}$, and CD45$^{dim}$; (b): intermediate – CD34$^{neg}$, IgM$^{neg}$, CD10$^{dim/pos}$ and CD45$^{dim}$; (c): mature CD3$^{neg}$, IgM$^{high}$, CD10$^{neg/dim}$ and CD45$^{high}$). Extended panel may be required to discriminate abnormal clone by staining for CD3, CD5, CD10, CD19, CD20, CD34, CD38, CD45, IgM, TdT, kappa and lambda immunoglobulin light chain [33,34]. Another flowcytometer report used 2 different 4-color antibody combinations of CD10, CD20, CD19, and CD38. The second 4-color antibody combination of CD10, CD20, CD22, and CD34. Both combinations categorize between early-stage; intermediate and late-stage HGs; and mature B cells [35,36].

Genomics: Gene expression of HGs, (Figure 2), showed differences of these maturation genes along differentiation stages. CD19 and CD22 are statistically significant over expressed in mature B cell than in HSCs, while CD 34 is statistically significant over expressed in HSCs than mature B cells. CD38 was not statically significant different in expression in both HSCs and Mature B Cells (Figure 2).

Figure 1 Representative figure for few stages of B cell maturation and differentiation along with their important biomarker expression, which may be used for characterization of HG with comparison to HSC, hematopoietic stem cell early HGs, late HGs and mature B lymphocyte. Markers were marked to each stages based upon data collected from previous published reports. Each marker is labeled with unique color code, intensity of color used to represent its relative expression, i.e. light color means dim or low expression of this marker at this stage of normal differentiation while dark color means string expression [15, 50-55].
Figure 2 Scatterplot for expression of important early (CD34) and late (CD19, CD79a) genes involved in Maturation and differentiation stages of HG which may be used for detecting HGs by flowcytometer-based assayData was extracted from public availableGSE13159 [56].

Figure 3 Risk ratio with 95% CI plotted for HGs level detected by flowcytometer 4-color assays as reported by five studies based and their value in predicting patient’s outcome. Favorable and unfavorable outcome refer to remission or relapse after bone marrow transplantation.
A transcription factor, expressed throughout B-cell maturation, has been evaluated in non-neoplastic bone marrow sections, which showed scattered positive nuclear staining in small B-lymphocytes/HGs [37-39]. Expression of the receptor tyrosine kinase-like orphan receptor 1 (ROR-1) was studied in a different subset of the lymphoid population. ROR1 was not expressed on the earliest B-cell precursors (CD34+/CD38+/CD19+/CD10+) and mature B cells (CD34+/CD38+/CD19+/CD10−) as defined by the population of CD10/CD19 expressing positive). However, ROR1 was positive on the B-cell precursors at an intermediate stage of maturation (CD34+/CD38+/CD19+/CD10+) and mature B cells (CD34+/CD38+/CD19+/CD10−) were negative for ROR1 [4,7,20,26,29,40-47]. Recently, Zap-70, Zeta-chain-associated protein kinase 70, a member of protein-tyrosine kinase family, expression was reported to be low in HGs [37,38]. Reports showed low BCL2, B-cell lymphoma, a human proto-oncogene located on chromosome 18, expression in mature and immature HGs [38,39,41,48,49]. The pathological CD5 expression in patients with increased HGs. CD5 was expressed in normal subset of polytypic B cells on a continuum, predominantly at the later stages of maturation, specifically on mature HGs and mature B cells. Thus, the difference in CD5 and surface Ig light chains expression allows for the distinction between normal CD5+ B-cells and CD5+ lymphoma cells chronic lymphocytic leukemia (CLL) or mantle cell lymphoma [18,38].

Factors affecting HGs levels

Presence and demography group: HGs could be detected morphologically in peripheral blood of neonates [6,46-57] and in umbilical cord blood [17,18,47]. They are better identified nowadays using a 4-color flow cytometry approach [2,8,58]. HGs can also be identified using a sensitive flow cytometer in peripheral blood in 65% of adults with certain clinical conditions [47,54]. HGs were reported to be present in high numbers in marrow from infants and young children, and then they showed a statistically significant decline with aging. There was no significant difference between males and females [15,36,59].

Conditions that affect HGs detection: Specimens processed by density gradient separation had a significantly higher percentage of HGs than those processed by ammonium chloride lysis mostly related to the removal of neutrophils, which would relatively increase HGs number [18]. There was a decline in mean percent HGs with increasing marrow involvement by neoplastic cells. The reason may be related to encroachment on HGs compartment by the neoplastic infiltrate, although other factors that inhibit Blymphocytopoiesis may play a role [18]. HGs are above 5% in these clinical conditions; lymphomas, various non-neoplastic blood cytopenias, post-chemotherapy, post-bone marrow transplantation, and AIDS were the most common [18].

HGs may be low (<0.1%) or even absent in hematological disorders, such as myelodysplastic syndrome (MDS) and aplastic anemia (AA) [31,60,61], possibly due to a T-cell mediated inhibition of hematopoiesis. Down-regulation of genes involved in B lymphopoiesis has been described in MDS (Figure 2) [62,63]. In chronic myeloid leukemia (CML), a significant but unexplained decrease in stage 1 and total HGs compared to age-matched controls has also been reported. The percentage of total HGs, as defined by the population of CD10/CD19 expressing event, decreased in the BM aspirates of patients with CML when compared to age-matched controls (0.26% vs. 0.87%, p<0.001). These differences were maintained in the BM of untreated patients with CML at diagnosis (0.29% vs. 0.87%, p=0.001), as well as the follow-up aspirates post-treatment (0.17% vs. 0.87%, p<0.001) [64].

Clinical significance of HGs

Minimal Residual Disease (MRD): The most important application of HGs’s phenotype knowledge is to distinguish HGs from minimal residual disease in patients treated for B-ALL, non-invasive molecular and flow cytometric MRD analysis are promising tools for future prospective trial using risk stratification with the level of MRD [65,66].

B Cell neoplasia: There are morphologic and phenotypic similarities between HGs and leukemic lymphoblasts in B-ALL [29]. B-lymphoblasts showed concordant expression of CD123 and CD34 in 91% of B-ALL cases (80% CD123+/CD34+ and 11% CD123−/CD34− cases), whereas the HGs had discordant expression(CD34+/CD123− in immature HGs and CD34−/CD123+ in mature HGs [67]. HGs can be distinguished from neoplastic immature lymphoid cells in bone marrow trephine biopsies by their specific morphological features, unique CD34+TdT+CD20< PAX5 immunophenotypic pattern; CD20 positive cells in (78%) of cases in comparison to TdT positive cells in (76%) [52]. HGs should be identified from B-CLL cells during the flow cytometric analysis to reduce ZAP-70 or CD38 false negatives in samples with a high percentage of HGs [68-80].

Prognostic role for hematological malignancies: The exact role of HGs in myeloid malignancies is intriguing. Patients with >0.01% HGs had a significantly better leukemia free and overall survival rates [8]. Moreover, patients who had a negative residual disease after induction and detectable HGs in the bone marrow by flow cytometry had a better (relapse free survival) RFS and OS (overall survival). HGs could be a useful tool to identify prognostic subgroups in MRD-negative patients [80].

Prognostic factor after stem cell transplantation: After stem cell transplantation HGs were quantified at day +30 after (HSCT) and were inversely correlated with the donor’s age. Patients with >5% HGs had a significantly longer overall survival and a lower rate of acute graft-versus-host disease [18,81]. Also the percentage of CD10+CD19+ bone marrow cells at day +100 was associated with improved event-free survival in the multivariate analysis after controlling for the disease stage, cytogenetic group, remission status and chronic graft-versus-host disease (GVHD) [81]. Following cord blood transplantation, a high percentage of HGs at day +21 was found to be associated with a lower rate of grade 3/4 acute, [13]. Disease relapse or complete remission in patients following bone marrow transplantation was examined in several recent published reports to examine risk ratio with 95% confidence interval for each study and/or patient groups extracted from these studies (Figure 3). Systematic review did not calculate overall risk ratio as more valid studies with homogenous patients are required for reliable calculation.

COMMENTS

We have examined 21 published reports and prepared a diagnostic HGs table that contains 10 studies reported how HGs

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### Table 1: studies used HGs as a diagnostic tool in various blood disorders.

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<tr>
<th>Study</th>
<th>Disease</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>A-Diagnosis</td>
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<tr>
<td>Zeidan et al 2016 [63]</td>
<td>B-ALL (MRD)</td>
<td>80% of B-ALL showed concordant expression pattern of the 2 antigens: 63% cases expressed both antigens, whereas 17% expressed neither. The distinct patterns of CD34/CD123 expression on HGs (discordant) and B-ALL blasts (concordant) are useful in differentiating small populations of residual blasts from HGs after induction therapy to detect MRD.</td>
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<tr>
<td>Carulli et al 2015 [69]</td>
<td>NHL</td>
<td>55 non-Hodgkin lymphoma (NHL) patients treated with rituximab-containing regimen. Maturity arrest at the level of stage 2 HGs, along with complete depletion of naïve B-lymphocytes (short-term effects, 2 month). Long-term 12 months follow up while treated with rituximab maintenance therapy, showed complete normalization of B-lymphocyte phenotype. Hypo-gammaglobulinemia was still observed in nine of the 21 patients.</td>
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<tr>
<td>Carulli et al 2014 [34]</td>
<td>NHL</td>
<td>-171 cases of B-cell NHL, either at diagnosis or during follow-up. The combination of K/λ/CD20/CD19/CD10/CD45/CD5 immunophenotyping was specific in detection of HGs in 97.6% of samples and distinguishes normal B-lymphocytes, neoplastic lymphocytes and HGs in a single step. HG percentage showed a significant inverse correlation with the absolute number of neutrophils.</td>
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<tr>
<td>Juranić et al 2014 [70]</td>
<td>Cyclic Neutropenia</td>
<td>The heterozygous mutation of ELANE gene generated severe cyclic neutropenia, granulocytic maturation arrest, an increased number of HGs (26% of marrow cells) in the bone marrow, an absence of neutrophils, and the presence of stage 3 HGs in peripheral blood. The percentage of HGs was inversely proportional to the absolute number of neutrophils.</td>
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<tr>
<td>Tang et al 2012 [61]</td>
<td>MDS</td>
<td>-73 MDS patients and 53 non-MDS patients increased total CD34(+ myeloblasts; decreased stage IIHG; altered CD45/CD5/CD117 expression of lymphoid or mature myelomonocytic antigens on CD34(+) myeloblasts; and several marked alterations in maturing myelomonocytic cells.</td>
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<tr>
<td>Anton-Harisi et al 2012 [71]</td>
<td>Acute megakaryoblastic leukemia</td>
<td>-2 acute myeloid leukemia (AML) M7 patient with 38% and 20% of HGs. Both had thrombocytopenia. BM smear in 1 patient shows 60% cells with morphologic features consistent with acute megakaryoblastic leukemia and the 2nd shows dry tap but on the following aspirate 10% cells with lymphoblastic morphology. Repeated work up gives diagnosis of M7.</td>
</tr>
<tr>
<td>Chow et al Feb 2011 [64]</td>
<td>CML</td>
<td>-CML patients checked for the presence of HGs and compared with an age-matched controls. The percentage of total and stage I HGs were decreased in CML at diagnosis and at follow-up post therapy when compared to age-matched controls (diagnosis: total, 0.29% vs. 0.87%, p = 0.001; diagnosis, stage I: 0.06% vs. 0.20%, p = 0.008; follow-up, total: 0.17% vs. 0.87%, p &lt; 0.001; follow-up, stage I: 0.04 vs. 0.20, p = 0.005).</td>
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<tr>
<td>Akyay et al 2011 [72]</td>
<td>ITP</td>
<td>-2 patients with thrombocytopenia and three lineage dysplasia in the bone marrow suggesting MDS with excess blasts. Light microscopic evaluation of marrow from both patients revealed periodic acid-Schiff (PAS)-negative blasts, flow cytometric analysis revealed excessive HGs in both patients, implying that the cells that were considered as degree of neutrophils were actually large HGs.</td>
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<tr>
<td>Sevilla et al 2009 [31]</td>
<td>AA &amp; MDS</td>
<td>-The percentage of total and early (stage I) HGs were significantly decreased in AA compared to controls, and they returned to normal numbers after hematopoietic stem-cell transplant. This demonstrates early B-cell lineage involvement in AA, similar to recent findings in MDS.</td>
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<td>Babusková et al 2008[73]</td>
<td>AML</td>
<td>-Multiple stages of HGs were observed twice as frequently in B-ALL (73.8%) and T-ALL (69.2%) samples as in AML, asparaginase (41.4%). Stage 3 HGs were found usually in children and were thus frequent in B-ALL. The HGs had an extremely high phenotypic stability unaffected by disease or therapy or by their coincidence with leukemia cells. After each leukemia therapy phase, characteristics of normal regenerating B-cells may be mistaken for a relapse.</td>
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<tr>
<td>B-Prognosis</td>
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<tr>
<td>Li et al 2016 [74]</td>
<td>AML</td>
<td>-Phenotypic analysis revealed a significantly lower proportion of abnormal chromosome karyotype and CD34 expression in HG-positive patients. Survival duration (both leukemia-free and overall) was significantly greater in the HG positive group than in the HG negative group and a lower relapse rate.</td>
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<tr>
<td>Wang et al 2016 [75]</td>
<td>ALL</td>
<td>-High-risk group had a significantly lower number of HGs than the intermediate-risk and low-risk groups (p &lt; 0.05). HGs in the complete remission group was significantly higher than in relapse group (p &lt; 0.05). Children with HGs ≤1.0% had a significantly lower event free survival (EFS).</td>
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<td>Chantepie et al 2016 [76]</td>
<td>AML</td>
<td>-Patients with HGs in bone marrow samples had a significantly better RFS and OS than patients without HGs (p = 0.0021, and p = 0.0016). Detectable HGs (51%) independently predicted RFS (HR = 0.61, 95% CI: 0.42 - 0.89, p = 0.012) and OS (HR = 0.59, 95% CI: 0.38 - 0.92, 0.019) controlling for age, ELN classification, the number of chemotherapy cycles to achieve complete remission (CR), performance status, secondary AML and flow cytometric MRD.</td>
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<td>Chu et al 2014 [9]</td>
<td>AML</td>
<td>-Patients who had detectable MRD ≥0.2% exhibited significantly lower leukemia free survival (LFS) than those who did not (13.5 vs. 48.0 months; p = 0.042).</td>
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<td>C-Misdiagnosis</td>
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</table>
A case where bone marrow infiltration of follicular lymphoma histopathologically mimicked HGs. 

Flow cytometry analysis of his bone marrow revealed a small distinct population of cells expressing dim CD10, CD19, CD22, CD38, dim CD58, HLA-DR, and dim CD45, which are characteristic of HGs however, demonstrated dim surface immunoglobulin lambda-light chain restriction. This case raises awareness of the potential pitfalls of working up bone marrow for involvement by B cell LPDs.

A case in a 16 months old male who was unsuccessfully treated for a pre-B cell ALL on the basis of flow cytometry of the bone marrow which showed CD19 and CD10 expressing 'blast' cells. A diagnosis of AML M7 was made on a subsequent bone marrow biopsy in which the blast cells expressed CD61 and Factor VIII, while they were negative for CD10 and CD20. Also present were a few CD10 and CD20 expressing small lymphoid cells, which were interpreted as HGs. The problem of mistaking HGs for 'blast' cells on flow cytometry, especially in the marrow of very young children where HGs are often prominent.

**Table 1**: studies used HGs as a diagnostic tool in various blood disorders.

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<tr>
<td>Guillory et al 2016 [77]</td>
<td>LPD</td>
<td>Flow cytometry analysis of his bone marrow revealed a small distinct population of cells expressing dim CD10, CD19, CD22, CD38, dim CD58, HLA-DR, and dim CD45, which are characteristic of HGs however, demonstrated dim surface immunoglobulin lambda-light chain restriction. This case raises awareness of the potential pitfalls of working up bone marrow for involvement by B cell LPDs.</td>
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<tr>
<td>Matsuda and Hirota 2015 [78]</td>
<td>FL</td>
<td>A case where bone marrow infiltration of follicular lymphoma histopathologically mimicked HGs.</td>
</tr>
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<td>Chaudhari et al 2014 [79]</td>
<td>AML</td>
<td>A case in a 16 months old male who was unsuccessfully treated for a pre-B cell ALL on the basis of flow cytometry of the bone marrow which showed CD19 and CD10 expressing 'blast' cells. A diagnosis of AML M7 was made on a subsequent bone marrow biopsy in which the blast cells expressed CD61 and Factor VIII, while they were negative for CD10 and CD20. Also present were a few CD10 and CD20 expressing small lymphoid cells, which were interpreted as HGs. The problem of mistaking HGs for 'blast' cells on flow cytometry, especially in the marrow of very young children where HGs are often prominent.</td>
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**Table 2**: Bone marrow transplantation studies used HGs detection as a prognostic biomarker in patient with various blood disorders.

<table>
<thead>
<tr>
<th>Study</th>
<th>Pt #</th>
<th>Age (Y)</th>
<th>Gender</th>
<th>Diagnosis (%)</th>
<th>Type of transplant</th>
<th>Detection Time</th>
<th>Detection Method</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>Hiroto et al 2016 [82]</td>
<td>134</td>
<td>Median</td>
<td>M:F</td>
<td>AML (52%), ALL (25%), MDS (12%), CML (5%), NHL (5%), MM (1%), SAA (1%)</td>
<td>CBT (R=0.32, P&lt;.02)</td>
<td>Day 90</td>
<td>Quantitative analysis (morphology)-Flow cytometry of bone marrow samples</td>
<td>HGs detected in 40.6% of patients at day 30.</td>
</tr>
<tr>
<td>Noriko et al 2015 [83]</td>
<td>260</td>
<td>Median</td>
<td>M:F</td>
<td>AML (n=7), ALL (n=49), MDS (n=33), SAA (n=7), NHL (n=10), ATCL (n=1)</td>
<td>BMT (n=192)</td>
<td>PBSC (n=43)</td>
<td>Day 30</td>
<td>Flow cytometry analysis - HGs are defined by very low side scatter, intermediate expression of CD45, and bright expression of CD19, CD10, and CD38.</td>
</tr>
<tr>
<td>Shima et al 2013 [14]</td>
<td>108</td>
<td>Median</td>
<td>M:F</td>
<td>AML (49.2), MDS (47.3), ALL (56.4)</td>
<td>MNCs of HGs on FACS.</td>
<td>Engraftment day when circulating granulocytes reached &gt; 0.5 X 10^9/L for 3 days</td>
<td>-B-cell precursors within the BM MNCs at the time of complete donor-type engraftment were higher in CBT recipients than in BMT recipients (6.37% vs 1.75%); P&lt;0.001. -In 106 of 108 patients, B-cell precursors were polyclonal based on the rearrangement analysis of the IGH genes. -The frequency of BM B-cell precursors significantly correlated with the number of blood B cells at the time of engraftment (R=0.47, P&lt;0.01). -Inversed correlation between donor age and percentage of BM MNCs in patients treated with BMT (R=0.32, P&lt;.02) and CBT (R=0.42, P&lt;.001). -Patients developed HGs&lt;5% of MNCs had significant better 3-year OS (100%) and RFS (93.3%). -HG&gt;5% of MNCs was more in patients with blood B cells at the time of engraftment were higher in CBT recipients than in BMT recipients (6.37% vs 1.75%); P&lt;0.001. -Patients developed HGs had a high NRM and developed infections and frequent grade II to IV acute GVHD compared to HG(−) patients.</td>
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</table>
could help in disease diagnosis, additional 4 studies showing how HGs could give clues on acute leukemia prognosis and 3 studies pointing how HGs might lead to misdiagnosis. A second table with four studies dedicated HGs in patients before and after BM transplantation and show how HGs levels affects outcome. HGs are precursors of normal B lymphocytes, which are detected morphologically and more accurately by flow cytometry nowadays. A 4-color assay is currently the best method to report HGs percentage in bone marrow samples from patient suffering from several blood diseases or healthy individual [15,18,34,36], these biomarkers may be selected from a list of surface and cytoplasmic biomarkers reported and represented in Figure (1) along with morphologic distinction. However, current HGs measurement by flowcytometry may be affected by changes in gene expression of normal B precursors in various disease status as shown in Figure (2), presence of complex cytogenetic may alter such biomarker expression pattern as shown in AML with normal or complex cytogenetic. Certain blood cancer may lack HGs detection such as MDS which may be related to low HGs level and a lower percentage in fond bone marrow. Detection of HGs may require additional precautions regarding specimen preparation as previously reported and represented in Figure (1) [81-84]. Detection of HGs may also play a critical role in non-B cell malignancies such as ALL, MDS which help in predicting disease free or relapse free survival outcome. Post-chemotherapy or following transplantation, HGs regenerate and their level may be detrimental to patient prognosis and prognostic outcome. Comparison to basal level of HG may be recommended to avoid false prediction of increase level or depleted one. False increase/decrease in HGs may be a requirement to the lab before using it as a reliable biomarker for cancer patients and following BM transplantation. Moreover, considering a basal level may be a better approach for correcting for changes in gene expression of CDs used in HGs immunophenotyping assay.

CONCLUSION

Current literature confirmed that HGs detection may play a critical prognostic role in BMT patients as well as a diagnostic tool for B-Cell neoplasia. However, reliable HGs assay cutoff requires valid large studies to estimate positive and negative predictive values. Basal detection may be recommended for patient follow up considering measurement limitations.

REFERENCES


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**Table 2:** Bone marrow transplantation studies used HGs detection as a prognostic biomarker in patient with various blood disorders.

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<thead>
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<tr>
<td>Honebrink et al2012 [13]</td>
<td>88</td>
<td>N/A</td>
<td>N/A</td>
<td>AML</td>
<td>Cord blood</td>
<td>Day 21 &amp; day 100</td>
<td>Morphological:</td>
<td>-Day 2; Patients with HGs = 0% develop grade III to IV aGVHD (38%, 95%, P=.05) -Patients who had a high BM HGs percentage at day 21 tended to have a high percentage at day 100 (85%) -At day 100, HGs range from 0% to 29.6% -Patients with high HGs percentages ≥0.9% had a 3-year OS of 76% Vs 49% for patients with HGs percentages&lt;0.9% (P = .02) -This improvement in OS was due to decrease in TRM, patients with HGs (≥0.9%) at day 100 showed a 1-year TRM rate of 2% Vs 31%, P&lt;.01</td>
</tr>
</tbody>
</table>

Abbreviations: LAML: Acute Myeloid Leukemia; ALL: Acute Lymphoblastic Leukemia; MDS: Myelodysplastic Syndrome; CML: Chronic Myeloid Leukemia; NHL: Non-Hodgkin Lymphoma; MM: Multiple Myeloma; SAA: Severe Aplastic Anemia
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