Review

Acute Promyelocytic Leukemia: update on the Mechanisms of Leukemogenesis, Resistance and on Innovative Treatment Strategies

NI Noguera [1,2,*] **, G Catalano** [1,2] **, C Banella** [1,2] **, M Divona** [3] **, I Faraoni** [4] **, T Ottone** [1,2] **, W Arcese** [1] **and MT Voso** [1,2]

[1] Department of Biomedicine and Prevention, Tor Vergata University of Rome, Rome, Italy

[2] Santa Lucia Foundation. Unit of Neuro-oncoematologia, I.R.C.C.S. Rome, Italy

[3] Policlinico Tor vergata, Rome, Italy

[4] Department of Systems Medicine, University of Rome Tor Vergata, 00173 Rom, Italy.

* Correspondence: n.noguera@hsantalucia.it; Tel.: +3906501703214, FAX: +3906501703318

Orcid: 0000-0001-7682-862X

Abstract: In this review, we highlight new findings that have deepened our understanding of the mechanisms of leukemogenesis, therapy and resistance in APL. PML-RARa sets the cellular landscape of Acute promyelocytic leukemia (APL) by repressing transcription of RARa target genes and disrupting PML-NBs. RAR receptors control the homeostasis of tissue growth, modeling and regeneration, PML NBs are involved in self-renewal of normal and cancer stem cells, DNA damage response, senescence and stress response. Additional somatic mutations in APL mainly involve FLT3, WT1, NRAS, KRAS, ARID1B and ARID1A genes. Treatment outcomes in patients with newly diagnosed APL improved dramatically since the advent of all-trans retinoic acid (ATRA) and arsenic trioxide (ATO). ATRA activates the transcription of blocked genes and degrades PML-RARα, while ATO degrades PML-RARa by promoting apoptosis and has a pro-oxidant effect. Resistance to ATRA and ATO may derive from mutations in the RARa ligand binding domain (LBD) and in the PML-B2 domain of PML-RARa, but such mutations cannot explain the majority of resistances experienced in the clinic, globally accounting for 5-10% of cases. Several studies are ongoing to unravel clonal evolution and resistance, suggesting the therapeutic potential of new retinoid molecules and combinatorial treatments of ATRA or ATO with different drugs acting through alternative mechanisms of action, which may lead to synergistic effects on growth control or induction of apoptosis in APL cells.

Keywords APL; Therapy; NGS; Resistance; ATO; ATRA; Ascorbate

Introduction

Acute promyelocytic leukemia (APL) is a subtype of acute myeloid leukemia (AML) characterized by a reciprocal and balanced translocation involving the retinoic acid receptor α (*RARa*) on chromosome 17 and promyelocytic leukemia (*PML*) gene on chromosome 15, which generates the oncogenic PML-RARα fusion protein [1–3]. PML-RARα has two primary effects: deregulates transcriptional control (acting as a transcriptional repressor of RARα target genes) and disrupts PML homeostatic function. RARα is a ligand-dependent transcription factor that binds to retinoid X receptors (RXR) to form transcriptionally active heterodimers. RA response elements (RARE) are found in genes that play pivotal roles in a series of physiological processes including cell growth, differentiation, survival and death. Retinoid receptors also activate kinase signaling pathways, which fine-tune the transcription of the retinoic acid target genes [4]. The *PML* gene, due to alternative splicing of its C-terminal exons, displays six nuclear and one cytoplasmic isoforms. The PML protein play a role in a number of cellular processes involving homeostasis and tumor

suppression mechanisms, including response to viral infections and stress, senescence, angiogenesis, differentiation, and maintenance of genome stability. To exert its functions, PML recruits a molecular apparatus organizing peculiar organelles known as nuclear bodies (PML-NBs) [5,6]. The PML-RARα fusion protein acts as a transcriptional repressor of RARa target genes leading to proliferation of myeloid progenitors and maturation arrest at the promyelocytic stage, and disrupts PML-NBs [7–10]. In the present review, we highlight new findings that have deepened our understanding of the mechanisms of leukemogenesis, and resistance, enabling the design of experimental treatment strategies in APL.

APL pathophysiology

RAR receptors (alpha, beta and gamma) signaling is pivotal in the homeostatic control of tissue growth, modeling, and regeneration. Evidence suggests that the RAR transcriptional pathway regulates hematopoietic stem cell (HSC) development, maintenance and expansion, as well as maturation/differentiation into distinct hematopoietic cell lineages.

Ligand-free RARs bind to RAREs on the DNA to repress transcription of RAR responsive genes, through the assemblage of the RAR co-repressors, which include NR corepressor (NCoR) and SMRT, triggering the recruitment of a high molecular weight complex containing histone deacetylase (HDAC), to maintain chromatin in a densely packed, inactive state. Retinoid binding induces conformational changes which cause the dissociation of co-repressors and induction of transcriptional activation of responsive genes [4]. PML-RARα takes control of RARE sites and has a dominant negative action on transcription, inhibiting activation by physiological ligands, causing the maturation arrest at the promyelocyte stage.

PML NBs dysfunction has been implicated in various cellular processes leading to the APL oncogenic phenotype [7,11]. Senescence is known to be the first physiological defense against cellular transformation. Two key observations have directly implicated PML in senescence: Ras-induced senescence is lost in a pml−/− context, conversely PML overexpression induces premature senescence [12,13]. PML NBs are stress-sensitive and are required for p53 action: cells lacking PML show a reduced propensity to undergo senescence or apoptosis in response to p53 activation [14,15]. Notably two of the most active drugs in APL therapy, ATRA and ATO, allow the reformation of PML NBs as the result of PML-RARα degradation [16,17].

PML-NBs also have an important role in the mechanisms of DNA damage response (DDR) via both NHEJ and HR repair pathways. Its disruption by PML-RARα strongly affects ATM activation, as well as CHK2 and NBN phosphorylation [18,19]. ATM kinases are clients of the HSP90α chaperone, whose inhibition leads to the destabilization of these important components of the DNA damage response [20]. Recently, we demonstrated that Hsp90 is downregulated in the presence of PML-RARα [21], thus could hampering DNA damage response in APL cells.

PML NBs are involved in the self-renewal of normal and cancer stem cells [22,23]. PML contributes to embryonic stem cells (ESC) self-renewal maintenance by controlling cell-cycle progression and sustaining the expression of crucial pluripotency factors [24]. Among these, phosphatase and Tensin homologue deleted on chromosome 10 (PTEN) is an important tumor suppressor and plays a pivotal role in the self-renewal of hematopoietic stem cells. Its ablation promotes the exhaustion of normal hematopoietic stem cells (HSCs) and the generation of leukemia-initiating cells (LICs) [25,26]. The ubiquitinylation and subcellular localization of PTEN are regulated by a HAUSP-PML network [27], we demonstrated that PML-RARα directly suppresses PTEN expression [28]. The lack of PTEN anticancer control could play a pivotal role in favoring the emergence, survival and proliferation of damaged stem cells, allowing the accumulation of additional genetic events towards leukemogenesis.

The PML-RARα phenotype is also characterized by the downregulation of autophagy-related genes (ATGs) (i.e., ULK1, BECN1, ATG14, ATG5, ATG7, ATG3, ATG4B and ATG4C) [29–31]. Autophagy or "self-eating" is a highly conserved, closely regulated homeostatic cellular activity that allows for the bulk degradation of long-lived proteins and cytoplasmic organelles [32].

Autophagy is one of the main cellular catabolic pathways controlling a variety of physiological processes and its disruption interferes with the machinery of self-renewal, differentiation and death [33], its roles in cancer initiation and progression and in determining the response of tumor cells to anticancer therapy are complicated. A recent study provided evidence for a new function for PML as a repressor of autophagy when associated at the mitochondrial-associated membrane (MAM) [34]. However, whether or not PML-RARa inhibits autophagy through its binding to MAM has not yet been investigated. These observations differ from data reporting that PML-RARa is involved in constitutive activation of autophagy through inhibiting the AKT/mTOR pathway in APL cells [35]. The reason for seemingly opposite effects of PML-RARa on the regulation of autophagy remains to be clarified. Figure 1 depicts the pathophysiologic aspects of APL (Figure 1).

Ethnicity is considered a measure of genetic and lifestyle. Some studies, mainly from Latino America, suggested that Latino population had a higher proportion of APL among all AML diagnosis, which ranged around 30-38% against less then 10-7% in the non-Latino population [36-38]Nevertheless Latino is not an ethnicity and is very difficult to define what is the characteristic of such population. On the other hand several reports did not find any significant variation in the incidence, and there is no hard evidence of any ethnic physiological or life style difference linked to APL incidence.
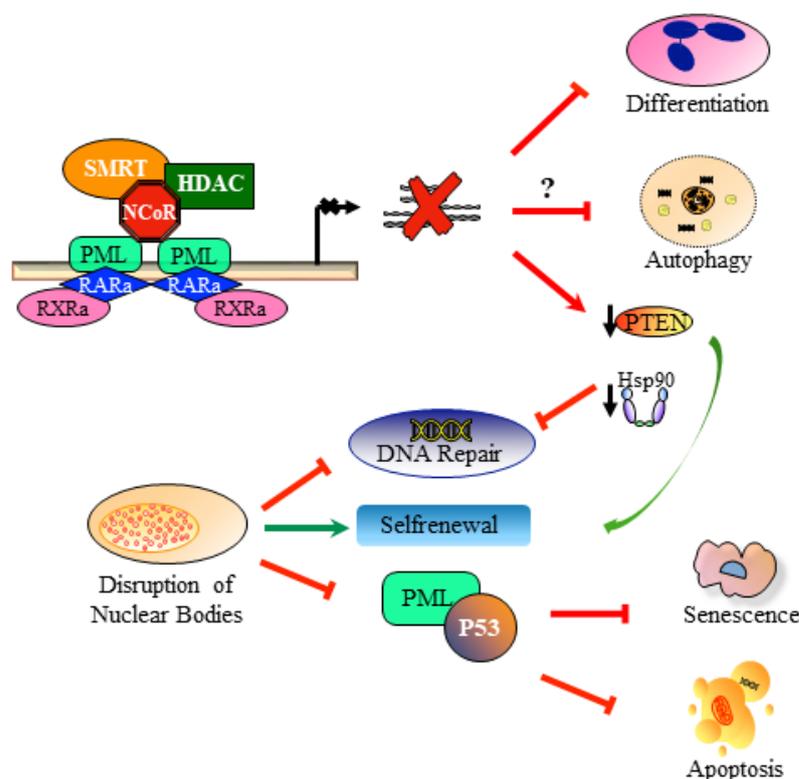

Figure 1. Schematic representation of the molecular mechanisms involved in APL Pathogenesis. PML/RARA exerts dominant-negative effects on RAR/RXR-dependent transcriptional control through the recruitment of co-repressor complexes (CoR) (top) and PML nuclear bodies assembly (bottom). The direct or indirect regulation of target genes is responsible for the differentiation block, aberrant self-renewal, and impairment of autophagy and apoptosis observed in APL blasts. PML nuclear bodies disruption drives enhanced self-renewal, inhibition of DNA damage response and inhibition of senescence and apoptosis, in part by p53 inactivation.

Additional genetic events

PML-RAR*α* rearrangement is the main pathogenetic event of APL. However, its expression in the bone marrow in a mouse model leads to a myeloproliferative phenotype similar to chronic myeloid leukemia, while the emergence of full-blown APL requires 12–14 months [12,39]. This long latency suggests that additional genetic/epigenetic changes are necessary to flare the APL phenotype. By next generation sequencing (NGS), a recurring point mutation (*Jak1* V657F or V658F in humans) and a recurring deletion in histone demethylase *Kdm6a* were identified in a mouse APL model [40]. *In vivo* data have shown that aberrant Jak1 signaling can play an important role in APL pathogenesis and that the JAK-STAT signaling may be activated by different mechanisms in a mouse model of APL. The role of *KDM6A* mutation in APL pathogenesis is not clear yet, but it may involve the dysregulation of Hox, Notch, or Rb signaling pathways [41–44].

The topography of somatic mutations in APL is defined by recurrent alterations of FLT3, WT1, NRAS, KRAS, ARID1B and ARID1A genes, and the near-absence of mutations in other common AML genes [45–48]. A recent survey of 153 primary and 69 relapse APL samples by whole-genome sequencing showed that both primary and relapse APL harbored an average of eight non-silent somatic mutations per exome. Recurrent alterations of *FLT3* (43%), *WT1* (14%), *NRAS* (10%) and *KRAS* (4%) in newly diagnosed APL were reported, whereas mutations in other genes commonly mutated in myeloid leukemia including *DNMT3A*, *NPM1*, *TET2*, *ASXL1* and *IDH1/2* were absent [45]. In a Chinese report on 84 APL samples studied by RT-PCR, the prevalence of mutations was 60.7% (51/84), with 27.4% *FLT3-ITD* mutations, 14% *WT1* mutation, 10% *FLT3-TKD*, 8% *TET2*, 6% *N-RAS*, 5% *ASXL1*, 2% *EZH2* mutations and 1% each for *MLL-PTD*, *IDH1* and *CBL* mutations, respectively. No mutations were found in other common leukemia-related genes: *JAK1*, *DNMT3*, *c-Kit*, *NPM1*, *IDH2*, *RUNX1* and *JAK2* (V617F) [46]. We reported a low frequency of mutations of *WT1* exon 7 and 9 in 103 APL samples (4%) [49]. Activating *FLT3* signaling mutations are often present in APL, associated with hyperleukocytosis, a major adverse risk factor in chemotherapy-based regimens [50,51]. FLT3, KRAS, trisomy 8 and deregulated expression of BCL2 have been described as cooperators of PML-RARa in mouse models of APL[52,53]. Recently, Esnault et al. demonstrated, also in an APL mouse model, that *FLT3-ITD* mutations severely blunt ATRA response. The combination of ATRA and ATO fully rescued therapeutic response in *FLT3-ITD*+ APLs, leading to PML-RARa degradation, PML nuclear body reformation, P53 activation and APL eradication [54]. This study further reinforces the biological importance of the presence of *FLT3-ITD* mutations independent from its allelic ratio in the context of the disease. A recent report by Iaccarino et al describe a median of two additional mutations per patient (range, 0-3) at the time of APL diagnosis, in 11 patients who later relapsed and a median of one mutation (range 0-2) in 21 of 33 APL patients, who remained in continuous complete remission (P = .0032). They also found NRAS and RUNX1 mutations only in patients who later relapsed, with *FLT3* (ITD/TKD: 5 of 11 patients, 45%) and NRAS (3 of 11 patients, 27%) as the most frequently mutated genes. The *FLT3-ITD* mutations were present in most high-risk patients, but were not significantly associated wtih the risk of relapse. The Authors suggest that molecular patterns detectable at diagnosis may predict treatment response. Comparing the initial mutational status of patients who relapsed during the course of disease (n = 11) with those in CCR (n = 33), they found differences in concomitant mutations, with *NRAS* and RUNX1 mutated only in the first group of patients, suggesting their possible role as predictive markers of relapse. Of note, also the number of concomitant mutations per patient was significantly higher in the group who later relapsed (P < .0001) indicating an accumulation of genetic alterations during disease progression. In particular, they found mutations associated with clonal hematopoietic expansion, like *ASXL1*, *DNMT3A*, *JAK2*, *SRSF2*, *TET2* and *TP53* [47]. However, validation studies are needed to confirm these hypothesis

The optimal management of APL requires early diagnosis, institution of aggressive supportive measures, appropriate management of treatment-related complications, and monitoring of measurable residual disease (MRD) for the presence of PML/RARa. MRD monitoring is not recommended in non–high-risk patients who achieve profound molecular remission (CRMRD2)

status after consolidation, independently from induction treatment (ATRA plus ATO or ATRA plus chemotherapy)[55]. Contrarily high-risk patients and those not responding well to induction therapy request frequent and accurate monitoring. As mentioned before a relatively large set of genes are mutated or aberrantly expressed in APL. These genetic alterations, over their significance in prognosis, might be of use as clonal markers in measuring MRD after treatment. The availability of new more sensitive methods of investigations, like deep sequencing and mutation-specific ddPCR, enable a better understanding of the clonal evolution in cases harbouring several mutations acquired during disease progression. But, apart from high-risk characteristics, how to discriminate at onset the cases that need a more timely diagnostic approach? The first study to propose a molecular risk score in APL was reported by Hecht et al. Although the sample size was limited (79 patients), the authors demonstrated that *BAALC, ERG* and *WT1* expression levels integrated into a score could offer a promising approach to guide the monitoring of patients with APL treated with ATRA and high doses of cytarabine [56, 57]. Recently Lucena-Araujo et al. in a recent study, propose the use of an integrative score in APL (ISAPL) based on *FLT3-ITD* mutational status, ΔNp73/TAp73 expression ratio, *ID1*, *BAALC*, *ERG* and *KMT2E* gene expression levels. They propose that the combination of gene mutation with gene expression analysis could improve outcome prediction in acute promyelocytic leukemia. The authors suggest that a better understanding of the molecular limitation of patients in responce to ATRA and anthracycline-based chemotherapy could serve as the basis for future initiatives aiming to change the current scenario for APL treatment in patients who live in low- and middle-income countries (LMIC) [58]. Adicional mutations events are resume in Table 1.

Immunophenotypic characteristics

APL cells show absent or minimally expression gp-170 as well as other proteins associated to multidrug resistance, such as MRP1, MRP2, and LRP, present in a high proportion of AMLs, a feature that may be relevant to explain the striking sensitivity of APL blasts to anthracyclines [59]. APL is characterized by low or negative CD34 expression, infrequent expression of HLA-DR and lack of CD7, CD11a, CD11b, CD14 and CD18, strong positivity for CD33, expression of CD13 and CD117 [60], and frequently show aberrant expression of the T-cell-associated antigen CD2 which is associated with the microgranular variant morphology and increased leukocyte counts at presentation [17,59,61]. CD56 expression has been associated with resistance to standard ATRA and chemotherapy [62]. In a recent Chinese review of 798 APL cases the authors describe high SSC, absence of expression of CD34 and HLA-DR, strong expression of CD33 in 90% of cases, consistent expression of CD13, CD9, CD123, expression of CD56, CD7, CD2 (sometimes). The remaining 10% of the cases show atypical APL phenotypes, positive for CD34 and/or HLA-DR expression, with decreased SSC, and frequent CD2 expression [63], suggesting that an inclusive approach is required to indicate further genetics or molecular biology tests at diagnosis.

Insight into the mechanisms of treatment resistance in APL

Knowledge on the mechanisms of resistance to treatment in APL is vitally important to develop new therapies. ATRA has a double therapeutic function in APL: activates the transcription of genes involved in myeloid lineage differentiation and degrades the PML-RARα oncoprotein. ATO degrades all PML containing molecular species, promoting apoptosis in APL cells, has a pro oxidant effect and damages protein structures at large by resolving disulphide bonds. Resistance to

Table 1. Additional Genetic Events

Author	Source	Number of samples		Method	Molecular Alterations		Ref
		Dx	Relapse		Dx	Relapse	
Madan, et al	Human	163	69	WGS	FLT3 (43%), WT1 (14%), NRAS (10%) and KRAS (4%), ARID1A (5%), ARID1B (3%), LRP1 (3%)	PML(17%), RARA (10), FLT3-ITD (25%), WT1 (18%), ARID 1B (12%) RUNX1 (5%), FLT3 (5%), NRAS (5%), ARID1B(5%), NRAS (5%), ETV6 (4%), FANCA (3%), TP53 (3%), LRP1 (3%), KMT2C (3%)	42
Yin J, et al	Human	84	-	Genomic DNA-PCR	FLT3-ITD (27%), WT1(14%), FLT3-TKD (10%), TET2 (8%), N-RAS (6%), ASXL1 (5%), EZH2 (2%), MLL-PTD (1%), IDH1 (1%) and CBL (1%)	-	43
Iaccarino, et al	Human	33	31	NGS (31-gene panel)	FLT3-ITD (34%), WT1 (20%), NRAS (7%), RUNX1 (5%), FLT3-TKD (9%), DNMT3A (5%), ETV6 (2%), MYC (2%), SETBP1 (2%), SF3B1 (5%), TET2 (%)	WT1 (13%), FLT3-ITD (10%), DNMT3A (10%), ETV6 (10%), FLT3-TKD (6%), TET2 (6%), ASXL1 (3%), JAK2 (3%), RUNX1 (3%) SRSSF2 (3%), TP53 (3%), U2AF1 (3%), PML (19%), RARa (10%)	44
Gaur, et al	Human	103	-	DNA Sequencing (Ex 7-8)	WT1 (4%)	-	46
Wartman, et al	Mouse model	-	-	NGS	Jak1 V657F or V658F and Kdm6a	-	40

WGS: whole genome sequence, NGS: nex generation sequencing

ATRA and ATO could derive mechanically from genetic mutations resulting in amino acid substitution in the RARa ligand binding domain (LBD) and in the PML-B2 domain of PML-RARa respectively [47,66–68]. LBD mutation are confined to three clusters regions and were confirmed in 18 out of 45 (40 %) relapsed patients treated with ATRA-chemotherapy [67]. Dicysteine C212/C213 in PMLB2 domain is critical for direct ATO binding and for the serial reaction of sumoylation, multimerization, and degradation of PML-RARa [69]. However such mutations cannot explain the majority of resistance to ATO experienced in the clinic.

Recently Lehmann-Che et al studied by exome sequencing 64 matched samples collected from patients at initial diagnosis, during remission, and following relapse after ATRA-chemotherapy treatment. They confirmed that APL is a relatively simple disease under the genetic profile, which at diagnosis is similar in patients who later relapse or remain in complete remission, except for a significant excess of WT1 mutations or loss (7/18, 40%) in relapsing patients, and, importantly, that some relapses were completely distinct from the diagnostic APL clone [68]. This has been previously observed also in chemotherapy-treated core-binding factor leukemias [70]. Lehmann-Che, et al identify, in addition to WT1 mutations, rare anomalies involving activators of MAP kinase pathway and/or other epigenetic controllers that disrupt key epigenetic or transcriptional regulators. Once relapsed, the disease often acquires additional oncogenic alterations and/or mutations impairing treatment response (RARa, NT5C2). Some mutations present at diagnosis were lost upon relapse, mainly including FLT3 and other passenger mutations. The data infer that the relapses derive from PML-RARA expressing clones, different from the one expanded at disease onset, that survived ATRA-chemotherapy [68].

We analyzed by NGS a 31 'myeloid' gene panel in 33 patients in continuous complete remission (CCR) and in 11 relapsed APL patients, including four cases with multiple relapses. All APL with multiple relapses after ATRA-ATO displayed a significantly higher number of mutations as compared to CCR patient samples, indicating an accumulation of genetic alterations during disease progression. In particular, we found mutations associated with clonal hematopoietic expansion, like *ASXL1*, *DNMT3A*, *JAK2*, *SRSF2*, *TET2* and *TP53* [47]. The mutational patterns suggested different models of disease progression. In some patients, relapses may originate from the driver clone present at diagnosis. In other cases, relapses probably emerged from ATO or ATRA -resistant subclones. Particularly, PML-mutated subclones seemed to arise under selective pressure of ATO treatment.

Esnault et al reported that FLT3-ITD severely blunts ATRA response, not preventing PML-RARα dislocation of NCoR/HDAC complex from the RARE motifs, but protecting the oncoprotein from degradation. Thus, although in the presence of FLT3 mutations the transcriptional output of initial ATRA response is unaffected, the retinoid fails to degrade PML-RARA protein, whose persistence in the cells confers the APL phenotype with PML nuclear body disruption and deactivation of P53 signaling. The resistance is overcome by ATO [54], reflecting the efficacy of the ATRA/ATO combination in patients with FLT3 mutation proven in different clinical studies. [71,72].

Autophagy is another mechanism involved in APL resistance. The relationship between autophagy and cancer is complex, with both deficiency and over-activation contributing to the development and progression of cancer. In general, during the advanced stages of malignant disease, clonal evolution reactivates autophagy to provide for the metabolic needs of the cells and to promote tumor growth, invasion and metastasis. APL cells display low levels of expression of autophagy genes and reduced autophagy activity: ATRA restores autophagy in these cells allowing granulocyte differentiation through the degradation of PML-RARa [73]. ATO also promotes autophagy-dependent clearance of PML-RARa in APL cells [73–75]. Hence, enhancing autophagy may have therapeutic benefits in maturation-resistant APL cells. However, the role of autophagy following APL therapy is not so simple, since some autophagy regulatory proteins (e.g., BECN1 and p62/SQSTM1) have been shown to play a pro-survival role during ATRA and ATO treatment. This might contribute to the development of resistance to treatment [33].

Alex et al. used whole exome sequencing to address ATO-resistance mechanisms in three NB4 APL cell line clones developed under ATO treatment pressure. They identified alterations in the redox system, the ubiquitin-proteasome degradation pathway and the PI3-AKT signaling pathway

[76]. Consistent with this report, low levels of ROS, glutathione and glucose uptake have been observed in ATO-resistant NB4 cells, proposing a metabolic rewiring hypothesis as ATO-resistance mechanism in APL cells [77]. Chendamarai using Micro-Array expression profiling studied 8 ATO-sensitive and and 8 ATO-resistant patient samples, and found the differential regulation of the following functional pathways: (i) Cell adhesion: Integrins, Cadherins and Mucins, (ii) Cell survival and anti-apoptosis: PI3-AKT, PTEN, NFκB, MAPK and JAK-STAT, (iii) Stem cell regulation: Wnt, Hedgehog and CD34 and (iv) Immune regulation: TNF-receptor super family genes, Interleukins. Multi drug resistant (MDR) glycoprotein is scarcely expressed by APL cells, there is evidence that after relapse and in therapy resistant NB4 cell subclones MDR and other detoxification related proteins (as MRP1) seem to be upregulated, but the role of detoxification is not capital in the resistance mechanism. P-glycoprotein (P-gp) and multidrug resistance-associated protein 1 (MRP1) are induced by arsenic trioxide (As2O3), but are not the main mechanism of As2O3-resistance in acute promyelocytic leukemia cells[78]

Very little is known on the role of the microenvironment in APL. Several studies have shown that RARs regulates non-hematopoietic cells present in the bone marrow microenvironment influencing stem cell fate [79–81].

Su M. et al proceeding from the premise that AML cells are responsive to ATRA *in vitro*, whereas the drug is not efficient in the clinic, and that APL patients relapse after ATRA monotherapy, hypothesized the enhanced activity of ATRA metabolizing enzyme cytochrome P450 gene CYP26 by stromal cells, which could contribute to the rescue of APL cells and to persistence of residual disease [82].

PML function is essential for immunosurveillance and has been proven that its degradation via ubiquitination promotes lung cancer progression by fostering an immunosuppressive and prometastatic tumor microenvironment [83]. During therapy, degradation of PML by ATO also occurs in the BM stromal cells mimicking this effect, and contributing to sparing APL stem cells in relapsing patients. A recent report provides evidence for the involvement of microenvironment-mediated drug-resistance in ATO treated APL cells, which is driven by the nuclear factor kappa B (NF-kappa B) pathway [84].

Finally, a very limited number of patients, showing an APL phenotype devoid of the t(15;17), exhibit a variety of X-RARa fusions: PLZF [85]; NuMA [86], NPM [85], STAT5b [87], FIP1L1 [88], PRKAR1A [89], ZBTB16 [90]; BCoR [91]; OBFC2A [92]; TBLR1[93]; GTF2I [94]; IRF2 [95]; FNDC3B [96] and TGF [93]. Interestingly, most patients expressing X-RARa show clinical resistance to ATRA and/or ATO, but the molecular mechanism involved is not well known. In the case of PLZF-RARa, the resistance to ATRA has been associated with the reciprocal transcript RARa-PLZF via CRABPI-upregulation [97]. The molecular mechanisms of ATRA resistance in STAT5b-RARa could be related to aberrant transcription regulation of STAT5b target genes, but the mechanism must be investigated. ZBTB16 and TBLR1 are also ATRA-resistant. ATO resistance in clinical setting has been observed in patients expressing PLZF-, STAT5b-, BCoR- and ZBTB16-RARa [90]. The lack of

ATO binding sites in X-RARa proteins may cause the resistance to ATO treatment. (Figure 2).
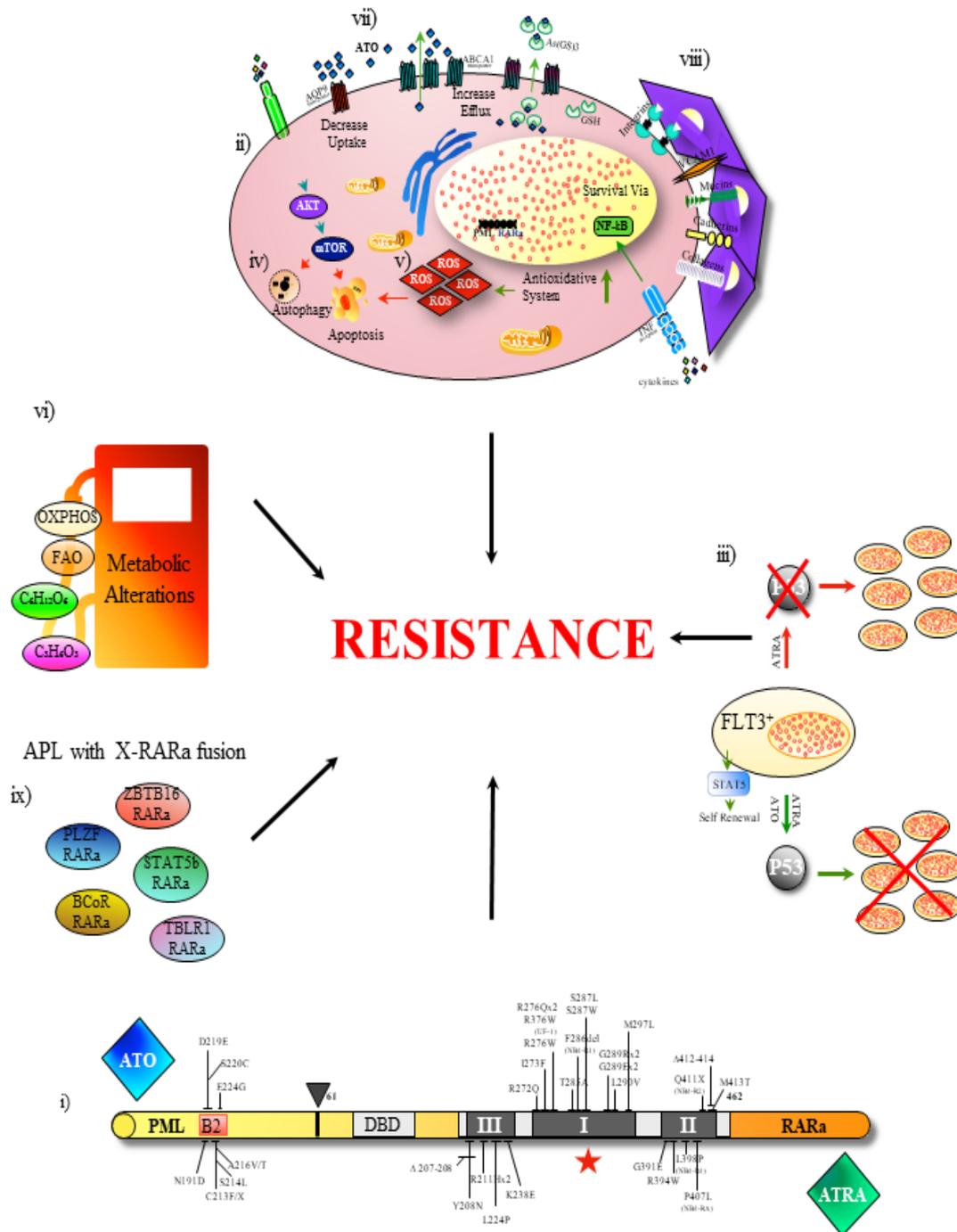

Figure 2. Mechanism of Resistance to ATO-ATRA Therapy in APL. Resistance to ATRA and ATO may derive from: i) genetic mutations resulting in aminoacid substitution in the RARa ligand binding domain (LBD) and in the PML-B2 domain of PML-RARa ii) deregulated pathways like AKT/mTOR, activators of MAP kinase pathway and/or other epigenetic controllers or additional gene mutations (ei *WT1*), iii) FLT3-ITD severely blunts ATRA response, which fails to degrade PML-RARA protein whose persistence in the cells confers the APL phenotype with PML nuclear body disruption and deactivation of P53 signaling. This type of resistance is overcome by ATO iv) some autophagy regulatory proteins BECN1 and p62/SQSTM1 have been shown to play a pro-survival role during ATRA and ATO treatment, v) alterations in the redox system. vi) Metabolic alterations vii) High expression of MDR proteins, viii) Microenvironment influences ix) Presence of X-RARa fusions.

9

Experimental strategies for the treatment of resistant APL

Treatment outcomes in patients with newly diagnosed APL have improved dramatically in the last three decades since the advent of ATRA and, some years later, the introduction of ATO-ATRA combined with chemotherapy resulted in cure rates above 80%; but was associated with the risk of severe infections and secondary leukemias [98–101]. ATO has been shown to act synergistically with ATRA to induce the degradation of the PML-RARA oncoprotein [102] and the chemo-free ATRA-ATO approach is nowadays regarded as the first treatment choice for patients with non-high-risk APL [71,72,103]. A recent review from the European leukemia network details the guidelines in the management of frontline and relapsed APL and the specific recommendations for the identification and management of the most important complications: bleeding disorder, differentiation syndrome, QT prolongation and all the other toxicities related to treatment with ATRA and ATO [55]

When diagnosed and treated promptly, APL is curable in the vast majority of patients, yet approximately 5 % of cases are resistant to standard therapy and 5 to 10% relapse and eventually become resistant (Coombs et al 2015). In these patients hematologic stem cell transplantation (allo-HSCT) is the only curative approach [55]. ATRA is the retinoid of choice, but other retinoids are being developed. A recent randomized study of the Japanese Adult Leukemia Study Group comparing the new retinoid molecule tamibarotene demonstrated a significant relapse-free survival benefit over ATRA as maintenance therapy [104].

Much effort has been dedicated to identify specific targets and novel compounds acting in synergy with, and preventing resistance to retinoids and ATO. HDAC inhibitors as sodium butyrate, valproic acid and trichostatin A have been used in combination with ATRA in the attempt to inhibit co-repressor complexes that contain HDACs recruited by PML-RARα[105]. Gemtuzumab ozogamicin (GO), an anti-CD33 monoclonal antibody linked with calicheamicin, efficiently targets highly CD33- expressing APL cells[106–108].

We recently reported that megadoses ascorbate (ASC) induce degradation of PML-RARa and cause apoptosis *in vitro* in a variety of human myeloid cell lines, including ATRA-and ATO-resistant cell lines, and cord blood-derived normal CD34+cells [109,110].
ATO itself is a pro-oxidant factor downregulating ROS scavenging proteins and disrupting redox pathways [69,111,112], which may act synergistically with ASC at high doses, also a potent oxidant [113–115]. Indeed, blasts from APL patients were highly sensitive to the ASC-ATO combination including a PLZF-RARa positive case [109]. APL cells higher sensitivity to redox unbalance is due in part to PML-RARα interfering with NRF2 subcellular distribution and inhibiting its transcriptional activity (manuscript in preparation). Of note, ASC treatment causes inhibition of activated FLT3 signaling [109] and the combination with ATRA can be of help in FLT3-mutated cases, since FLT3-ITD mutation blocks the therapeutic response to ATRA in an APL mouse model [54]. Recently, Masciarelli et al observed a strong synergistic cytotoxic effect of ATO and the endoplasmic reticulum (ER) stress-inducing drug Tunicamycin (Tm) in ATRA sensitive and resistant APL cell lines [116]. Gu et al reported that pharicin B, a novel natural entkaurene diterpenoid, a family of compounds with a long-standing history of medical applications as traditional Eastern remedies, stabilizes RARα protein and has a synergistic effect with ATRA in inducing differentiation in AML cells. It also overcame ATRA resistance in two NB4 subclones [117]. Wang et al. identified a novel synthetic small compound, named LG-362B, that induces caspases-mediated degradation of PML-RARα, overcoming ATRA resistance and inducing cellular differentiation in transplantable APL murine models [118]. Calvo et al reported that Benznidazole (BZL), a nitro aromatic anti-parassitary drug, inhibits the proliferation of leukemic cells by blocking the cell cycle at the G0/G1 phase through up-regulation of p27 [119]. Lu and Yan reported that 2-bromopalmitate, an inhibitor of fatty acid oxidation, overcomes ATRA resistance in cell lines and *in vivo* APL mouse models. Mechanistically, 2- Bromopalmitate covalently binds and stabilizes RARα protein, leading to enhanced transcription of RARα-target genes. They propose the combination of ATRA and 2-Bromopalmitate as a promising therapeutic strategy to overcome resistance in

relapsed APL patients [120]. Ganesan et al reported a synergistic effect of ATO plus Bortezomib in both ATO-sensitive and resistant APL cell lines. The mechanism of the synergy involved downregulation of the NFκB pathway, increase in unfolded protein response (UPR) and in reactive oxygen species generation in the malignant cell. PML-RARa oncoprotein is effectively cleared with this combination despite the inhibition of the proteasome by bortezomib, since the clearance is mediated through a p62-dependent autophagy pathway [77]. As mentioned before, autophagy downregulation by PML-RARα contributes to the differentiation block, therefore potentiation of this mechanism could be a desired strategy for the differentiation therapy of APL. In this line, rapamycin and lithium, two well-known activators of autophagy, may enhance therapeutic effectiveness of both ATRA and ATO in APL cells. Recently, Hussain et al reported that phenylarsine oxide (PAO), one of the organic arsenic derivatives, could induce PLZF-RARα degradation through the ubiquitin proteasome degradation pathway and cause apoptosis [121]. Experimental strategies for resistance are resumed in Table 2.

Prophylaxis for incidence of CNS relapse

In the ATO era central nervous system (CNS) involvement is rare in APL but causes poor prognosis. There are no hard biological data available concerning APL CNS localization, it had been associated with several factors including high WBC count (>10 × 10^9/L), CNS hemorrhage, expression of CD2, and/or CD56 in blasts, PML-RARA bcr3 isoform, differentiation syndrome, and above all induction therapy with single agent ATRA and regimens without Cytarabine [122]. Disproved a possible association between the use of ATRA and the development of extramedullary disease [123], it is conceivable that the emergence of such a complication was more apparent due to better therapy and prolonged survival of resistant patients. ATO is known to cross the blood-brain barrier and has CNS penetration at therapeutically meaningful levels (CSF concentration at 20% to 50% of plasma concentration). Recently Sanz et al reported that there are no formal data supporting the use of CNS prophylaxis in the ATO era [124]. Also Larson et al do not recommend intrathecal chemotherapy (ITT) in the treatment of APL for any risk, thus prophylactic ITT was not used in trials that incorporated ATRA and ATO [125-128].

Conclusion and future perspectives

Since the first insights into the PML-RARa network and the differentiating effect of retinoids, APL has been a fascinating field for researchers, first example of an acute myeloid leukemia cured without antiblastic chemotherapy. In all, a very successful history of setting the clinical standards, at least in countries that without economical restraints for the expenses necessary for early diagnosis and treatment. One of the main challenge in APL to date is prompt diagnosis and treament, since the early death rate still reaches 15%, which is unacceptable in this disease. Yet, approximately 5 to 10% of patients will relapse and may become resistant. Thus, identification of patients at risk of clonal evolution and resistance is of vital importance. The complete definition of the genomic landscape of APL and the characterization of meaningful accessory genetic alterations, point mutations, gene copy number amplification or loss, and modification of the epigenome may pave the way for a deeper understanding of the regulatory networks in APL cells. In particular, definition of metabolic peculiarities may provide useful prognostic information and therapeutic targets, facilitating the development of active and safe agents to be tested in clinical trials.

Table 2. Experimental Strategies for Resistance

Author	Drug	Function	Study	Source	Result	Follow up	p	Ref
Takeshita, et al.	Tamibarotene (TAM)	RAR α agonist	Clinical trial	270 Patients	RFS %: TAM 94; ATRA 84	7- Year	0.027	104
Lo Coco, et al	Gentuzumab Ozogamicin	Anti CD33 + Calicamicin	Prospective Study	16 Patients Relapse	RFS % 43 ± 15%	31 month	-	106
Gale, et al	CEP-701 (Lestaurtinib)	FLT3 inhibitor	*In vitro*	Primary APL blast (n=6)	Greater effect on cell survival/proliferation in FLT3/ITD cells, but this inhibition was reduced in the presence of ATRA	-	-	107
Mastrangelo, et al	Ascorbate Megadose	Pro-oxidant,	*In vitro*	Cells Lines (n=6)	Highly sensitive, with an average 50 % lethal concentration (LC50) of 3 mM Normal CD34+ not sensitive	-	-	109
Noguera, et al	Ascorbate Megadose	Pro-oxidant,	*In vitro*	Primary APL (n=9) and AML (n=33) Blast; Cells Lines (n=5)	Higer sensitivity ASC induce PML/RARa and PML degradation ASC potenciate the effect of ATO Normal CD34+ not sensitive	-	<0.001	110
Masciarelli, et al	Tunicamycin	endoplasmic reticulum (ER) stress-inducing drug	*In vitro*	Primary APL Blast; ATRA sensitive and resistant APL cell	ER stress + ATO induced apoptosis in RA-sensitive an RA-resistant APL cell lines	-	<0.005	116
Gu, et al	pharicin B,	stabilizes RARα protein	*In vitro*	Primary APL Blast; ATRA sensitive and resistant APL cell lines	Induced apoptosis in RA-sensitive and RA-resistant APL cell lines	-	<0.001	117
Wang, et al	LG-362B,	caspases-mediated degradation of PML-RARα	In *vitro* e in *vivo*	Primary APL Blast; ATRA sensitive and resistant APL cell lines Murin models	Inhibits the proliferation of APL in vitro and in vivo Synergistic or additive differentiation effect with ATRA Overcom ATRA resistance	-	RTW: <0.01	118
Lu and Yang	2-bromopalmitate (2-Br)	inhibitor of fatty acid oxidation	*In vitro*	Primary APL Blast; ATRA sensitive and resistant APL cell lines Murin models	ATRA + 2Br to overcoming ATRA resistance	-	Blast: <0,05 to <0,001 (n=7); >0,05 (n=4) RTW: <0.05	120
Ganesan et al	ATO plus Bortezomib	downregulation of the NFκB pathway, PML-RARa degradation inhibition of the proteasome by bortezomib	*In vitro* e in *vivo*	ATO sensitive and resistant APL cell lines Murin models	Synergistic effect in both ATO sensitive and ATO resistant APL cell lines Reduce leukemic burden and induce long-term survival in an APL mouse model	-	OS mouse: 0.0001	77
Hussain et al	phenylarsine oxide (PAO)	organic arsenic derivatives	*In vitro*	Cells Lines transfected with PLZF-RARa	PLZF-RARa degradation	-	-	121

RFS: relapse-free survival, RTW: reduction tumor weight, OS: overal survival

Authors contribution: NIN write the manuscript, GC co-wrote the manuscript, CB contributed with the design of figures, MD, IF and TO critically reviewed the manuscript and contributed with the graphical abstract, WA and MTV critically reviewed the manuscript and amended the final report.

Conflicts of Interest: The authors declare no conflict of interests.

Reference

1. De Thé, H.; Chomienne, C.; Lanotte, M.; Degos, L.; Dejean, A. The t(15;17) translocation of acute promyelocytic leukaemia fuses the retinoic acid receptor α gene to a novel transcribed locus. Nature 1990.

2. Alcalay, M.; Zangrilli, D.; Pandolfi, P.P.; Longo, L.; Mencarelli, A.; Giacomucci, A.; Rocchi, M.; Biondi, A.; Rambaldi, A.; Lo Coco, F.; et al. Translocation breakpoint of acute promyelocytic leukemia lies within the retinoic acid receptor α locus. Proc. Natl. Acad. Sci. U. S. A. 1991.

3. Grignani, F.; Ferrucci, P.F.; Testa, U.; Talamo, G.; Fagioli, M.; Alcalay, M.; Mencarelli, A.; Grignani, F.; Peschle, C.; Nicoletti, I.; et al. The acute promyelocytic leukemia-specific PML-RARα fusion protein inhibits differentiation and promotes survival of myeloid precursor cells. Cell 1993, 74, 423–431.

4. Di Masi, A.; Leboffe, L.; De Marinis, E.; Pagano, F.; Cicconi, L.; Rochette-Egly, C.; Lo-Coco, F.; Ascenzi, P.; Nervi, C. Retinoic acid receptors: From molecular mechanisms to cancer therapy. Mol. Aspects Med. 2015.

5. Hadjimichael, C.; Chanoumidou, K.; Nikolaou, C.; Klonizakis, A.; Theodosi, G.I.; Makatounakis, T.; Papamatheakis, J.; Kretsovali, A. Promyelocytic Leukemia Protein Is an Essential Regulator of Stem Cell Pluripotency and Somatic Cell Reprogramming. Stem Cell Reports 2017, 8, 1366–1378.

6. Lallemand-Breitenbach, V.; de Thé, H. PML nuclear bodies. Cold Spring Harb. Perspect. Biol. 2010.

7. Grignani, F.; De Matteis, S.; Nervi, C.; Tomassoni, L.; Gelmetti, V.; Cioce, M.; Fanelli, M.; Ruthardt, M.; Ferrara, F.F.; Zamir, I.; et al. Fusion proteins of the retinoic acid receptor-α recruit histone deacetylase in promyelocytic leukaemia. Nature 1998.

8. Wang, K.; Wang, P.; Shi, J.; Zhu, X.; He, M.; Jia, X.; Yang, X.; Qiu, F.; Jin, W.; Qian, M.; et al. PML/RARα Targets Promoter Regions Containing PU.1 Consensus and RARE Half Sites in Acute Promyelocytic Leukemia. Cancer Cell 2010, 17, 186–197.

9. Martens, J.H.A.; Brinkman, A.B.; Simmer, F.; Francoijs, K.J.; Nebbioso, A.; Ferrara, F.; Altucci, L.; Stunnenberg, H.G. PML-RARα/RXR Alters the Epigenetic Landscape in Acute Promyelocytic Leukemia. Cancer Cell 2010.

10. Fabiani, E.; Falconi, G.; Noguera, N.I.; Saulle, E.; Cicconi, L.; Divona, M.; Banella, C.; Picardi, A.; Cerio, A.M.; Boe, L.; et al. The forkhead box C1 (FOXC1) transcription factor is downregulated in acute promyelocytic leukemia. Oncotarget 2017, 8.

11. Koken, M.H.; Puvion-Dutilleul, F.; Guillemin, M.C.; Viron, A.; Linares-Cruz, G.; Stuurman, N.; de Jong, L.; Szostecki, C.; Calvo, F.; Chomienne, C. The t(15;17) translocation alters a nuclear body in a retinoic acid-reversible fashion. EMBO J. 1994.

12. Brown, D.; Kogan, S.; Lagasse, E.; Weissman, I.; Alcalay, M.; Pelicci, P.G.; Atwater, S.; Bishop, J.M. A PMLRARα transgene initiates murine acute promyelocytic leukemia. Proc. Natl. Acad. Sci. U. S. A. 1997.

13.   Bischof, O.; Kirsh, O.; Pearson, M.; Itahana, K.; Pelicci, P.G.; Dejean, A. Deconstructing PML-induced premature senescence. EMBO J. 2002.

14.   Gottifredi, V.; Prives, C. P53 and PML: New partners in tumor suppression. Trends Cell Biol. 2001.

15.   De Stanchina, E.; Querido, E.; Narita, M.; Davuluri, R. V.; Pandolfi, P.P.; Ferbeyre, G.; Lowe, S.W. PML is a direct p53 target that modulates p53 effector functions. Mol. Cell 2004.

16.   Zhu, J.; Lallemand-Breitenbach, V.; De Thé, H. Pathways of retinoic acid- or arsenic trioxide-induced PML/RARα catabolism, role of oncogene degradation in disease remission. Oncogene 2001.

17.   Lo-Coco, F.; Hasan, S.K. Understanding the molecular pathogenesis of acute promyelocytic leukemia. Best Pract. Res. Clin. Haematol. 2014, 27, 3–9.

18.   Di Masi, A.; Cilli, D.; Berardinelli, F.; Talarico, A.; Pallavicini, I.; Pennisi, R.; Leone, S.; Antoccia, A.; Noguera, N.I.; Lo-Coco, F.; et al. PML nuclear body disruption impairs DNA double-strand break sensing and repair in APL. Cell Death Dis. 2016, 7.

19.   Voisset, E.; Moravcsik, E.; Stratford, E.W.; Jaye, A.; Palgrave, C.J.; Hills, R.K.; Salomoni, P.; Kogan, S.C.; Solomon, E.; Grimwade, D. PML nuclear body disruption cooperates in APL pathogenesis and impairs DNA damage repair pathways in mice. Blood 2018, 131, 636–648.

20.   Pennisi, R.; Ascenzi, P.; di Masi, A. Hsp90: A new player in DNA Repair? Biomolecules 2015.

21.   Piredda, M.L.; Gaur, G.; Catalano, G.; Divona, M.; Banella, C.; Travaglini, S.; Puzzangara, M.C.; Voso, M.T.; Lo-Coco, F.; Noguera, N.I. PML/RARA inhibits expression of HSP90 and its target AKT. Br. J. Haematol. 2019, 184, 937–948.

22.   Ito, K.; Bernardi, R.; Morotti, A.; Matsuoka, S.; Saglio, G.; Ikeda, Y.; Rosenblatt, J.; Avigan, D.E.; Teruya-Feldstein, J.; Pandolfi, P.P. PML targeting eradicates quiescent leukaemia-initiating cells. Nature 2008.

23.   Regad, T.; Bellodi, C.; Nicotera, P.; Salomoni, P. The tumor suppressor Pml regulates cell fate in the developing neocortex. Nat. Neurosci. 2009.

24.   Hadjimichael, C.; Chanoumidou, K.; Nikolaou, C.; Klonizakis, A.; Theodosi, G.I.; Makatounakis, T.; Papamatheakis, J.; Kretsovali, A. Promyelocytic Leukemia Protein Is an Essential Regulator of Stem Cell Pluripotency and Somatic Cell Reprogramming. Stem Cell Reports 2017.

25.   Yilmaz, Ö.H.; Valdez, R.; Theisen, B.K.; Guo, W.; Ferguson, D.O.; Wu, H.; Morrison, S.J. Pten dependence distinguishes haematopoietic stem cells from leukaemia-initiating cells. Nature 2006.

26.   Zhang, J.; Grindley, J.C.; Yin, T.; Jayasinghe, S.; He, X.C.; Ross, J.T.; Haug, J.S.; Rupp, D.; Porter-Westpfahl, K.S.; Wiedemann, L.M.; et al. PTEN maintains haematopoietic stem cells and acts in lineage choice and leukaemia prevention. Nature 2006.

27.   Song, M.S.; Salmena, L.; Carracedo, A.; Egia, A.; Lo-Coco, F.; Teruya-Feldstein, J.; Pandolfi, P.P. The deubiquitinylation and localization of PTEN are regulated by a HAUSP-PML network. Nature 2008.

28.   Noguera, N.I.; Song, M.S.; Divona, M.; Catalano, G.; Calvo, K.L.; García, F.; Ottone, T.; Florenzano, F.; Faraoni, I.; Battistini, L.; et al. Nucleophosmin/B26 regulates PTEN through interaction with HAUSP in acute myeloid leukemia. Leukemia 2013, 27.

29.   Orfali, N.; O'Donovan, T.R.; Nyhan, M.J.; Britschgi, A.; Tschan, M.P.; Cahill, M.R.; Mongan, N.P.; Gudas, L.J.; McKenna, S.L. Induction of autophagy is a key component of all-trans-retinoic acid-induced differentiation in leukemia cells and a potential target for pharmacologic modulation. Exp. Hematol. 2015.

30.   Brigger, D.; Proikas-Cezanne, T.; Tschan, M.P. WIPI-Dependent autophagy during neutrophil differentiation of NB4 acute promyelocytic leukemia cells. Cell Death Dis. 2014.

31.   Jin, J.; Britschgi, A.; Schläfli, A.M.; Humbert, M.; Shan-Krauer, D.; Batliner, J.; Federzoni, E.A.; Ernst, M.; Torbett, B.E.; Yousefi, S.; et al. Low autophagy (ATG) gene expression is associated

with an immature AML blast cell phenotype and can be restored during AML differentiation therapy. Oxid. Med. Cell. Longev. 2018.

32. Klionsky, D.J. Autophagy: From phenomenology to molecular understanding in less than a decade. Nat. Rev. Mol. Cell Biol. 2007.

33. Moosavi, M.A.; Djavaheri-Mergny, M. Autophagy: New Insights into Mechanisms of Action and Resistance of Treatment in Acute Promyelocytic leukemia. Int. J. Mol. Sci. 2019, 20, 3559.

34. Ronchini, C.; Brozzi, A.; Riva, L.; Luzi, L.; Gruszka, A.M.; Melloni, G.E.M.; Scanziani, E.; Dharmalingam, G.; Mutarelli, M.; Belcastro, V.; et al. PML-RARA-Associated cooperating mutations belong to a transcriptional network that is deregulated in myeloid leukemias. Leukemia 2017.

35. Huang, Y.; Hou, J.K.; Chen, T.T.; Zhao, X.Y.; Yan, Z.W.; Zhang, J.; Yang, J.; Kogan, S.C.; Chen, G.Q. PML-RARα enhances constitutive autophagic activity through inhibiting the Akt/mTOR pathway. Autophagy 2011.

36. Yamamoto, J.F.; Goodman, M.T. Patterns of leukemia incidence in the United States by subtype and demographic characteristics, 1997-2002. Cancer Causes Control 2008.

37. Douer, D. The epidemiology of acute promyelocytic leukaemia. Best Pract. Res. Clin. Haematol. 2003.

38. Matasar, M.J.; Ritchie, E.K.; Consedine, N.; Magai, C.; Neugut, A.I. Incidence rates of acute promyelocytic leukemia among Hispanics, blacks, Asians, and non-Hispanic whites in the United States. *Eur. J. Cancer Prev.* **2006**.

39. Kogan, S.C. Mouse models of acute promyelocytic leukemia. Curr. Top. Microbiol. Immunol. 2007.

40. Wartman, L.D.; Larson, D.E.; Xiang, Z.; Ding, L.; Chen, K.; Lin, L.; Cahan, P.; Klco, J.M.; Welch, J.S.; Li, C.; et al. Sequencing a mouse acute promyelocytic leukemia genome reveals genetic events relevant for disease progression. J. Clin. Invest. 2011.

41. Agger, K.; Cloos, P.A.C.; Christensen, J.; Pasini, D.; Rose, S.; Rappsilber, J.; Issaeva, I.; Canaani, E.; Salcini, A.E.; Helin, K. UTX and JMJD3 are histone H3K27 demethylases involved in HOX gene regulation and development. Nature 2007.

42. Terashima, M.; Ishimura, A.; Yoshida, M.; Suzuki, Y.; Sugano, S.; Suzuki, T. The tumor suppressor Rb and its related Rbl2 genes are regulated by Utx histone demethylase. Biochem. Biophys. Res. Commun. 2010.

43. Wang, J.K.; Tsai, M.C.; Poulin, G.; Adler, A.S.; Chen, S.; Liu, H.; Shi, Y.; Chang, H.Y. The histone demethylase UTX enables RB-dependent cell fate control. Genes Dev. 2010.

44. Herz, H.M.; Madden, L.D.; Chen, Z.; Bolduc, C.; Buff, E.; Gupta, R.; Davuluri, R.; Shilatifard, A.; Hariharan, I.K.; Bergmann, A. The H3K27me3 Demethylase dUTX Is a Suppressor of Notch- and Rb-Dependent Tumors in Drosophila. Mol. Cell. Biol. 2010.

45. Madan, V.; Shyamsunder, P.; Han, L.; Mayakonda, A.; Nagata, Y.; Sundaresan, J.; Kanojia, D.; Yoshida, K.; Ganesan, S.; Hattori, N.; et al. Comprehensive mutational analysis of primary and relapse acute promyelocytic leukemia. Leukemia 2016.

46. Yin, J.; Sun, A.N.; Tian, X.P.; Tian, H.; Wang, R.X.; Yang, Z.; Wang, X.L.; Wu, D.P.; Qiu, H.Y.; Pan, J.L.; et al. [Clinical significance of common leukemia gene mutations in patients with acute promyelocytic leukemia]. Zhongguo Shi Yan Xue Ye Xue Za Zhi 2013.

47. Iaccarino, L.; Ottone, T.; Alfonso, V.; Cicconi, L.; Divona, M.; Lavorgna, S.; Travaglini, S.; Ferrantini, A.; Falconi, G.; Baer, C.; et al. Mutational landscape of patients with acute promyelocytic leukemia at diagnosis and relapse. Am. J. Hematol. 2019, 1–7.

48. Calvo, K.L.; Ojeda, M.J.; Ammatuna, E.; Lavorgna, S.; Ottone, T.; Targovnik, H.M.; Lo-Coco, F.; Noguera, N.I. Detection of the nucleophosmin gene mutations in acute myelogenous leukemia through RT-PCR and polyacrylamide gel electrophoresis. Eur. J. Haematol. 2009, 82.

49. Gaur, G.C.; Ramadan, S.M.; Cicconi, L.; Noguera, N.I.; Luna, I.; Such, E.; Lavorgna, S.; Di Giandomenico, J.; Sanz, M.A.; Lo-Coco, F. Analysis of mutational status, SNP rs16754, and expression levels of Wilms tumor 1 (WT1) gene in acute promyelocytic leukemia. Ann. Hematol. 2012, 91.

50. Noguera, N.I.; Breccia, M.; Divona, M.; Diverio, D.; Costa, V.; De Santis, S.; Avvisati, G.; Pinazzi, M.B.; Petti, M.C.; Mandelli, F.; et al. Alterations of the FLT3 gene in acute promyelocytic leukemia: Association with diagnostic characteristics and analysis of clinical outcome in patients treated with the Italian AIDA protocol. Leukemia 2002, 16.

51. Beitinjaneh, A.; Jang, S.; Roukoz, H.; Majhail, N.S. Prognostic significance of FLT3 internal tandem duplication and tyrosine kinase domain mutations in acute promyelocytic leukemia: A systematic review. Leuk. Res. 2010.

52. Kelly, L.M.; Kutok, J.L.; Williams, I.R.; Boulton, C.L.; Amaral, S.M.; Curley, D.P.; Ley, T.J.; Gilliland, D.G. PML/RARα and FLT3-ITD induce an APL-like disease in a mouse model. Proc. Natl. Acad. Sci. U. S. A. 2002.

53. McCormack, E.; Bruserud, O.; Gjertsen, B.T. Review: Genetic models of acute myeloid leukaemia. Oncogene 2008.

54. Esnault, C.; Rahmé, R.; Rice, K.L.; Berthier, C.; Gaillard, C.; Quentin, S.; Maubert, A.L.; Kogan, S.; de Thé, H. FLT3-ITD impedes retinoic acid, but not arsenic, responses in murine acute promyelocytic leukemias. Blood 2019, 133, 1495–1506.

55. Sanz, M.A.; Fenaux, P.; Tallman, M.S.; Estey, E.H.; Löwenberg, B.; Naoe, T.; Lengfelder, E.; Döhner, H.; Burnett, A.K.; Chen, S.J.; et al. Management of acute promyelocytic leukemia: Updated recommendations from an expert panel of the European LeukemiaNet. Blood 2019, 133, 1630–1643.

56. Hecht, A.; Nowak, D.; Nowak, V.; Hanfstein, B.; Büchner, T.; Spiekermann, K.; Weiß, C.; Hofmann, W.K.; Lengfelder, E.; Nolte, F. A molecular risk score integrating BAALC, ERG and WT1 expression levels for risk stratification in acute promyelocytic leukemia. Leuk. Res. 2015.

57. Hecht, A.; Doll, S.; Altmann, H.; Nowak, D.; Lengfelder, E.; Röllig, C.; Ehninger, G.; Spiekermann, K.; Hiddemann, W.; Weiß, C.; et al. Validation of a Molecular Risk Score for Prognosis of Patients With Acute Promyelocytic Leukemia Treated With All-trans Retinoic Acid and Chemotherapy-containing Regimens. Clin. Lymphoma, Myeloma Leuk. 2017.

58. Lucena-Araujo, A.R.; Coelho-Silva, J.L.; Pereira-Martins, D.A.; Silveira, D.R.; Koury, L.C. de A.; Melo, R.A.M.; Bittencourt, R.; Pagnano, K.; Pasquini, R.; Nunes, E.C.; et al. Combining gene mutation with gene expression analysis improves outcomes prediction in acute promyelocytic leukemia. Blood 2019, blood.2019000239.

59. Paietta, E.; Goloubeva, O.; Neuberg, D.; Bennett, J.M.; Gallagher, R.; Racevskis, J.; Dewald, G.; Wiernik, P.H.; Tallman, M.S. A surrogate marker profile for PML/RAR? expressing acute promyelocytic leukemia and the association of immunophenotypic markers with morphologic and molecular subtypes. Cytometry 2004.

60. Paietta, E. Expression of cell-surface antigens in acute promyelocytic leukaemia. Best Pract. Res. Clin. Haematol. 2003.

61. Albano, F.; Mestice, A.; Pannunzio, A.; Lanza, F.; Martino, B.; Pastore, D.; Ferrara, F.; Carluccio, P.; Nobile, F.; Castoldi, G.; et al. The biological characteristics of CD34+ CD2+ adult acute promyelocytic leukemia and the CD34- CD2- hypergranular (M3) and microgranular (M3v) phenotypes. Haematologica 2006.

62. Montesinos, P.; Rayón, C.; Vellenga, E.; Brunet, S.; González, J.; González, M.; Holowiecka, A.; Esteve, J.; Bergua, J.; González, J.D.; et al. Clinical significance of CD56 expression in patients with acute promyelocytic leukemia treated with all-trans retinoic acid and anthracycline-based regimens. Blood 2011.

63. Gong, J.Y.; Li, Y.Y.; Li, C.W.; Wang, Y.S.; Liu, Y.; Wang, C.; Ru, K.; Mi, Y.C.; Wang, J.X.; Wang, H.J. Application of immunophenotypic analysis and molecular genetics in the diagnosis of acute promyelocytic leukemia. Zhonghua Xue Ye Xue Za Zhi 2019.

64. Montesinos, P.; Díaz-Mediavilla, J.; Debén, G.; Prates, V.; Tormo, M.; Rubio, V.; Pérez, I.; Fernández, I.; Viguria, M.; Rayón, C.; et al. Central nervous system involvement at first relapse in patients with acute promyelocytic leukemia treated with all-trans retinoic acid and anthracycline monochemotherapy without intrathecal prophylaxis. Haematologica 2009.

65. Sanz MA, Grimwade D, Tallman MS, et al. Management of acute promyelocytic leukemia: recommendations from an expert panel on behalf of the European LeukemiaNet. Blood. 2009;113(9):1875-1891.

66. Shao, W.; Benedetti, L.; Lamph, W.W.; Nervi, C.; Miller, W.H. A retinoid-resistant acute promyelocytic leukemia subclone expresses a dominant negative PML-RARα mutation. Blood 1997.

67. Gallagher, R.E.; Moser, B.K.; Racevskis, J.; Poiré, X.; Bloomfield, C.D.; Carroll, A.J.; Ketterling, R.P.; Roulston, D.; Schachter-Tokarz, E.; Zhou, D.C.; et al. Treatment-influenced associations of PML-RARα

mutations, FLT3 mutations, and additional chromosome abnormalities in relapsed acute promyelocytic leukemia. Blood 2012.

68. Lehmann-Che, J.; Bally, C.; Letouzé, E.; Berthier, C.; Yuan, H.; Jollivet, F.; Ades, L.; Cassinat, B.; Hirsch, P.; Pigneux, A.; et al. Dual origin of relapses in retinoic-Acid resistant acute promyelocytic leukemia. Nat. Commun. 2018, 9, 1–8.

69. Jeanne, M.; Lallemand-Breitenbach, V.; Ferhi, O.; Koken, M.; Le Bras, M.; Duffort, S.; Peres, L.; Berthier, C.; Soilihi, H.; Raught, B.; et al. PML/RARA Oxidation and Arsenic Binding Initiate the Antileukemia Response of As2O3. Cancer Cell 2010.

70. Van Delft, F.W.; Horsley, S.; Colman, S.; Anderson, K.; Bateman, C.; Kempski, H.; Zuna, J.; Eckert, C.; Saha, V.; Kearney, L.; et al. Clonal origins of relapse in ETV6-RUNX1 acute lymphoblastic leukemia. Blood 2011.

71. Lo-Coco, F.; Avvisati, G.; Vignetti, M.; Thiede, C.; Orlando, S.M.; Iacobelli, S.; Ferrara, F.; Fazi, P.; Cicconi, L.; Di Bona, E.; et al. Retinoic acid and arsenic trioxide for acute promyelocytic leukemia. N. Engl. J. Med. 2013.

72. Burnett, A.K.; Russell, N.H.; Hills, R.K.; Bowen, D.; Kell, J.; Knapper, S.; Morgan, Y.G.; Lok, J.; Grech, A.; Jones, G.; et al. Arsenic trioxide and all-trans retinoic acid treatment for acute promyelocytic leukaemia in all risk groups (AML17): Results of a randomised, controlled, phase 3 trial. Lancet Oncol. 2015.

73. Isakson, P.; Bjørås, M.; Bøe, S.O.; Simonsen, A. Autophagy contributes to therapy-induced degradation of the PML/RARA oncoprotein. Blood 2010.

74. Wang, Z.; Cao, L.; Kang, R.; Yang, M.; Liu, L.; Zhao, Y.; Yu, Y.; Xie, M.; Yin, X.; Livesey, K.M.; et al. Autophagy regulates myeloid cell differentiation by p62/SQSTM1-mediated degradation of PML-RARα oncoprotein. Autophagy 2011.

75. Qian, W.; Liu, J.; Jin, J.; Ni, W.; Xu, W. Arsenic trioxide induces not only apoptosis but also autophagic cell death in leukemia cell lines via up-regulation of Beclin-1. Leuk. Res. 2007.

76. A.A., A.; E., C.; S., G.; N., B.; H.K., P.; S., D. Arsenic trioxide resistance: More to it than mutations in PML-RARalpha. Blood 2014, 124.

77. Ganesan, S.; Alex, A.A.; Chendamarai, E.; Balasundaram, N.; Palani, H.K.; David, S.; Kulkarni, U.; Aiyaz, M.; Mugasimangalam, R.; Korula, A.; et al. Rationale and efficacy of proteasome inhibitor combined with arsenic trioxide in the treatment of acute promyelocytic leukemia. Leukemia 2016.

78. Takeshita, A.; Shinjo, K.; Naito, K.; Matsui, H.; Shigeno, K.; Nakamura, S.; Horii, T.; Maekawa, M.; Kitamura, K.; Naoe, T.; et al. P-glycoprotein (P-gp) and multidrug resistance-associated protein 1 (MRP1) are induced by arsenic trioxide (As2O3), but are not the main mechanism of As2O3-resistance in acute promyelocytic leukemia cells [7]. Leukemia 2003.

79. Conserva, M.R.; Anelli, L.; Zagaria, A.; Specchia, G.; Albano, F. The Pleiotropic Role of Retinoic Acid/Retinoic Acid Receptors Signaling: From Vitamin A Metabolism to Gene Rearrangements in Acute Promyelocytic Leukemia. Int. J. Mol. Sci. 2019.

80. Hisada, K.; Hata, K.; Ichida, F.; Matsubara, T.; Orimo, H.; Nakano, T.; Yatani, H.; Nishimura, R.; Yoneda, T. Retinoic acid regulates commitment of undifferentiated mesenchymal stem cells into osteoblasts and adipocytes. J. Bone Miner. Metab. 2013.

81. Cao, J.; Ma, Y.; Yao, W.; Zhang, X.; Wu, D. Retinoids regulate adipogenesis involving the TGFβ/SMAD and Wnt/β-catenin pathways in human bone marrow mesenchymal stem cells. Int. J. Mol. Sci. 2017.

82. Su, M.; Alonso, S.; Jones, J.W.; Yu, J.; Kane, M.A.; Jones, R.J.; Ghiaur, G. All-trans retinoic acid activity in acute myeloid leukemia: Role of cytochrome P450 enzyme expression by the microenvironment. PLoS One 2015.

83. Wang, Y.T.; Chen, J.; Chang, C.W.; Jen, J.; Huang, T.Y.; Chen, C.M.; Shen, R.; Liang, S.Y.; Cheng, I.C.; Yang, S.C.; et al. Ubiquitination of tumor suppressor PML regulates prometastatic and immunosuppressive tumor microenvironment. J. Clin. Invest. 2017.

84. Chendamarai, E.; Ganesan, S.; Alex, A.A.; Kamath, V.; Nair, S.C.; Nellickal, A.J.; Janet, N.B.; Srivastava, V.; Lakshmi, K.M.; Viswabandya, A.; et al. Comparison of newly diagnosed and relapsed patients with acute promyelocytic leukemia treated with arsenic trioxide: Insight into mechanisms of resistance. PLoS One 2015, 10, 1–15.

85. Sainty, D.; Liso, V.; Cantu-Rajnoldi, A.; Head, D.; Mozziconacci, M.J.; Arnoulet, C.; Benattar, L.; Fenu, S.; Mancini, M.; Duchayne, E.; et al. A new morphologic classification system for acute promyelocytic leukemia distinguishes cases with underlying PLZF/RARA gene rearrangements. Blood 2000.

86. Wells, R.A.; Catzavelos, C.; Kamel-Reid, S. Fusion of retinoic acid receptor α to NuMA, the nuclear mitotic apparatus protein, by a variant translocation in acute promyelocytic leukaemia. Nat. Genet. 1997.

87. Arnould, C.; Philippe, C.; Bourdon, V.; Grégoire, M.J.; Berger, R.; Jonveaux, P. The signal transducer and activator of transcription STAT5b gene is a new partner of retinoic acid receptor α in acute promyelocytic-like leukaemia. Hum. Mol. Genet. 1999.

88. Kondo, T.; Mori, A.; Darmanin, S.; Hashino, S.; Tanaka, J.; Asaka, M. The seventh pathogenic fusion gene FIP1L1-RARA was isolated from a t(4;17)-positive acute promyelocytic leukemia. Haematologica 2008.

89. Qiu, J.J.; Lu, X.; Zeisig, B.B.; Ma, Z.; Cai, X.; Chen, S.; Gronemeyer, H.; Tweardy, D.J.; So, C.W.E.; Dong, S. Leukemic transformation by the APL fusion protein PRKAR1A-RARα critically depends on recruitment of RXRα. Blood 2010.

90. Adams, J.; Nassiri, M. Acute promyelocytic leukemia a review and discussion of variant translocations. Arch. Pathol. Lab. Med. 2015.

91. Ichikawa, S.; Ichikawa, S.; Ishikawa, I.; Takahashi, T.; Fujiwara, T.; Harigae, H. Successful treatment of acute promyelocytic leukemia with a t(X;17)(p11.4;q21) and BCOR-RARA fusion gene. Cancer Genet. 2015.

92. Won, D.; Shin, S.Y.; Park, C.J.; Jang, S.; Chi, H.S.; Lee, K.H.; Lee, J.O.; Seo, E.J. OBFC2A/RARA: A novel fusion gene in variant acute promyelocytic leukemia. Blood 2013.

93. Chen, Y.; Li, S.; Zhou, C.; Li, C.; Ru, K.; Rao, Q.; Xing, H.; Tian, Z.; Tang, K.; Mi, Y.; et al. TBLR1 fuses to retinoid acid receptor α in a variant t(3;17)(q26;q21) translocation of acute promyelocytic leukemia. Blood 2014.

94. Li, J.; Zhong, H.Y.; Zhang, Y.; Xiao, L.; Bai, L.H.; Liu, S.F.; Zhou, G.B.; Zhang, G. Sen GTF2I-RARA is a novel fusion transcript in a t(7;17) variant of acute promyelocytic leukaemia with clinical resistance to retinoic acid. Br. J. Haematol. 2015.

95. Yin, C.C.; Jain, N.; Mehrotra, M.; Zhang, J.; Protopopov, A.; Zuo, Z.; Pemmaraju, N.; DiNardo, C.; Hirsch-Ginsberg, C.; Wang, S.A.; et al. Identification of a novel fusion gene, IRF2BP2-RARA, in acute promyelocytic leukemia. JNCCN J. Natl. Compr. Cancer Netw. 2015.

96. Cheng, C.K.; Wang, A.Z.; Wong, T.H.Y.; Wan, T.S.K.; Cheung, J.S.; Raghupathy, R.; Chan, N.P.H.; Ng, M.H.L. To the editor: FNDC3B is another novel partner fused to RARA in the t(3;17)(q26;q21) variant of acute promyelocytic leukemia. Blood 2017.

97. Guidez, F.; Parks, S.; Wong, H.; Jovanovic, J. V.; Mays, A.; Gilkes, A.F.; Mills, K.I.; Guillemin, M.C.; Hobbs, R.M.; Pandolfi, P.P.; et al. RARα-PLZF overcomes PLZF-mediated repression of CRABPI, contributing to retinoid resistance in t(11;17) acute promyelocytic leukemia. Proc. Natl. Acad. Sci. U. S. A. 2007.

98. Breccia, M.; Diverio, D.; Noguera, N.I.; Visani, G.; Santoro, A.; Locatelli, F.; Damiani, D.; Marmont, F.; Vignetti, M.; Petti, M.C.; et al. Clinico-biological features and outcome of acute promyelocytic leukemia patients with persistent polymerase chain reaction-detectable disease after AIDA front-line induction and consolidation therapy. Haematologica 2004, 89.

99. Sanz, M.A.; Lo-Coco, F. Modern approaches to treating acute promyelocytic leukemia. J. Clin. Oncol. 2011.

100. Montesinos, P.; González, J.D.; González, J.; Rayón, C.; De Lisa, E.; Amigo, M.L.; Ossenkoppele, G.J.; Peñarrubia, M.J.; Pérez-Encinas, M.; Bergua, J.; et al. Therapy-related myeloid neoplasms in patients with acute promyelocytic leukemia treated with all-trans-retinoic acid and anthracycline-based chemotherapy. J. Clin. Oncol. 2010.

101. Fenaux, P.; Wang, Z.Z.; Degos, L. Treatment of acute promyelocytic leukemia by retinoids. Curr. Top. Microbiol. Immunol. 2007.

102. de Thé, H.; Pandolfi, P.P.; Chen, Z. Acute Promyelocytic Leukemia: A Paradigm for Oncoprotein-Targeted Cure. Cancer Cell 2017, 32, 552–560.

103. Watts, J.M.; Tallman, M.S. Acute promyelocytic leukemia: What is the new standard of care? Blood Rev. 2014.

104. Takeshita, A.; Asou, N.; Atsuta, Y.; Sakura, T.; Ueda, Y.; Sawa, M.; Dobashi, N.; Taniguchi, Y.; Suzuki, R.; Nakagawa, M.; et al. Tamibarotene maintenance improved relapse-free survival of acute promyelocytic leukemia: a final result of prospective, randomized, JALSG-APL204 study. Leukemia 2019.

105. Zhou, D.C.; Kim, S.H.; Ding, W.; Schultz, C.; Warrell, R.P.; Gallagher, R.E. Frequent mutations in the ligand-binding domain of PML-RARα after multiple relapses of acute promyelocytic leukemia: Analysis for functional relationship to response to all-trans retinoic acid and histone deacetylase inhibitors in vitro and in vivo. Blood 2002.

106. Lo-Coco, F.; Cimino, G.; Breccia, M.; Noguera, N.I.; Diverio, D.; Finolezzi, E.; Pogliani, E.M.; Di Bona, E.; Micalizzi, C.; Kropp, M.; et al. Gemtuzumab ozogamicin (Mylotarg) as a single agent for molecularly relapsed acute promyelocytic leukemia. Blood 2004, 104.

107. Gale, R.E.; Hills, R.; Pizzey, A.R.; Kottaridis, P.D.; Swirsky, D.; Gilkes, A.F.; Nugent, E.; Mills, K.I.; Wheatley, K.; Solomon, E.; et al. Relationship between FLT3 mutation status, biologic characteristics, and response to targeted therapy in acute promyelocytic leukemia. Blood 2005.

108. Lo Coco, F.; Ammatuna, E.; Noguera, N. Treatment of acute promyelocytic leukemia with gemtuzumab ozogamicin. Clin. Adv. Hematol. Oncol. 2006, 4.

109. Noguera, N.I.; Pelosi, E.; Angelini, D.F.; Piredda, M.L.; Guerrera, G.; Piras, E.; Battistini, L.; Massai, L.; Berardi, A.; Catalano, G.; et al. High-dose ascorbate and arsenic trioxide selectively kill acute myeloid leukemia and acute promyelocytic leukemia blasts in vitro. Oncotarget 2017, 8.

110. Mastrangelo, D.; Massai, L.; Lo Coco, F.; Noguera, N.I.; Borgia, L.; Fioritoni, G.; Berardi, A.; Iacone, A.; Muscettola, M.; Pelosi, E.; et al. Cytotoxic effects of high concentrations of sodium ascorbate on human myeloid cell lines. Ann. Hematol. 2015, 94.

111. Bernardini, S.; Nuccetelli, M.; Noguera, N.I.; Bellincampi, L.; Lunghi, P.; Bonati, A.; Mann, K.; Miller Jr., W.H.; Federici, G.; Lo Coco, F. Role of GSTP1-1 in mediating the effect of As2O3 in the Acute Promyelocytic Leukemia cell line NB4. Ann. Hematol. 2006, 85.

112. de Thé, H.; Le Bras, M.; Lallemand-Breitenbach, V. Acute promyelocytic leukemia, arsenic, and PML bodies. J. Cell Biol. 2012, 198, 11–21.

113. Mastrangelo, D.; Massai, L.; Fioritoni, G.; Coco, F. Lo; Noguera, N.; Testa, U. High Doses of Vitamin C and Leukemia: In Vitro Update. In Myeloid Leukemia; 2018.

114. Chen, Q.; Espey, M.G.; Sun, A.Y.; Pooput, C.; Kirk, K.L.; Krishna, M.C.; Khosh, D.B.; Drisko, J.; Levine, M. Pharmacologic doses of ascorbate act as a prooxidant and decrease growth of aggressive tumor xenografts in mice. Proc. Natl. Acad. Sci. U. S. A. 2008.

115. Chen, Q.; Espey, M.G.; Sun, A.Y.; Lee, J.H.; Krishna, M.C.; Shacter, E.; Choyke, P.L.; Pooput, C.; Kirk, K.L.; Buettner, G.R.; et al. Ascorbate in pharmacologic concentrations selectively generates ascorbate radical and hydrogen peroxide in extracellular fluid in vivo. Proc. Natl. Acad. Sci. U. S. A. 2007.

116. Masciarelli, S.; Capuano, E.; Ottone, T.; Divona, M.; De Panfilis, S.; Banella, C.; Noguera, N.I.; Picardi, A.; Fontemaggi, G.; Blandino, G.; et al. Retinoic acid and arsenic trioxide sensitize acute promyelocytic leukemia cells to ER stress. Leukemia 2018, 32.

117. Gu, Z.M.; Wu, Y.L.; Zhou, M.Y.; Liu, C.X.; Xu, H.Z.; Yan, H.; Zhao, Y.; Huang, Y.; Sun, H.D.; Chen, G.Q. Pharicin B stabilizes retinoic acid receptor-α and presents synergistic differentiation induction with ATRA in myeloid leukemic cells. Blood 2010.

118. Wang, X.; Lin, Q.; Lv, F.; Liu, N.; Xu, Y.; Liu, M.; Chen, Y.; Yi, Z. LG-362B targets PML-RARα and blocks ATRA resistance of acute promyelocytic leukemia. Leukemia 2016.

119. Calvo, K.L.; Ronco, M.T.; Noguera, N.I.; García, F. Benznidazole modulates cell proliferation in acute leukemia cells. Immunopharmacol. Immunotoxicol. 2013, 35.

120. Ying Lu, Jin-Song Yan, Li Xia, Kang Qin, Qian-Qian Yin, Hong-Tao Xu, Meng-Qing Gao, Xiao-Ning Qu, Yu-Ting Sun and Guo-Qiang Chen 2-Bromopalmitate targets retinoic acid receptor alpha and overcomes all-trans retinoic acid resistance of acute promyelocytic leukemia Haematologica. 2019.

121. Hussain, L.; Maimaitiyiming, Y.; Su, L. De; Wang, Q.Q.; Naranmandura, H. Phenylarsine Oxide Can Induce Degradation of PLZF-RARα Variant Fusion Protein of Acute Promyelocytic Leukemia. Chem. Res. Toxicol. 2019.

122. Aya Furuya 'Central nervous system involvement of acute promyelocytic leukemia, three case reports' Clin Case Rep. 2017.

123. Specchia, G.; Lo Coco, F.; Vignetti, M.; Avvisati, G.; Fazi, P.; Albano, F.; Di Raimondo, F.; Martino, B.; Ferrara, F.; Selleri, C.; et al. Extramedullary involvement at relapse in acute promyelocytic leukemia patients treated or not with all-trans retinoic acid: A report by the Gruppo Italiano Malattie Ematologiche dell'Adulto. J. Clin. Oncol. 2001.

124. Montesinos, P.; Díaz-Mediavilla, J.; Debén, G.; Prates, V.; Tormo, M.; Rubio, V.; Pérez, I.; Fernández, I.; Viguria, M.; Rayón, C.; et al. Central nervous system involvement at first relapse in patients with acute promyelocytic leukemia treated with all-trans retinoic acid and anthracycline monochemotherapy without intrathecal prophylaxis. Haematologica 2009.

125. Abaza, Y.; Kantarjian, H.; Garcia-Manero, G.; Estey, E.; Borthakur, G.; Jabbour, E.; Faderl, S.; O'Brien, S.; Wierda, W.; Pierce, S.; et al. Long-term outcome of acute promyelocytic leukemia treated with all-trans-retinoic acid, arsenic trioxide, and gemtuzumab. Blood 2017.

126. Iland, H.J.; Collins, M.; Bradstock, K.; Supple, S.G.; Catalano, A.; Hertzberg, M.; Browett, P.; Grigg, A.; Firkin, F.; Campbell, L.J.; et al. Use of arsenic trioxide in remission induction and consolidation therapy for acute promyelocytic leukaemia in the Australasian Leukaemia and Lymphoma Group (ALLG) APML4 study: A non-randomised phase 2 trial. Lancet Haematol. 2015.

127. Burnett, A.K.; Russell, N.H.; Hills, R.K.; Bowen, D.; Kell, J.; Knapper, S.; Morgan, Y.G.; Lok, J.; Grech, A.; Jones, G.; et al. Arsenic trioxide and all-trans retinoic acid treatment for acute promyelocytic leukaemia in all risk groups (AML17): Results of a randomised, controlled, phase 3 trial. Lancet Oncol. 2015.

128. Osman, A.E.G.; Anderson, J.; Churpek, J.E.; Christ, T.N.; Curran, E.; Godley, L.A.; Liu, H.; Thirman, M.J.; Odenike, T.; Stock, W.; et al. Treatment of Acute Promyelocytic Leukemia in Adults. J. Oncol. Pract. 2018.