**Diagnosis of multi-system inflammatory syndrome in children by a whole-blood transcriptional signature**

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**Conflict of Interest Statement**

The authors have no conflicts of interest to declare.The funders had no role in the study design, the collection, analysis, and interpretation of data, the writing of the report, and the decision to submit the manuscript for publication. Heather Jackson wrote the first draft of the manuscript**.** No honorarium, grant, or other form of payment was given to anyone to produce the manuscript.

**Funding Sources**

Supported by the European Union’s Horizon 2020 Program under grants (848196 DIAMONDS, 668303 PERFORM, 279185 EUCLIDS, Prof Levin), by the Imperial Biomedical Research Centre (BRC) of the National Institute for Health Research (NIHR), grants (206508/Z/17/Z and MRF-160-0008-ELP-KAFO-C0801, to Dr. Kaforou) from the Wellcome Trust and the Medical Research Foundation, a grant (215214/Z/19/Z, to Ms Jackson) from the Wellcome Trust, a grant (R61HD105590-01 PreVAIL kIds, to Dr. Burns) from the National Institutes of Health, and grants (WDPI\_G28062 and WDPI\_P89720, to Drs Herberg and Georgiou) from the Community Jameel Imperial College COVID-19 Excellence Fund and the Rosetrees Trust. This work has been supported by the Imperial Confidence in Concept Scheme, funded by MRC Confidence in Concept, Wellcome Trust Institutional Strategic Support Fund (ISSF), NIHR Imperial BRC, and Rosetrees Trust (to Rodriguez-Manzano and Kaforou).

**Data Statement**

Gene counts and patient metadata from EUCLIDS RNA-Seq (including KD patients) are available at ArrayExpress under accession E-MTAB-11671. Data for the PERFORM RNA-Seq are also available in ArrayExpress (ID pending). Code used in the analyses can be found at: <https://github.com/PIDBG/misc_transcriptomic_signature>.

**Key Words**

paediatric infectious diseases; transcriptomics; diagnostic signature; rapid diagnostics; MIS-C; COVID-19; host diagnostics; host response

**Abstract (245/250 words)**

**Objective**

To identify a diagnostic blood transcriptomic signature that distinguishes multisystem inflammatory syndrome in children (MIS-C) from Kawasaki Disease (KD), bacterial infections and viral infections.

**Study design**

Children presenting with MIS-C to participating hospitals in the United Kingdom and the European Union between April 2020-April 2021 were prospectively recruited. Whole blood RNA Sequencing was performed, contrasting the transcriptomes of children with MIS-C (*n*=38) to those from children with KD (*n*=136), definite bacterial (DB; *n*=188) and viral infections (DV; *n*=138). Genes significantly differentially expressed (SDE) between MIS-C and comparator groups were identified. Feature selection was used to identify genes that optimally distinguish MIS-C from other diseases, which were subsequently translated into RT-qPCR assays and evaluated in an independent validation set comprising MIS-C (*n*=37), KD (*n*=19), DB (*n*=56), DV (*n*=43), and COVID-19 (*n*=39).

**Results**

In the discovery set, 5,696 genes were SDE between MIS-C and combined comparator disease groups. Five genes were identified as potential MIS-C diagnostic biomarkers (*HSPBAP1*, *VPS37C*, *TGFB1*, *MX2*, *TRBV11-2*), achieving an AUC of 96.8% (95% CI: 94.6%-98.9%) in the discovery set, and were translated into RT-qPCR assays. The RT-qPCR 5-gene signature achieved an AUC of 93.2% (95% CI: 88.3%-97.7%) in the independent validation set when distinguishing MIS-C from KD, DB, and DV.

**Conclusion**

MIS-C can be distinguished from KD, DB, and DV groups using a 5-gene blood RNA expression signature. The small number of genes in the signature, and good performance in both discovery and validation sets should enable the development of a diagnostic test for MIS-C.

**Introduction**

Since its recognition in 2020, Multi-system Inflammatory Syndrome in Children (MIS-C) temporally associated with SARS-CoV-2 infection has emerged as an important cause of critical illness in children worldwide (1-4). MIS-C occurs 2-6 weeks after SARS-CoV-2 infection (1, 2, 4) and is characterized by persistent fever and non-specific symptoms, particularly abdominal pain, vomiting, headache, and fatigue (4-6). Conjunctival injection and rash resembling Kawasaki Disease (KD) occur in many patients (2, 7, 8). Severely affected children often develop shock and multi-organ failure (4, 5). Laboratory studies show increased inflammation with elevated C-reactive protein (CRP), ferritin, troponin, and brain natriuretic peptide (BNP), and reduced haemoglobin, platelets, and lymphocytes (4).

MIS-C diagnosis is based on clinical criteria established by consensus in the early months after the first recognition of the disorder. Diagnostic criteria from the WHO (9), Royal College of Paediatrics (United Kingdom) (10) and CDC (USA) (11) are largely overlapping and require the presence of fever, multi-system organ involvement, laboratory evidence of inflammation, and exclusion of other infectious and inflammatory disorders. The CDC and WHO definitions also include evidence of recent SARS-CoV-2 infection or exposure.

While the hastily developed case definitions for MIS-C have provided clinicians with valuable tools for recognition of this new disorder, these were created by expert opinion after the initial cluster of less than sixty patients (4). Until now, a major difficulty facing clinicians in diagnosis and management of MIS-C has been the lack of a reliable diagnostic test. The clinical features of MIS-C are non-specific and overlap with those of many childhood infectious and inflammatory diseases, including sepsis, severe bacterial and viral infections, KD, staphylococcal and streptococcal toxic shock syndromes, gastrointestinal infections, appendicitis, systemic juvenile rheumatoid arthritis, macrophage activation syndrome, and hemophagocytic lymphohistiocytosis (HLH) (12-14) . Due to these diagnostic difficulties, patients are often treated with prolonged courses of antibiotics while awaiting cultures to exclude bacterial infection before the diagnosis of MIS-C is considered. Conversely, the similarity in features with disorders such as HLH and KD has led to several immunomodulatory agents typically used in these other conditions being administered to children with MIS-C with no clear evidence yet of the optimal treatment (15, 16). Thus, there is an urgent need for a diagnostic test to distinguish MIS-C from other paediatric infectious and inflammatory disorders.

A growing body of research suggests that individual infectious and inflammatory diseases are characterised by unique patterns of host RNA abundance in whole blood (17). Sparse gene signatures, based on small numbers of transcripts have been reported for several diseases including tuberculosis disease (18-21) , malaria (22), bacterial and viral infections (23-26), and KD (27). MIS-C has already been shown to elicit specific changes in gene expression compared to healthy controls and paediatric COVID-19 using targeted and untargeted transcriptomic approaches, respectively (28, 29). We show here that MIS-C can be distinguished from KD and a wide range of bacterial and viral infections by a sparse RNA signature that could form the basis of a diagnostic test for clinical use.

**Methods**

**Clinical cohorts and study design**

At the onset of the COVID-19 pandemic, the authors had ongoing patient recruitment to successive European Union-funded international studies: DIAMONDS (Diagnosis and Management of Febrile Illness using RNA Personalised Molecular Signature Diagnosis) and PERFORM (Personalised Risk assessment in Febrile illness to Optimise Real-life Management across the European Union). Samples and data were also available from studies recruiting before the start of the COVID-19 pandemic: EUCLIDS (European Union Childhood Life-Threatening Infectious Disease Study) and Kawasaki Disease Research Centre Study at the University of California San Diego (UCSD). Further details of each cohort are provided in Supplementary Methods.

Patients recruited to each study were phenotyped according to our published algorithm (Supplementary Methods) (24, 30, 31). KD was diagnosed on the basis of the American Heart Association diagnostic criteria (32), and MIS-C was diagnosed based on the WHO criteria (9). In both discovery and validation sets, we included patients with MIS-C, KD, confirmed bacterial infection (termed definite bacterial; DB), and confirmed viral infections (definite viral; DV). Healthy control children were included but only used to correct for batch effects between groups. The DB group mainly included patients in whom an appropriate bacterial pathogen was isolated from a normally sterile site. However, we also included a group of pathogens which are normally identified only on mucosal surfaces or by non-culture methods, such as *Campylobacter*, *Salmonella*, *Borrelia burgdorferi*, and *Bordetella pertussis.* We termed these non-sterile site definite bacterial infections (NSDB), which we considered important to include as a comparator due to the predominance of gastrointestinal symptoms in MIS-C cases, resembling enteric infections and the breadth of multi-system symptoms. DV was conditional upon identification of a virus compatible with the clinical syndrome with no evidence of bacterial infection and CRP ≤ 60mg/L. In the validation set, we additionally included children with COVID-19. Signature discovery was performed using a discovery set generated through RNA Sequencing (RNA-Seq). Signature validation was carried out using an independent validation set generated by reverse transcription-quantitative polymerase chain reaction (RT-qPCR).

**Study oversight and ethics**

Patients were recruited according to the approved enrolment procedures of each study, and with the informed consent of parents and assent for older children. Each study was approved by the relevant institutional and national research ethics committees: DIAMONDS (London – Dulwich Research Ethics Committee: 20/HRA/1714); PERFORM (London – Central Research Ethics Committee: 16/LO/1684); and EUCLIDS (NRES Committee London – Fulham: 11/LO/1982) studies. The UCSD KD study was approved by the UCSD Investigational Review Board (University of California San Diego (Human Research Protection Program 140220).

**Signature Discovery Stage**

**Sample collection and RNA Sequencing**

Venous blood was collected from patients at the earliest time point after recruitment and prior to treatment with IVIG or immunomodulator into PAXgene Blood RNA (PreAnalytiX, Germany) and stored at -80oC until extraction. Total RNA was isolated using recommended methodology (including miRNA for PAXgene blood RNA vacutainers and after additional DNAse treatment and sent for RNA-Seq at The Wellcome Centre for Human Genetics in Oxford, United Kingdom using a Novaseq6000 platform at 150bp paired-end configuration, generating a raw read count of 30 million reads per sample.

**Analysis of RNA Sequencing data and discovery of diagnostic gene signature**

All statistical analyses were performed using the statistical software R (R version 4.0.3) (33). Full details of the normalisation and quality control (QC) methods for the RNA-Seq data are in the Supplementary Methods. Healthy paediatric controls included in the RNA-Seq experiment were used for batch normalisation. After QC, genes significantly differentially expressed (SDE) between MIS-C and each of the individual disease groups (KD, DV, and DB), as well as the groups combined were identified using DESeq2 (34), with age, sex and RNA-Seq dataset included in the DESeq2 model. Genes with Benjamini-Hochberg (BH) (35) adjusted *p*-values <0.05 were considered significantly differentially expressed (SDE). Genes with adjusted *p*-values <0.001, absolute log fold-change (LFC) values >0.5, and with mean gene count >50 in all disease groups and >100 in at least one disease group were taken forward to variable selection using a modified version of Forward Selection-Partial Least Squares (FS-PLS) (19, 24, 36). The modified version of FS-PLS enables multiple comparisons to be considered in parallel (36) with details of the comparisons considered in the Supplementary Materials. The performance of the combined FS-PLS set and the top SDE gene between MIS-C and all other disease groups was evaluated using the area under the receiver operating characteristic (ROC) curve (AUC) calculated using a weighted disease risk score (DRS) for each individual calculated from the combined information of all transcripts in the model (Supplementary Methods). The weighted DRS is an adaptation of the DRS approach described in (20, 24, 26). The optimal weighted DRS threshold for MIS-C classification in the discovery set was selected using the Youden’s index (37) which optimises the trade-off between sensitivity and specificity to maximise AUC.

**Signature Validation Stage**

**Translation to RT-qPCR assays**

Genes identified in the discovery phase were considered for validation by RT-qPCR, in addition to a reference gene – Glyceraldehyde 3-phosphate dehydrogenase (*GAPDH*) - which was used to normalise the RNA input of each sample. Primers were designed as described in Supplementary Methods (Table 3, available at [www.jpeds.com](http://www.jpeds.com)). The validation was performed using the Biomark HD (Fluidigm) and the 192.24 Dynamic Array™ integrated fluidic circuit (IFC) following manufacturer instructions. The IFC required the following three steps: reverse transcription, pre-amplification, RT-qPCR (Supplementary Methods).

**Statistical analysis of RT-qPCR data.**

Following quality control and normalisation of the RT-qPCR data (Supplementary Methods), the performance of the signature was evaluated. Weighted DRS were calculated for each sample using coefficients for each gene in the RT-qPCR signature that were calculated by a generalised logistic regression model (GLM) contrasting MIS-C to KD, DV and DB (details in Supplementary Methods). The performance of the RT-qPCR signature was evaluated through the weighted DRS in ROC models that contrasted MIS-C to previously “seen” groups included in the discovery set - KD, DV and DB - and then separately with COVID-19 which was not included in the discovery cohort.

**Data availability**

Gene counts and patient metadata from EUCLIDS RNA-Seq (including KD patients) are available at ArrayExpress under accession E-MTAB-11671. Data for the PERFORM RNA-Seq are also available in ArrayExpress (ID pending). Code used in the analyses can be found at: <https://github.com/PIDBG/misc_transcriptomic_signature>.

**Results**

To identify an RNA signature for diagnosing MIS-C, we established a discovery set and a separate validation set (Figure 1). Whole blood transcriptomes of MIS-C patients (*n*=38) and patients with KD (*n*=136), viral infections (*n*=138), bacterial infections (*n*=188), and healthy controls (*n*=134) were included in the discovery cohort.

MIS-C patients were older than the comparator disease groups (median age 126 months *vs*. 30 months for KD, 7 months for viral, and 38 months for bacterial) and had a longer median duration of symptoms prior to presentation (6 days) than the bacterial infection groups (2 days for bacterial), but similar to KD (6 days) and viral infections (5 days) (Table 1). A high proportion of MIS-C patients presented with shock (52%, *n*=37), 60.6% (*n*=23) were admitted to intensive care, 52% (*n*=20) required inotropes, and 13.2% (*n*=5) and 10.5% (*n*=4) required non-invasive and invasive ventilation, respectively. The causative pathogens for the confirmed bacterial and viral infections are summarised in Table 2 (available at [www.jpeds.com](http://www.jpeds.com)).

The patients in the validation cohort were similar to those in the discovery set, apart from a different range of causative pathogens (Table 1, Table 2 available at [www.jpeds.com](http://www.jpeds.com)). The validation cohort was composed of patients with MIS-C (*n*=37), KD (n=17), confirmed viral infections not including COVID-19 (*n*=41), COVID-19 (*n*=39), confirmed bacterial infections (*n*=50), and healthy controls (*n*=24) (Supplementary Methods). See Fig. 1 for details of samples that were excluded. PCA showed visible clustering of patients according to disease group (Fig. 2A available at [www.jpeds.com](http://www.jpeds.com)).

**RNA differential expression analysis**

Overall, 5,696 genes were found to be SDE (BH-adjusted *p*-value <0.05) between MIS-C and the combined KD, viral and bacterial infection groups with 3,250 and 2,446 genes over- and under-expressed in MIS-C, respectively (Fig. 3A available at [www.jpeds.com](http://www.jpeds.com) and Supplementary File 1). For MIS-C *vs.* KD, 4,786 genes were SDE (2,681 and 2,105 genes over- and under-expressed respectively; Fig. 3B available at [www.jpeds.com](http://www.jpeds.com), Supplementary File 2). For MIS-C *vs.* viral infection, 10,654 genes were SDE (5,973 and 4,681 genes over- and under-expressed respectively; Fig. 3C available at [www.jpeds.com](http://www.jpeds.com), Supplementary File 3). For MIS-C *vs*. bacterial infection 3,718 genes were SDE (1,776 and 1,942 genes over- and under-expressed respectively; Fig. 3D available at [www.jpeds.com](http://www.jpeds.com), Supplementary File 4). T Cell Receptor Beta Variable 11-2 (*TRBV11-2*) was the top SDE gene for MIS-C *vs*. the comparator groups combined (BH-adjusted *p*-value: 7.14410-27; LFC: 1.99) (Fig. 3A available at [www.jpeds.com](http://www.jpeds.com)).

**Identification of diagnostic combination of genes**

Variable selection using FS-PLS identified four genes distinguishing MIS-C from KD, viral and bacterial infections: HSPB1 Associated Protein 1 (*HSPBAP1*), Vacuolar Protein Sorting-Associated Protein 37C (*VPS37C*), Transforming Growth Factor Beta 1 (*TGFB1*) and MX Dynamin Like GTPase 2 (*MX2*). To introduce redundancy to the gene set for subsequent transfer to RT-qPCR assays, the top SDE gene - *TRBV11-2* - was also included. *TRBV11-2* was not selected by FS-PLS due to cut-offs introduced to avoid the risk of overfitting (Supplementary Methods). When the 5 genes were combined as a weighted DRS for each patient (Fig. 4A), MIS-C was distinguished from the combined comparator diseases with AUC of 96.8% (95% CI: 94.6%-98.9%; Fig. 4B) with a sensitivity of 86.1% and specificity of 94.7% (Fig. 4A). When the individual comparator groups were considered separately, the 5-gene combination achieved an AUC of 93.2% (95% CI: 88.8%-97.5%; Fig. 4C) for MIS-C vs. KD, 99.1% (95% CI: 98.1%-100%; Fig. 4D) for MIS-C vs. viral, and 97.7% (95% CI: 95.9%-99.4%; Fig. 4E), for MIS-C vs. bacterial.

**RT-qPCR validation**

The 5 candidate biomarker genes identified from the discovery set were taken forward to RT-qPCR validation together with the “housekeeping “gene *GAPDH*. The 5 candidate genes were combined into a gene signature – the RT-qPCR signature – and the performance of the signature was evaluated in the validation set.

To optimise performance of the signature on a different platform, a weighted DRS for each patient was calculated (details in Supplementary Methods, with gene coefficients in Supplementary Results). ROC plots and AUCs were calculated using the weighted DRS for all patients to evaluate the signature’s performance at distinguishing MIS-C and comparator phenotypic groups either with or without the COVID-19 group which was not included in the discovery set. The 5-gene RT-qPCR signature achieved a sensitivity of 91.7% and specificity of 81.7% for distinguishing MIS-C from the disease groups included in the discovery set - excluding COVID-19 - with an AUC of 93.2 (95% CI: 88.8%-97.7%; Fig. 5A and 5C).

When the signature was assessed in the specific disease groups, the highest AUCs were observed when distinguishing MIS-C from bacterial infections with an AUC of 97.6% (95% CI: 94.8%-100%; Fig. 5F). When bacterial samples were split into sterile site and non-sterile site bacteria, the 5-gene RT-qPCR signature achieved an AUC of 97.8% (95% CI: 95.3%-100%) for MIS-C vs. sterile site bacteria and 96% (95% CI: 90.3%-100%) for MIS-C vs. non-sterile site bacteria. The 5-gene RT-qPCR signature achieved an AUC of 90.8% (95% CI: 81.6%-100%) for distinguishing between MIS-C vs. KD (Fig. 5D), 89% (95% CI: 82%-96%) for MIS-C vs. viral (Fig. 5E), and 83.5% (95% CI: 74.5%-92.6%) for MIS-C vs. COVID-19 (Fig. 5G). The 5-gene RT-qPCR signature achieved an AUC of 90.8 (95% CI: 85.8%-95.8%) when contrasting MIS-C against all phenotypic groups including COVID-19 (Fig. 5C).

**Discussion**

We used whole blood RNA-Seq to compare the blood transcriptomes of patients with MIS-C to those with KD, bacterial and viral infections. Despite overlapping clinical and laboratory features between these conditions, there were clear differences in the blood transcriptome, with 4,786, 10,654 and 3,718 SDE genes between MIS-C *vs*. KD, *vs*. viral, and *vs*. bacterial infections, respectively, providing further support that MIS-C is a biologically distinct entity.

Using feature selection tools, we identified a minimal gene signature distinguishing MIS-C from the other disease groups. We performed cross-platform validation of the biomarker genes in an independent patient set using RT-qPCR, a methodology more suited for clinical use of the signature as a diagnostic test. Patients included reflected not only disease groups in the discovery set (MIS-C, KD, viral and bacterial infections) but also COVID-19. Cross-platform validation of the genes identified by RNA-Seq to RT-qPCR in the independent patient cohort showed similar performance of the RT-qPCR signature to that in the RNA-Seq discovery set.

Since the emergence of MIS-C in 2020, diagnosis has been challenging, as the clinical and laboratory features are often indistinguishable from those of a wide range of other diseases. There has been particular difficulty in distinguishing MIS-C from KD, with reports early in the pandemic from several countries documenting an upsurge in KD-like inflammatory syndromes (8, 38), which with hindsight may have been misdiagnoses of MIS-C as KD. In addition, similarities between MIS-C and sepsis, septic shock, staphylococcal, and streptococcal shock syndromes present considerable difficulties in terms of managing patients (4, 13, 39), as administering immunomodulating agents (the usual treatment for MIS-C) to patients with severe infections may be deleterious. Additionally, many patients who turn out to have MIS-C receive prolonged courses of broad-spectrum antibiotics before the diagnosis is made. The diagnostic difficulty is most acute in low- and middle-income countries, where a wide range of prevalent infections share features with MIS-C.

The overlap in clinical features between MIS-C and KD led to immunoglobulin - the proven treatment for KD - being widely adopted as initial treatment for MIS-C. As there is evidence that MIS-C outcome may be no different when steroids are used instead of IVIG (16), and since immunoglobulin is expensive with limited availability in some countries, a test capable of distinguishing between the two disorders would be helpful in targeting specific treatments for each disease.

Although we have focused on the use of genes as diagnostic biomarkers tool, the extensive RNA-Seq data comparing MIS-C with other diseases will provide the scientific community with a valuable resource for exploring the biological pathways and host response distinguishing MIS-C from other disorders. Further biological exploration of the data is likely to identify novel mechanisms and pathways mediating MIS-C as targets for novel therapies.

The genes included in the 5-gene RT-qPCR signature have biological functions that may provide insight into pathogenesis of MIS-C. *HSPBAP1* regulates expression of *TMPRSS2*, the gene encoding the enzyme Transmembrane protease, serine 2, which is used by SARS-CoV-2 for S protein priming (40). *TGFB1* encodes a ligand that, amongst other functions, modulates expression and activation of cytokines including interferon gamma and tumour necrosis factor alpha (TNF-α). Elevated expression of *TGFB1* in CD4+ T cells and higher numbers of TGFB1-expressing T and CD14-positive cells have been observed in a small set of patients with severe COVID-19 (41). *VPS37C* is involved in endosomal sorting and has been shown to play a role in viral budding, specifically of human immunodeficiency virus, type 1 (HIV-1) by the HIV-1 Gag protein (42). *MX2* encodes a GTPase and is part of the antiviral response induced by type 1 and 3 interferons. Elevated levels of *MX2* have been identified in individuals with SARS-CoV-2 (43), and other viral infections (44). Our finding that *TRBV11-2* is the most SDE gene is in keeping with previous reports, where expansion of peripheral T cells carrying *TRBV11-2* has been correlated with disease severity and serum cytokine levels (45, 46). Furthermore, it has been postulated that the selective expansion of specific T-cell V beta subsets is being driven by a super-antigen mediated process (45-48).

Our study has several limitations. The MIS-C patients included in the signature discovery and validation sets were recruited during the period of April 2020-April 2021. As such, the SARS-CoV-2 variants that triggered the illness are limited to those that were circulating during this period and notably, would not include the Omicron variant that was first detected in November 2021. The Omicron variant appears to be linked with less severe manifestations of MIS-C (49-51). External validation of the gene panel in larger numbers of patients across different periods of the pandemic, and different global settings, will be needed to assess the robustness of the signature in the face of different viral pathogen genetics. A limitation of all studies exploring patients with MIS-C and KD is that there is no gold-standard diagnostic test for either illness. However, the KD patients included in the discovery set were recruited prior to the COVID-19 pandemic. For MIS-C, we made every effort to only include in both the discovery and validation patients meeting the WHO definition, including evidence of recent SARS-CoV-2 infection detected by antibody or PCR. Despite these limitations, our data provides evidence that MIS-C is a distinct syndrome characterised by a unique transcriptomic signature, and that a diagnostic test based on a small number of RNA transcripts is achievable.

Our finding that MIS-C can be distinguished from other conditions using a small RNA signature, and that detection of this signature by RT-qPCR achieves similar accuracy to that of RNA-Seq, paves the way for development of a rapid test to distinguish MIS-C from other phenotypically similar diseases. As a range of devices that can provide RT-qPCR results rapidly are now available, including several platforms already in use in clinical settings worldwide (52-54), the development of a clinically applicable test for MIS-C based on the 5-gene RT-qPCR signature can be readily achieved.

**References**

1. Dufort EM, Koumans EH, Chow EJ, Rosenthal EM, Muse A, Rowlands J, et al. Multisystem Inflammatory Syndrome in Children in New York State. N Engl J Med. 2020;383(4):347-58.

2. Feldstein LR, Rose EB, Horwitz SM, Collins JP, Newhams MM, Son MBF, et al. Multisystem Inflammatory Syndrome in U.S. Children and Adolescents. N Engl J Med. 2020;383(4):334-46.

3. Levin M. Childhood Multisystem Inflammatory Syndrome — A New Challenge in the Pandemic. New England Journal of Medicine. 2020;383(4):393-5.

4. Whittaker E, Bamford A, Kenny J, Kaforou M, Jones CE, Shah P, et al. Clinical Characteristics of 58 Children With a Pediatric Inflammatory Multisystem Syndrome Temporally Associated With SARS-CoV-2. JAMA. 2020;324(3):259-69.

5. Belhadjer Z, Meot M, Bajolle F, Khraiche D, Legendre A, Abakka S, et al. Acute Heart Failure in Multisystem Inflammatory Syndrome in Children in the Context of Global SARS-CoV-2 Pandemic. Circulation. 2020;142(5):429-36.

6. Rubens JH, Akindele NP, Tschudy MM, Sick-Samuels AC. Acute covid-19 and multisystem inflammatory syndrome in children. BMJ. 2021;372:n385.

7. Consiglio CR, Cotugno N, Sardh F, Pou C, Amodio D, Rodriguez L, et al. The Immunology of Multisystem Inflammatory Syndrome in Children with COVID-19. Cell. 2020;183(4):968-81 e7.

8. Verdoni L, Mazza A, Gervasoni A, Martelli L, Ruggeri M, Ciuffreda M, et al. An outbreak of severe Kawasaki-like disease at the Italian epicentre of the SARS-CoV-2 epidemic: an observational cohort study. The Lancet. 2020;395(10239):1771-8.

9. Organisation WH. Multisystem inflammatory syndrome in children and adolescents with COVID-19. 2020.

10. Health RCoPaC. Paediatric multisystem inflammatory syndrome temporally associated with COVID-19 (PIMS) - guidance for clinicians Royal College of Paediatrics and Child Health website2020 [Available from: rcpch.ac.uk/resources/paediatric-multisystem-inflammatory-syndrome-temporally-associated-covid-19-pims-guidance.

11. Prevention CfDCa. Information for Healthcare Providers about Multisystem Inflammatory Syndrome in Children (MIS-C). 2020.

12. Kumar D, Rostad CA, Jaggi P, Villacis Nunez DS, Prince C, Lu A, et al. Distinguishing immune activation and inflammatory signatures of multisystem inflammatory syndrome in children (MIS-C) versus hemophagocytic lymphohistiocytosis (HLH). J Allergy Clin Immunol. 2022;149(5):1592-606 e16.

13. Noval Rivas M, Porritt RA, Cheng MH, Bahar I, Arditi M. COVID-19-associated multisystem inflammatory syndrome in children (MIS-C): A novel disease that mimics toxic shock syndrome-the superantigen hypothesis. The Journal of allergy and clinical immunology. 2021;147(1):57-9.

14. Otar Yener G, Paç Kısaarslan A, Ulu K, Atalay E, Haşlak F, Özdel S, et al. Differences and similarities of multisystem inflammatory syndrome in children, Kawasaki disease and macrophage activating syndrome due to systemic juvenile idiopathic arthritis: a comparative study. Rheumatology international. 2022;42(5):879-89.

15. Davies P, Lillie J, Prayle A, Evans C, Griffiths B, du Pré P, et al. Association Between Treatments and Short-Term Biochemical Improvements and Clinical Outcomes in Post-Severe Acute Respiratory Syndrome Coronavirus-2 Inflammatory Syndrome. Pediatric Critical Care Medicine. 2021;22(5).

16. McArdle AJ, Vito O, Patel H, Seaby EG, Shah P, Wilson C, et al. Treatment of Multisystem Inflammatory Syndrome in Children. N Engl J Med. 2021;385(1):11-22.

17. Gliddon HD, Herberg JA, Levin M, Kaforou M. Genome-wide host RNA signatures of infectious diseases: discovery and clinical translation. Immunology. 2018;153(2):171-8.

18. Anderson ST, Kaforou M, Brent AJ, Wright VJ, Banwell CM, Chagaluka G, et al. Diagnosis of childhood tuberculosis and host RNA expression in Africa. N Engl J Med. 2014;370(18):1712-23.

19. Gliddon HD, Kaforou M, Alikian M, Habgood-Coote D, Zhou C, Oni T, et al. Identification of Reduced Host Transcriptomic Signatures for Tuberculosis Disease and Digital PCR-Based Validation and Quantification. Frontiers in Immunology. 2021;12.

20. Kaforou M, Wright VJ, Oni T, French N, Anderson ST, Bangani N, et al. Detection of Tuberculosis in HIV-Infected and -Uninfected African Adults Using Whole Blood RNA Expression Signatures: A Case-Control Study. PLOS Medicine. 2013;10(10):e1001538.

21. Sweeney TE, Braviak L, Tato CM, Khatri P. Genome-wide expression for diagnosis of pulmonary tuberculosis: a multicohort analysis. Lancet Respir Med. 2016;4(3):213-24.

22. Omar M, Marchionni L, Häcker G, Badr MT. Host Blood Gene Signatures Can Detect the Progression to Severe and Cerebral Malaria. Frontiers in cellular and infection microbiology. 2021;11:743616-.

23. Herberg JA, Kaforou M, Gormley S, Sumner ER, Patel S, Jones KD, et al. Transcriptomic profiling in childhood H1N1/09 influenza reveals reduced expression of protein synthesis genes. J Infect Dis. 2013;208(10):1664-8.

24. Herberg JA, Kaforou M, Wright VJ, Shailes H, Eleftherohorinou H, Hoggart CJ, et al. Diagnostic Test Accuracy of a 2-Transcript Host RNA Signature for Discriminating Bacterial vs Viral Infection in Febrile Children. JAMA. 2016;316(8):835-45.

25. Kaforou M, Herberg JA, Wright VJ, Coin LJM, Levin M. Diagnosis of Bacterial Infection Using a 2-Transcript Host RNA Signature in Febrile Infants 60 Days or Younger. JAMA. 2017;317(15):1577-8.

26. Li HK, Kaforou, M., Rodriguez-Manzano, J., Channon-Wells, S., Moniri, A., Habgood-Coote, D., Gupta, R., Mills, E. A., Arancon, D., Lin, J., Chiu, Y., Pennisi, I., Miglietta, L., Obaray, N., Mehta, R., Herberg, J., Wright, V. J., Georgiou, P., Shallcross, L., Mentzer, A. J., Levin, M., Cooke, G., Noursadeghi, M. and Sriskandan, S. . Discovery and Validation of a 3-Gene Transcriptional Signature to Distinguish COVID-19 and Other Viral Infections from Bacterial Sepsis in Adults; A Case-Control then Observational Cohort Study.

27. Wright VJ, Herberg JA, Kaforou M, Shimizu C, Eleftherohorinou H, Shailes H, et al. Diagnosis of Kawasaki Disease Using a Minimal Whole-Blood Gene Expression Signature. JAMA Pediatrics. 2018;172(10):e182293-e.

28. Beckmann ND, Comella PH, Cheng E, Lepow L, Beckmann AG, Tyler SR, et al. Downregulation of exhausted cytotoxic T cells in gene expression networks of multisystem inflammatory syndrome in children. Nature Communications. 2021;12(1):4854.

29. Spracklen TF, Mendelsohn SC, Butters C, Facey-Thomas H, Stander R, Abrahams D, et al. IL27 gene expression distinguishes multisystem inflammatory syndrome in children from febrile illness in a South African cohort. Frontiers in Immunology. 2022;13.

30. Nijman RG, Oostenbrink R, Moll HA, Casals-Pascual C, von Both U, Cunnington A, et al. A Novel Framework for Phenotyping Children With Suspected or Confirmed Infection for Future Biomarker Studies. Front Pediatr. 2021;9:688272.

31. Martinon-Torres F, Salas A, Rivero-Calle I, Cebey-Lopez M, Pardo-Seco J, Herberg JA, et al. Life-threatening infections in children in Europe (the EUCLIDS Project): a prospective cohort study. Lancet Child Adolesc Health. 2018;2(6):404-14.

32. McCrindle BW, Rowley AH, Newburger JW, Burns JC, Bolger AF, Gewitz M, et al. Diagnosis, Treatment, and Long-Term Management of Kawasaki Disease: A Scientific Statement for Health Professionals From the American Heart Association. Circulation. 2017;135(17):e927-e99.

33. Team RC. R: A Language and Environment for Statistical Computing. 2022.

34. Love MI, Huber W, Anders S. Moderated estimation of fold change and dispersion for RNA-seq data with DESeq2. Genome Biology. 2014;15(12):550.

35. Benjamini Y, Hochberg Y. Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. Journal of the Royal Statistical Society Series B (Methodological). 1995;57(1):289-300.

36. Coin LJ. Lachlancoin/fspls: Minimal TB Biomarkers (Version 0.5.1 Zenodo2018 [

37. Youden WJ. Index for rating diagnostic tests. Cancer. 1950;3(1):32-5.

38. Ouldali N, Bagheri H, Salvo F, Antona D, Pariente A, Leblanc C, et al. Hyper inflammatory syndrome following COVID-19 mRNA vaccine in children: A national post-authorization pharmacovigilance study. The Lancet Regional Health – Europe. 2022;17.

39. Riphagen S, Gomez X, Gonzalez-Martinez C, Wilkinson N, Theocharis P. Hyperinflammatory shock in children during COVID-19 pandemic. Lancet. 2020;395(10237):1607-8.

40. Hoffmann M, Kleine-Weber H, Schroeder S, Krüger N, Herrler T, Erichsen S, et al. SARS-CoV-2 Cell Entry Depends on ACE2 and TMPRSS2 and Is Blocked by a Clinically Proven Protease Inhibitor. Cell. 2020;181(2):271-80.e8.

41. Ferreira-Gomes M, Kruglov A, Durek P, Heinrich F, Tizian C, Heinz GA, et al. SARS-CoV-2 in severe COVID-19 induces a TGF-β-dominated chronic immune response that does not target itself. Nature Communications. 2021;12(1):1961.

42. Eastman SW, Martin-Serrano J, Chung W, Zang T, Bieniasz PD. Identification of human VPS37C, a component of endosomal sorting complex required for transport-I important for viral budding. J Biol Chem. 2005;280(1):628-36.

43. Bizzotto J, Sanchis P, Abbate M, Lage-Vickers S, Lavignolle R, Toro A, et al. SARS-CoV-2 Infection Boosts MX1 Antiviral Effector in COVID-19 Patients. iScience. 2020;23(10):101585.

44. Staeheli P, Haller O. Human MX2/MxB: a Potent Interferon-Induced Postentry Inhibitor of Herpesviruses and HIV-1. J Virol. 2018;92(24).

45. Hoste L, Roels L, Naesens L, Bosteels V, Vanhee S, Dupont S, et al. TIM3+ TRBV11-2 T cells and IFNgamma signature in patrolling monocytes and CD16+ NK cells delineate MIS-C. J Exp Med. 2022;219(2).

46. Porritt RA, Paschold L, Rivas MN, Cheng MH, Yonker LM, Chandnani H, et al. HLA class I-associated expansion of TRBV11-2 T cells in multisystem inflammatory syndrome in children. J Clin Invest. 2021;131(10).

47. Sacco K, Castagnoli R, Vakkilainen S, Liu C, Delmonte OM, Oguz C, et al. Immunopathological signatures in multisystem inflammatory syndrome in children and pediatric COVID-19. Nat Med. 2022.

48. Ramaswamy A, Brodsky NN, Sumida TS, Comi M, Asashima H, Hoehn KB, et al. Immune dysregulation and autoreactivity correlate with disease severity in SARS-CoV-2-associated multisystem inflammatory syndrome in children. Immunity. 2021;54(5):1083-95 e7.

49. Holm M, Espenhain L, Glenthøj J, Schmidt LS, Nordly SB, Hartling UB, et al. Risk and Phenotype of Multisystem Inflammatory Syndrome in Vaccinated and Unvaccinated Danish Children Before and During the Omicron Wave. JAMA Pediatrics. 2022;176(8):821-3.

50. Levy N, Koppel JH, Kaplan O, Yechiam H, Shahar-Nissan K, Cohen NK, et al. Severity and Incidence of Multisystem Inflammatory Syndrome in Children During 3 SARS-CoV-2 Pandemic Waves in Israel. JAMA. 2022;327(24):2452-4.

51. Wolter N, Jassat W, Walaza S, Welch R, Moultrie H, Groome M, et al. Early assessment of the clinical severity of the SARS-CoV-2 omicron variant in South Africa: a data linkage study. Lancet. 2022;399(10323):437-46.

52. Hong LZ, Zhou L, Zou R, Khoo CM, Chew ALS, Chin C-L, et al. Systematic evaluation of multiple qPCR platforms, NanoString and miRNA-Seq for microRNA biomarker discovery in human biofluids. Scientific Reports. 2021;11(1):4435.

53. Pabinger S, Rödiger S, Kriegner A, Vierlinger K, Weinhäusel A. A survey of tools for the analysis of quantitative PCR (qPCR) data. Biomolecular Detection and Quantification. 2014;1(1):23-33.

54. Hirotsu Y, Maejima M, Shibusawa M, Natori Y, Nagakubo Y, Hosaka K, et al. Direct comparison of Xpert Xpress, FilmArray Respiratory Panel, Lumipulse antigen test, and RT-qPCR in 165 nasopharyngeal swabs. BMC Infectious Diseases. 2022;22(1):221.

**Figure Legends**

**Figure 1:** **Consort diagram showing the cohorts included in this study and the key steps performed.** Outliers were determined using the Hotelling’s t-squared test with a confidence level of 0.99 using values from principal components (PC) 1 and 2 from principal component analysis (PCA).

**Figure 2 (ONLINE ONLY):** Principal Component Analysis (PCA) performed on the discovery dataset after normalisation with principal components 1-6 shown. Points represent samples and are coloured by phenotype (A), sex at birth (B), age (C), and RNA-seq batch (D). Available at [www.jpeds.com](http://www.jpeds.com)

**Figure 3 (ONLINE ONLY):** Volcano plots showing log2 fold change (LFC) values and adjusted -log10 p-values from differential expression analysis comparing A: MIS-C vs. KD, viral infections, and bacterial infections combined; B: MIS-C vs. KD; C: MIS-C vs. viral infections; D: MIS-C vs. bacterial infection. Points are coloured as followed: red - genes with adjusted p-values <0.05 and absolute LFC >1; yellow – genes with adjusted p-values <0.05 and absolute LFC <1; green – absolute LFC >1; and black = not significant (NS). Genes to the right of 0 are increased in MIS-C patients. Available at [www.jpeds.com](http://www.jpeds.com)

**Figure 4:** **Performance of the 5 gene combination in the RNA-Seq discovery set.** **A:** Boxplots showing the disease risk score for patients from the different disease groups included in the RNA-Seq discovery set. The dashed line represents the threshold of classification calculated using the Youden’s index by maximising both sensitivity and specificity of MIS-C vs. KD, viral and bacterial. **B**: ROC curve for the performance of the combination of 5 genes identified in the discovery dataset in the MIS-C vs. KD, viral and bacterial combined; **C**: ROC curve for the performance of the signature for MIS-C vs. KD; **D**: ROC curve for the performance of the signature for MIS-C vs. viral; and **E**: ROC curve for the performance of the signature for MIS-C vs. bacterial. AUCs and 95% confidence intervals (CI) are printed on the plots. KD: Kawasaki Disease; MIS-C: Multisystem Inflammatory Syndrome in Children.

**Figure 5: Performance of the 5-gene RT-qPCR signature in the RT-qPCR validation set.** **A.** Boxplots showing the disease risk score for patients from the different disease groups. The dashed line represents the threshold of classification for the validation set calculated using the Youden’s index by maximising both sensitivity and specificity of MIS-C vs. KD, viral and bacterial. Sensitivity = 91.7% and specificity = 81.7% for MIS-C vs. KD, viral and bacterial. **B:** ROC curve for evaluating the performance of the 5-gene RT-qPCR signature in contrasting MIS-C from all comparator groups including COVID-19. **C:** ROC curve showing performance for MIS-C vs. all comparator groups excluding COVID-19. **D-G**: performance in contrasting MIS-C from individual comparator groups. AUCs and 95% confidence intervals (CI) are printed on the plots. KD: Kawasaki Disease, MIS-C: Multisystem Inflammatory Syndrome in Children DB: combined sterile site and non-sterile site bacterial groups.

**Table Legends**

**Table 1**: Demographic and clinical characteristics of the patients with MIS-C, KD, DB and DV infections used in the case-control discovery set and the RT-qPCR validation set. Values are median (IQR) unless stated. IQR: interquartile range.

**Table 2 (ONLINE ONLY)**: The frequency of causative pathogens identified in the definite bacterial (DB) and definite viral (DV) patient groups the discovery RNA-seq cohort and the validation RT-qPCR cohorts. Available at [www.jpeds.com](http://www.jpeds.com)

**Table 3 (ONLINE ONLY)**: Primer sets developed in this study. GAPDH was used as the reference gene. Available at [www.jpeds.com](http://www.jpeds.com)