Mutational profiling in suspected triple-negative essential thrombocythaemia using targeted next-generation sequencing in a real-world cohort

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ABSTRACT

Essential thrombocythaemia (ET) is driven by somatic mutations involving the JAK2, CALR and MPL genes. Approximately 10% of patients lack driver mutations and are referred as ‘triple-negative’ ET (TN-ET). This diagnosis of TN-ET, however, relies on bone marrow examination that is not always performed in routine practice, and thus in the real-world setting, there are a group of cases with suspected TN-myeloproliferativeneoplasm. In this real-world cohort, patients with suspected TN-ET were initially rescreened for JAK2, CALR and MPL and then targeted next-generation sequencing (NGS) was applied. The 35 patients with suspected TN-ET had a median age at diagnosis of 43 years (range 16–79) and a follow-up of 10 years (range 2–28). The median platelet count was 758×10⁹/L (range 479–2903). Thrombosis prior to and following diagnosis was noted in 20% and 17% of patients. Six patients were JAK2V617F and two patients were CALR positive on repeat screening. NGS results showed that 24 of 27 patients harboured no mutations. Four mutations were noted in three patients. There was no evidence of clonality for the majority of patients with suspected TN-ET with targeted NGS analysis. Detection of driver mutations in those who were previously screened suggests that regular rescreening is required. This study also questions the diagnosis of TN-ET without the existence of a clonal marker.

INTRODUCTION

Essential thrombocythaemia (ET) is a BCR-ABL1-negative myeloproliferative neoplasm (MPN), characterised by clonal proliferation of the megakaryocytic lineage leading to thrombocytosis. The disease is complicated by thrombotic and haemorrhagic events, variable progression to myelofibrosis and rarely transformation to acute myeloid leukaemia.1 ET is driven by generally mutually exclusive somatic driver mutations involving the JAK2, CALR and MPL genes with reported frequencies at 50%–60%, 20%–30% and 1%–5%, respectively.2 These mutations all induce constitutive activation of the JAK-STAT signalling pathway and its downstream effectors in a cytokine-independent manner leading to a myeloproliferative phenotype. A small proportion of ET patients do not harbour any of the three common driver mutations and are referred to as ‘triple-negative’ ET (TN-ET). This cohort of patients accounts for 10%–15% of ET diagnoses and appears to be a heterogeneous entity comprising clonal and polyclonal diseases.3 Recent high-throughput sequencing studies, using targeted gene panels and whole-exome sequencing, have interrogated the genetic basis of TN-ET. These have identified mutations in genes involved in epigenetic regulation (TET2, DNMT3A, ASXL1, EZH2, IDH1 and IDH2), RNA splicing (SF3B1, SRSF2, and U2AF1) and regulation of cytokine signalling (CBL). Although mutations in these genes are not restricted to MPNs, their presence in the TN-ET cohort can be of diagnostic value, providing evidence of clonality.4 This study aimed to determine the molecular profile of patients with suspected TN-ET using next-generation sequencing (NGS) and to identify potential clonal biomarkers. Clinical outcomes including thrombohaemorrhagic complications, myelofibrosis-free and leukaemia-free survival were also documented.

METHODS

A real-world cohort of 35 patients was included with a diagnosis of ET between the years of 1989 and 2018 according to the WHO classification. A retrospective audit of diagnosis and outcomes was undertaken.

Data collection

Demographic characteristics (age and gender) and clinical information (year of diagnosis, cardiovascular risk factors, blood parameters, bone marrow (BM) morphology, treatment and clinical outcomes) were determined. BM biopsy material was only available in 25 of the 35 cases and was reviewed blinded by an independent haematologist. The remaining 10 cases did not have a BM but were considered likely to have a diagnosis of ET because in the past in the real-world setting patients with a persistently elevated platelet count and no other cause have had a diagnosis of ET.5 Patients with suspected TN-ET were included after excluding JAK2V617F, CALR exon 9 and MPL exon 10 mutations by conventional techniques (allele-specific PCR, DNA fragment analysis and Sanger sequencing, respectively).5 6

Next-generation sequencing

Genomic DNA was extracted from whole peripheral blood and retested for JAK2V617F, CALR exon...
9 and MPL exon 10 mutations by conventional techniques. NGS was performed using the Illumina MiSeqTM platform and the Trusight Myeloid gene panel. Sequence variants were called using Somatic Variant Caller (Illumina), with variant filtering using a custom Classification Tree within the Cartagenia BENCH software. Reporting required total read depth >100× for known variants and >300× for novel variants and allelic frequencies >5%.

### RESULTS

#### Clinical characteristics and haematological values

Thirty-five patients with suspected TN-ET, diagnosed between the years of 1989 and 2018, were included in the study. The median age at diagnosis was 43 years (range 16–79) and 83% were female individuals (table 1). The median duration of clinical follow-up was 10 years (range 2–28). Full blood count parameters at presentation (prior to initiating treatment) are shown in table 1. The median platelet count at presentation was 758×10^9/L (range 479–2903). Cardiovascular risk factors and thrombohaemorrhagic complications prior to and following diagnosis are depicted in table 1. Thrombosis prior to and following ET diagnosis was noted in 20% and 17% of patients, respectively. No patients had any significant haemorrhage. In this retrospective selected group of patients, no patients progressed to myelofibrosis or acute myeloid leukaemia. One patient died from metastatic disease of unknown origin, unrelated to the haematological condition, however, the diagnosis of ET was made in this particular patient in 1989 with a BM consistent with ET. Twenty-one patients (60%) were on cytoreductive therapy and 14 (40%) on antiplatelet therapy alone.

#### Molecular results

As the median duration of the clinical follow-up was 10 years, all cases were rescreened for the canonical driver mutations by conventional approaches. Of interest, six patients were JAK2V617F positive and two patients were CALR positive on repeat screening (table 2). Twenty-seven patients were subsequently sequenced with the Trusight Myeloid gene panel. Four mutations were detected in 3 patients (table 3) with the remaining 24 patients not harbouring any identifiable mutations. Of the 24 patients without an identifiable mutation, 16 had available BM biopsies. When reviewed by an independent

### Table 1 Clinical and biological characteristics in 35 patients with suspected triple-negative essential thrombocythaemia

| Age at diagnosis (years)* | Gender (M/F) | Haemoglobin (g/L)* | Haematocrit % | Platelet count (>10^9/L)* | Leucocyte count (>10^9/L)* | Neutrophil count (>10^9/L)* | Cardiovascular risk factors, n (%) | Thrombohaemorrhagic complications, n (%) |
|--------------------------|--------------|-------------------|---------------|--------------------------|--------------------------|--------------------------|-----------------------------------|-----------------------------------|
| 43 (16–79)               | 8/29         | 139 (96–164)      | 40 (28–48)    | 758 (479–2903)           | 8.5 (4.2–17.2)           | 5.4 (2.2–10.7)          | Hypertension 14 (40)                | Thrombosis prior to diagnosis 7 (20) |
|                          |              |                   |               |                          |                          |                          | Hyperlipidaemia 16 (46)            | Thrombosis following diagnosis 6 (17) |
|                          |              |                   |               |                          |                          |                          | Smoking 6 (17)                    | Major bleeding prior to diagnosis 0 (0) |
|                          |              |                   |               |                          |                          |                          | Diabetes mellitus 1 (2.8)         | Major bleeding following diagnosis 0 (0) |
|                          |              |                   |               |                          |                          |                          |                                   | Thrombosis prior to diagnosis 7 (20) |

Haematological and clinical information was collected at diagnosis; information concerning thrombosis and haemorrhage included events after diagnosis.

*Median (range).

### Table 2 Clinical and biological characteristics at most recent follow in nine patients with suspected triple-negative essential thrombocythaemia in which driver mutations were detected on rescreening

| Patient | Age/Sex* at diagnosis | Hb (g/L) | Hct % | Plt (>10^9/L) | F/U | Cytoreductive treatment | Trephine review | Mutation |
|---------|------------------------|----------|-------|--------------|-----|------------------------|-----------------|----------|
| 1       | M/60                   | 15       | 0.43  | 391          | 13  | Y                      |                 | JAK2V617F—9% |
| 5       | M/71                   | 9.2      | 0.25  | 263          | 15  | Y                      |                 | JAK2V617F—13% |
| 6       | F/69                   | 13.9     | 0.42  | 620          | 12  | Y                      |                 | JAK2V617F—8% |
| 10      | F/56                   | 13       | 0.4   | 379          | 15  | Y1                     |                 | JAK2V617F—4% |
| 18      | F/25                   | 11.3     | 0.34  | 453          | 13  | Y                      |                 | CALR pos |
| 19      | F/57                   | 13.8     | 0.4   | 463          | 7   | Y                      |                 | JAK2V617F—15% |
| 26      | F/33                   | 15       | 11.7  | 700          | 8   | N                      |                 | CALR pos |
| 34      | F/59                   | 14       | 0.4   | 514          | 2   | N                      |                 | CALR pos |

Haematological and clinical information was collected at retesting.

*Median (range).

†Patient 10 was diagnosed in 2003 and received hydroxyurea but was stopped due to the formation of a leg ulcer.

F/U, median follow-up; Hb, haemoglobin; Hct, haematocrit; Plt, platelets.

### Table 3 Clinical and biological characteristics in three patients with suspected triple-negative essential thrombocythaemia found to have mutations with next-generation sequencing

| Patient | Age/Sex* | Hb (g/L) | Hct % | Plt (>10^9/L) | F/U | Trephine review | Mutation—%VAF |
|---------|----------|----------|-------|--------------|-----|-----------------|---------------|
| 11      | 79/F     | 14       | 0.41  | 520          | 3   | P               | MPL: c.1544G>T, p.(Trp515Leu)—8% |
| 12      | 69/F     | 11.8     | 0.36  | 287          | 14  | P               | TET2: c.5650A>G, p.(Thr1884Ala)—12% |
| 31      | 42/F     | 12       | 0.36  | 352          | 12  | P               | CBL: c.1259G>A, p.(Arg420Gln)—24% |

Haematological and clinical information was collected at retesting.

*Median (range).

†Patient 10 was diagnosed in 2003 and received hydroxyurea but was stopped due to the formation of a leg ulcer.

F/U, median follow-up; Hb, haemoglobin; Hct, haematocrit; Plt, platelets; VAF, variant allele frequency.
DISCUSSION

In this real-world cohort of cases, we investigated the mutational profiles and reviewed the bone marrow biopsies of 35 cases of suspected TN-ET with a median clinical follow-up of 10 years. The detection of JAK2V617F and CALR mutations in 23% of patients when rescreened implies that the use of sensitive screening tools for driver mutations should be encouraged in the diagnostic workup of these cases. The rescreening of JAK2V617F used a sensitive real-time quantitative PCR assay that likely contributed to the enhanced identification of JAK2-positive cases. Low allele burden in JAK2 mutants have been well described in other series of TN-MPNs but may also indicate clonal haematopoiesis of indeterminate potential.3 7 8 Sensitivity can be improved when using isolated granulocytes or platelets in comparison with whole blood.9 The use of NGS is further supported by the observation that atypical JAK2 and MPL mutations have been identified in a series of TN-MPN.10–12 Our series prompted the histological review in cases with available material. Of 13 cases where no identifiable clonal marker was identified, 4 patients showed morphological features of ET (figure 1, table 4). Again these results imply that either the four cases had polyclonal haematopoiesis and may be hereditary MPN disorders or the technical limitations of the assay prevented the discovery of a clonal marker. In this particular study, we used the Illumina Trusight Myeloid gene panel that is limited to 54 genes and only exon 10 of the MLPL gene and exon 12/14 of JAK2 are included with the potential of missing rarer mutations.

We recognise certain limitations of this study, including the fact that all patients did not have BM trephines as required for a WHO diagnosis of ET. As this is a retrospective series of cases with a median follow-up of 10 years, all available cases (n=25) were assessed by an independent haematologist. The difference of opinion between the original diagnosis and that on review highlights the difficulty of producing completely reproducible morphological assessments in the real-world setting. In this setting, patients with a persistently elevated platelet count and no other causes have in the past been labelled as ET without BM.4 Now that clonal abnormalities are detected a raised platelet and the detection of a clone may be sufficient to have a diagnosis of ET.

This real-world series demonstrates that a sizeable proportion of patients do not have a clonal disease, which raises issues concerning the management where cytoreductive therapy may not be warranted.

CONCLUSION

We have found no genetic evidence for clonality in the majority of patients diagnosed with suspected TN-ET using targeted myeloid gene panel NGS. We propose rescreening for canonical driver mutations in these cases.

Table 4 Clinical and biological characteristics in four patients with suspected triple-negative ET without evidence of a clonal marker and histological suggestive of ET

| Patient ID | Age/Sex* | Hb (g/L) | Hct % | Plt (×10⁹/L) | F/U | Cytoreductive treatment | Trephine at diagnosis |
|------------|----------|----------|-------|--------------|-----|------------------------|-----------------------|
| 25         | 75/F     | 12       | 0.37  | 615          | 2   | Y                      | Increase in number of megakaryocytes with clustering and nuclear lobulation |
| 27†        | 43/F     | 12       | 0.36  | 581          | 8   | Y                      | Increased numbers of megakaryocytes. Pleomorphic in size with some large hyperlobulated forms. Grade 2 reticulin |
| 30         | 70/M     | 11.8     | 0.33  | 517          | 3   | Y                      | Normal to increased megakaryocytes. Predominance of large mature forms some with deeply lobulated nuclei. |
| 33         | 40/F     | 12.7     | 0.38  | 1018         | 3   | N                      | Increased loosely, clustered and large megakaryocytes. Some megakaryocytes have abnormal nuclei. No fibrosis |

Haematological and clinical information was collected at retesting.

*Median (range).
†Patient 27 was diagnosed as ET with a BM 3 years post presentation and by this stage progression seems to have occurred.

BM, bone marrow; ET, essential thrombocythaemia; F/U, median follow-up; Hb, haemoglobin; Hct, haematocrit; Plt, platelets.
mutations is indicated, in light of their detection on repeat genotyping in this group of patients.

This study should encourage others to reconsider the diagnosis in a similar set of real-world cases that exist within MPN clinics throughout the country.

Correction notice This article has been corrected since it was published Online First. Rosin McAllister has been added as an author of the paper.

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