Modified Duke/European Society of Cardiology 2015 clinical criteria for infective endocarditis: time for an update?

Alfonso Jan Kemp Pecoraro, Philipus George Herbst, Colette Pienaar, Jantjie Taljaard, Hans Prozesky, Jacques Janson, Anton Frans Doubell

ABSTRACT

Background The diagnosis of infective endocarditis (IE) is based on the modified Duke/European Society of Cardiology (ESC) 2015 clinical criteria. The sensitivity of the criteria is unknown in South Africa, but high rates of blood culture negative endocarditis (BCNIE), coupled with a change in the clinical features of IE, may limit the sensitivity.

Methods The Tygerberg Endocarditis Cohort study prospectively enrolled patients with IE between November 2019 and June 2021. A standardised protocol for organism detection, with management of patients by an Endocarditis Team, was employed. Patients with definite IE by pathological criteria were analysed to determine the sensitivity of the current clinical criteria.

Results Eighty consecutive patients with IE were included of which 45 (56.3%) had definite IE by pathological criteria. In patients with definite IE by pathological criteria, 26/45 (57.8%) of patients were classified as definite IE by clinical criteria. BCNIE was present in 25/45 (55.6%) of patients and less than three minor clinical criteria were present in 32/45 (75.6%) of patients. The elevation of Bartonella serology to a major microbiological criterion of the modified Duke/ESC 2015 clinical criteria would increase the sensitivity (57.8% vs 77.8%; p=0.07).

Conclusion The sensitivity of the modified Duke/ESC 2015 clinical criteria is lower than expected in patients with IE by pathological criteria. The elevation of Bartonella serology to a major microbiological criterion of the modified Duke/ESC 2015 clinical criteria would increase the sensitivity (57.8% vs 77.8%; p=0.07).

INTRODUCTION

The clinical diagnosis of infective endocarditis (IE), despite advances in both imaging technologies and techniques of culturing organisms, remains challenging. Current clinical diagnosis of IE is based on the modified Duke/European Society of Cardiology (ESC) 2015 clinical criteria for the diagnosis of IE, with the presence of typical imaging features of IE and the identification of a causative organism (predominantly from blood cultures) the two major components of the criteria. In the absence of both major criteria being present, either one major criterion with three or more of the minor criteria or no major criteria with all five minor criteria would classify patients as definite IE. The gold standard for the diagnosis of IE remains histopathological examination revealing active endocarditis or the presence of microorganisms within either a vegetation or valve tissue. The Duke criteria, with a reported sensitivity of 70%–80%, misclassify a number of patients with confirmed IE by pathological criteria, as possible IE. This is driven primarily by a lower sensitivity in patients with blood culture negative IE (BCNIE), prosthetic valve endocarditis (PVE) and device-related endocarditis (DRE).

Key questions

What is already known about this subject?

⇒ The sensitivity of the modified Duke/European Society of Cardiology 2015 clinical criteria for the diagnosis of infective endocarditis (IE) is unknown in South Africa, a country with high rates of blood culture negative IE and low prevalence of Coxiella burnetii-associated IE.

What does this study add?

⇒ The sensitivity of the current clinical criteria is lower than expected in a South African cohort of patients with IE by pathological criteria. The lower than expected sensitivity is due to the high rates of Bartonella-associated IE coupled with a low incidence of minor criteria in patients with IE.

How might this impact on clinical practice?

⇒ The elevation of Bartonella serology to a major microbiological criterion, similar to the status of Coxiella burnetii in the current criteria, may increase the sensitivity of the current clinical criteria.
Modifications were made to the original Duke criteria to increase the sensitivity of the clinical criteria in these groups of patients. The modified Duke criteria elevated positive serology for *Coxiella burnetii* to a major microbiological criterion and expanded the major imaging criteria to include transtoesophageal echocardiography (TEE). \(^1\) \(^4\) \(^6\) *Coxiella burnetii*, an obligate intracellular bacterium that cannot be cultured on synthetic culture media, is the most common cause of BCNIE in European cohorts and its serological addition to the modified Duke criteria has increased the sensitivity of the criteria in these cohorts. \(^2\) \(^4\) Subsequent to the modified Duke criteria, the modified Duke/ESC 2015 clinical criteria were introduced; this expanded the major imaging criteria to include typical imaging features by cardiac computed tomography (CT) with or without 18-fluorodeoxyglucose positron emission tomography (18FDG-PET). \(^2\) \(^4\) This expansion of the major imaging criteria were specifically introduced to increase the sensitivity of the criteria in patients with PVE or DRE. \(^2\) The minor criteria have remained mostly unchanged since the introduction of the Duke criteria, although many of the clinical features retained in the minor criteria are rarely encountered in patients with IE today. \(^1\)

In South Africa, IE is characterised by high rates of BCNIE (up to 60%) and very low rates of *Coxiella burnetii*-associated IE which means that the majority of patients with IE will not fulful the major microbiological criteria. \(^1\) \(^8\) – \(^11\) The high rates of BCNIE in South Africa appear to be related to a combination of antibiotic use prior to blood culture sampling and causative organisms that are difficult to culture, particularly the *Bartonella* species. \(^8\) \(^9\) \(^12\) \(^13\) The classification of patients with BCNIE into definite or possible IE according to current clinical criteria therefore often hinge on the presence of a number of minor criteria. \(^2\) A decrease in the number of patients with predisposing heart disease \(^10\) \(^11\) coupled with the observed decrease in the presence of Roth spots, Janeway lesions and Osler nodules is a likely reason for the higher proportion of possible IE (up to 35%) reported in more recent cohorts when compared with older cohorts of patients treated for IE in South Africa. \(^8\) \(^9\)

Recently, *Bartonella* species has emerged as an important cause of BCNIE in the Western Cape region of South Africa. \(^12\) \(^13\) The gold standard for the microbiological diagnosis of *Bartonella*-associated IE is PCR and sequencing of the bacterial 16S rRNA gene performed directly on the affected valve tissue. \(^12\) *Bartonella* serology, performed on venous blood samples, may suggest active *Bartonella* infection but does not confirm *Bartonella*-associated IE. In the setting of patients with clinical and imaging features of IE with negative blood cultures, an IgG titre above 1:128 and/or IgM titre above 1:40 is suggestive of infection with *Bartonella* species and makes it a likely cause of BCNIE. \(^12\) \(^13\) Positive serology for *Bartonella* species in patients with BCNIE, in contrast to positive serology for *Coxiella burnetii*, currently represents only a minor criterion in the current modified Duke/ESC 2015 clinical criteria. \(^2\)

A prospective cohort of patients, presenting with IE in our region, was analysed to describe the typical clinical features observed. From this cohort, a group of patients with definite IE by pathological criteria \(^2\) was selected to determine the sensitivity of modified Duke/ESC 2015 clinical criteria and determine possible causes of misclassification.

**METHODS**

**Study design and participants**

Consecutive patients presenting with IE to the Division of Cardiology, Department of Medicine at Tygerberg Hospital in Cape Town, South Africa, between November 2019 and June 2021 were prospectively enrolled in the Tygerberg Endocarditis Cohort study as previously described. \(^12\) \(^13\) \(^14\) Patients with known or newly diagnosed malignancy were excluded. The Division of Cardiology at Tygerberg Hospital is a public sector tertiary referral centre that serves a population of approximately 2.4 million people. \(^15\) Patients with features of IE presenting to hospitals within the referral network are referred to Tygerberg Hospital for definitive care. \(^17\) The Division of Cardiology is categorised as a high volume centre for the diagnosis and management of IE. \(^18\) Patients were managed by an Endocarditis Team following diagnostic and management criteria as set out by current guidelines. \(^2\)

**Clinical evaluation**

All patients were evaluated by at least one member of the Endocarditis Team on presentation and clinical features, specifically the presence of criteria for the diagnosis of IE, were documented. Thereafter patients were evaluated daily, the presence and timing of any major adverse events (death, embolic events and renal failure requiring dialysis) documented and antimicrobial therapy tailored as microbiology results became available. A weekly Endocarditis Team meeting was held to review all current cases and discuss management decisions.

**Echocardiographic evaluation**

Enrolled patients underwent transthoracic echocardiography with the majority of patients also undergoing TEE. \(^19\) \(^20\) In addition to a standard echocardiographic evaluation, \(^19\) \(^20\) a detailed assessment of the underlying heart and valvular structure, with a specific focus on the presence of underlying predisposing heart disease or endocardial abnormality, was performed. \(^2\) \(^5\) \(^14\) \(^21\) \(^22\) \(^26\)

**Additional imaging**

Cardiac CT with or without 18FDG-PET scanning as well as cardiac MRI were performed at the discretion of the Endocarditis Team.

**Microbiological assessment**

A standardised stepwise protocol for organism detection was utilised to identify the common causative organisms
of IE and to minimise the rate of BCNIE.\textsuperscript{11,12} Blood cultures were collected and processed according to current international guidelines and as previously reported.\textsuperscript{2,12} If no pathogen was isolated from blood cultures after 5 days of incubation, patients were defined as having BCNIE.

All patients with BCNIE underwent further testing (all tests performed in parallel), including:
- Serology was performed using indirect immunofluorescence assays (IFA) for detection of IgM and IgG antibodies to \textit{Bartonella henselae} and \textit{Bartonella quintana} (FOCUS Diagnostics, Cypress, California, USA). An IgG titre above 1:128 and/or IgM titre above 1:40 was considered positive for \textit{Bartonella henselae} and \textit{Bartonella quintana}.\textsuperscript{12,15} Specific antibodies to \textit{Coxiella burnetii} were also determined by IFA, with an IgG phase 1 titre above 1:800 considered positive.\textsuperscript{2} Enzyme immunoassays were performed to detect IgM and IgG antibodies to \textit{Brucella species}, \textit{Legionella pneumophila} (EUROIMMUN, Lübeck, Germany) and \textit{Mycoplasma pneumoniae} (EUROIMMU).
- Broad range PCR and sequencing was performed on negative blood culture bottles for detection of the bacterial 16S rRNA and fungal ITS2 genes.
- BACTEC Myco/F Lytic vials (Becton Dickinson, San Jose, California, USA) were collected for the isolation of Mycobacteria, including \textit{Mycobacterium tuberculosis} (MTB) and non-tuberculous Mycobacteria.
- Testing for antinuclear antibodies and anti-cardiolipin antibodies.

A sample of heart valve tissue was collected from all patients who underwent surgery (or at post mortem) and this was submitted for:
- Bacterial and fungal culture.
- Broad range PCR and sequencing of 16S rRNA and ITS2.
- Histopathological examination to detect bacteria and fungi, as well as histopathological features of IE.

**Statistical analysis**

Statistical analysis was done using SPSS V.27 for iOS and JASP (V.0.14.1) for iOS.

Continuous variables were reported as mean with SD if normally distributed, alternatively as median with IQR. Categorical variables were reported as counts and percentages. To compare the diagnostic sensitivities of the modified Duke/ESC 2015 clinical criteria and our proposed elevation of \textit{Bartonella} serology to a major microbiological criterion, the \(\chi^2\) test was performed. For all analyses, two-sided tests of significance were performed with an alpha of 0.05.

**RESULTS**

A total of 80 consecutive patients with IE were included with the characteristics at diagnosis summarised in Table 1. Histopathological samples were available in 43 of 46 patients who underwent surgery and from two post mortems performed. Definite IE by pathological criteria was confirmed in all 45 of these cases. In patients with definite IE by pathological criteria, 26/45 (57.8\%) of patients were classified as definite IE by clinical criteria.
BCNIE was present in 25/45 (55.6%) of patients and more than two minor clinical criteria were present in the minority of patients (24.4%). Aetiologies associated with the misclassification of patients as ‘possible IE’ by clinical criteria are summarised in Table 3. The elevation of Bartonella serology to a major microbiological criterion of the modified Duke/ESC 2015 clinical criteria would have increased the sensitivity to accurately diagnose definite IE (57.8% vs 77.8%; p=0.07) (Figure 1).

Bartonella serology was positive in 16/38 (42.1%) of patients with BCNIE in our cohort (Figure 2). Eleven of the 16 patients underwent surgery with definite IE confirmed by pathological criteria in all 11 (100%) patients. PCR performed on valve tissue identified the causative organism as Bartonella quintana in nine patients and Bartonella henselae in one patient. None of the patients with BCPIE who had PCR performed on their valve tissue, returned positive PCR for Bartonella species.

DISCUSSION

We have observed a lower than expected sensitivity (57.8%) of the modified Duke/ESC 2015 clinical criteria to classify patients with definite IE by pathological criteria, as such. The sensitivity in our cohort is lower than reported in first-world cohorts where sensitivities of up to 80% are frequently reported. Although no previous study has evaluated the sensitivity of either the original Duke criteria or subsequent modifications in a South African cohort, a recent retrospective cohort of patients treated for IE have reported rates of definite IE of 59%–64%.

The likely causes of the clinical misclassification of patients with definite IE by pathological criteria as
Special populations

Possible IE in our cohort, are the high rate of BCNIE (55.6%) with no cases of Coxiella burnetii (absence of a major criteria), coupled with a low prevalence of the minor criteria. In this group of patients with only a single major criteria, three or more minor clinical criteria must be present to fulfil the criteria for definite IE. Three or more minor clinical criteria were present in only 24.4% of our cohort with definite IE by pathological criteria (table 2). The minor clinical criteria comprise a number of clinical features that have decreased in prevalence in the developed world since the original publication of the Duke criteria. We have observed a similar trend with the majority of patients (75.6%) with definite IE by pathological criteria having less than three of the minor criteria present (table 2).

The high rate of BCNIE was predominantly caused by non-culturable organisms, specifically Bartonella species, rather than antibiotic use prior to blood culture sampling (tables 1 and 3). The detection of active Bartonella

---

Table 3 Causes of misclassification of patients with BCNIE as possible rather than definite endocarditis by the modified Duke/ESC 2015 clinical criteria

| Case | Major imaging criteria | No of minor criteria present | Possible cause of misclassification |
|------|------------------------|-----------------------------|-----------------------------------|
| 1    | Vegetation             | 2                           | Antibiotic use prior to blood culture sampling |
| 2    | Vegetation             | 2                           | Bartonella quintana*               |
| 3    | Dehiscence of a prosthetic valve. FDG PET-CT positive | 2 | Systemic lupus erythematosus with possible Mycobacterium tuberculosis† |
| 4    | Vegetation with tissue destruction FDG PET-CT positive | 0 | Mycobacterium tuberculosis‡ |
| 5    | Vegetation/Abscess     | 2                           | Bartonella quintana*               |
| 6    | Vegetation             | 0                           | Unknown                           |
| 7    | Vegetation             | 2                           | Unknown                           |
| 8    | Vegetation/perforation | 2                           | Bartonella quintana*               |
| 9    | Vegetation/perforation | 1                           | Mycoplasma species‡               |
| 10   | Vegetation             | 2                           | Bartonella quintana*               |
| 11   | Vegetation/perforation | 2                           | Alternaria species                 |
| 12   | Vegetation/perforation/ Abscess | 2 | Bartonella quintana*           |
| 13   | Abscess                | 2                           | Mycobacterium tuberculosis‡       |
| 14   | Vegetation/perforation | 2                           | Bartonella quintana*               |
| 15   | Vegetation/perforation | 2                           | Bartonella quintana*               |
| 16   | Vegetation/perforation | 2                           | Bartonella quintana*               |
| 17   | Vegetation             | 2                           | Antibiotic use prior to blood culture sampling |
|      | Vegetation, perforation | 0                           | Unknown                           |
| 19   | Vegetation, perforation | 2                           | Antibiotic use prior to blood culture sampling, Streptococcus gallolyticus subsp. pasteuriannus identified by PCR of valve tissue |

*Diagnosis based on positive serology and PCR performed on valve tissue. †Diagnosis based on typical imaging and histopathological features. ‡Diagnosis based on positive serology. BCNIE, blood culture negative endocarditis; FDG PET/CT, fluorodeoxyglucose positron emission tomography.

---

Figure 1 Sensitivity of the modified Duke/ESC 2015 clinical criteria with and without the elevation of Bartonella serology to a major microbiological criterion in patients with confirmed IE by pathological criteria (n=45). ESC, European Society of Cardiology; IE, infective endocarditis.

Figure 2 Analysis of patients with Bartonella serology suggesting active infection. BCNIE, blood culture negative infective endocarditis; BCPIE, blood culture positive infective endocarditis; IE, infective endocarditis.
infection with serology in patients with BCNIE is currently regarded as a minor criterion in contrast to serology for Coxiella burnetii which is part of the major criteria. The addition of Coxiella burnetii serology to the current guidelines was motivated on the basis that Coxiella burnetii is a common cause of BCNIE in European cohorts, specifically in France, and upgrading serological detection from a minor to a major criterion increased the sensitivity of the guideline criteria. We have previously reported the emergence of Bartonella species as a cause of BCNIE and the elevation of positive Bartonella serology to the major criteria could be motivated on a similar basis as the elevation of serology for Coxiella burnetii to the major criteria. In this cohort of patients with definite IE by pathological criteria, the elevation of Bartonella serology to a major microbiological criteria would increase the sensitivity of the clinical criteria to 77.8% (figure 1), which is similar to the reported sensitivities of the current modified Duke/ESC 2015 clinical criteria in developed-world cohorts. Serology for Bartonella species was positive in 11 of the patients with BCNIE who underwent surgery, with 16S rRNA PCR performed on valve tissue confirming Bartonella quintana in nine patients and Bartonella henselae in one patient (figure 2). This also suggests a low false-positive rate for the serological test when used in patients with a high pre-test probability for IE. One patient with active systemic lupus erythematosus (SLE) returned positive serology for Bartonella species, Brucella, Mycoplasma and Coxiella burnetii; this was likely due to cross-reactivity of the antibodies associated with SLE. Serology for Bartonella after treatment of SLE was negative and PCR performed on the surgical specimen was negative for all these organisms. Importantly, none of the patients with BCPIE or BCNIE with negative serology for Bartonella species returned positive 16 rRNA PCR for Bartonella species (figure 2).

The frequency of occurrence of some of the clinical features incorporated in the minor criteria of the modified Duke/ESC 2015 clinical criteria was low in this study (table 2) and contributed to the lower than expected sensitivity of these criteria. This is particularly evident in this cohort because of the high prevalence of Bartonella-associated IE. Immunological features such as Roth spots, Janeway lesions and Osler nodules were rarely detected, similar to previous reports from South Africa. The most commonly observed clinical features were new-onset dyspnoea, clubbing, anaemia, haematuria and evidence of embolic events. When comparing our cohort to previous cohorts of IE in South Africa, the presence of fever and a predisposing endocardial abnormalities was lower while the proportion of patients with intravenous drug use remained low (table 1). A possible explanation for the higher than expected rate of clubbing and lower rate of documented fever may be the proportion of patients with Bartonella-associated IE in our cohort. The majority of our patients with Bartonella-associated IE had clubbing (15/16; 93.8%). In contrast, fever was only documented in one patient (6.3%) with Bartonella-associated IE.

A significant number of patients presented with clinical features of acute or acute on chronic severe valvar regurgitation, with the majority confirmed to be either acute or acute on chronic severe by echocardiographic criteria. This suggests that a significant number of patients present early with acute IE and may offer a partial explanation for the decrease in clinical features listed in the minor criteria when compared with the era when viridans streptococci was the predominant organism.

CONCLUSION
We have observed a lower than expected sensitivity (57.8%) of the modified Duke/ESC 2015 clinical criteria to diagnose definite IE utilising the pathological criteria as the gold standard. This lower sensitivity appears to be driven primarily by the high rate of Bartonella-associated BCNIE, coupled with a low prevalence of the clinical features incorporated into the minor criteria. Elevation of positive serology for Bartonella to a major criterion, similar to the previous modification of the criteria for Coxiella burnetii, will increase the sensitivity of the modified Duke/ESC 2015 clinical criteria in regions with a high prevalence of Bartonella-associated IE.

Limitations
Although Bartonella species are a frequent cause of BCNIE in the Western Cape region of South Africa and many other countries, the elevation of serology for Bartonella to a major criteria is unlikely to affect the sensitivity in countries with a low prevalence of this organism. The validity of this new criteria must be confirmed in different prospective cohorts of patients and should include the analysis of specificity and accuracy. We only performed serology for Bartonella species in patients with BCNIE and thus could not evaluate the specificity of the serological criteria utilised. Patients with known or newly diagnosed malignancy were excluded from this study.

Author affiliations
1Division of Cardiology, Department of Medicine, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
2Division of Medical Microbiology, Department of Pathology, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
3National Health Laboratory Service, Johannesburg, Gauteng, South Africa
4Division of Infectious Diseases, Department of Medicine, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
5Department of Medicine, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
6Division of Cardiothoracic Surgery, Department of Surgery, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
7Department of Anatomical Pathology, Stellenbosch University and Tygerberg Hospital, Cape Town, South Africa
8Division of Medical Microbiology, Department of Pathology, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
9Division of Infectious Diseases, Department of Medicine, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
10Department of Cardiology, University of Cape Town, Cape Town, South Africa
11Department of Anatomical Pathology, Stellenbosch University and Tygerberg Hospital, Cape Town, South Africa
12Department of Medicine, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
13Division of Medical Microbiology, Department of Pathology, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, Western Cape, South Africa
14Department of Cardiology, University of Cape Town, Cape Town, South Africa
15Department of Pathology, Stellenbosch University and Tygerberg Hospital, Cape Town, South Africa
16Department of Cardiology, University of Cape Town, Cape Town, South Africa
17Department of Cardiology, University of Cape Town, Cape Town, South Africa
18Department of Cardiology, University of Cape Town, Cape Town, South Africa
19Department of Cardiology, University of Cape Town, Cape Town, South Africa
20Department of Cardiology, University of Cape Town, Cape Town, South Africa
21Department of Cardiology, University of Cape Town, Cape Town, South Africa
22Department of Cardiology, University of Cape Town, Cape Town, South Africa
23Department of Cardiology, University of Cape Town, Cape Town, South Africa
24Department of Cardiology, University of Cape Town, Cape Town, South Africa
25Department of Cardiology, University of Cape Town, Cape Town, South Africa
26Department of Cardiology, University of Cape Town, Cape Town, South Africa
27Department of Cardiology, University of Cape Town, Cape Town, South Africa
28Department of Cardiology, University of Cape Town, Cape Town, South Africa
29Department of Cardiology, University of Cape Town, Cape Town, South Africa
30Department of Cardiology, University of Cape Town, Cape Town, South Africa

Acknowledgements
Dr E Ngaranande, Research coordinator, Division of Cardiology, Department of Medicine, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, South Africa. Dr A Ismail, Division of Cardiology, Department of Medicine, Stellenbosch University Faculty of Medicine and Health Sciences, Cape Town, South Africa. Dr D Zaharie, Department of Anatomical Pathology, Stellenbosch University and Tygerberg Hospital, Cape Town, South Africa.

Contributors
All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing or revision of the manuscript. AJ KP as the primary investigator and
guarantor was responsible for the conception and design of the study, acquisition of data, analysis and interpretation as well as drafting of the manuscript. CP, PGH and AFD contributed to the conception and design of the study, acquisition of data, analysis and interpretation as well as revising the manuscript critically for important intellectual content. HP, JT and JJ contributed to the acquisition, analysis and interpretation of data as well as revising the manuscript critically for important intellectual content.

**Funding** The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

**Competing interests** None declared.

**Patient consent for publication** Not applicable.

**Ethics approval** This study was approved by the Health Research Ethics Committee of Stellenbosch University (Project number S19/08/162) and performed in accordance with the Declaration of Helsinki (2013 version). All patients signed written informed consent. Waiver of consent was approved for patients that demised before consent.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available on reasonable request.

**Open access** This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is demised before consent.

**REFERENCES**

1. Pecoraro AJ, Doubell AF. Infective endocarditis in South Africa. *Cardiovasc Diagn Ther* 2020;10:252–61.
2. Habib G, Lancetti P, Antunes MJ, et al. 2015 ESC guidelines for the management of infective endocarditis. *Eur Heart J* 2015;36:3075–128.
3. Hoen B, Béguénot I, Rabaud C, et al. The Duke criteria for diagnosing infective endocarditis are specific: analysis of 100 patients with acute fever or fever of unknown origin. *Clin Infect Dis* 1996;23:298–302.
4. Habib G, Derumeaux G, Avierinos JF, et al. Variable and limitations of the Duke criteria for the diagnosis of infective endocarditis. *J Am Coll Cardiol* 1999;33:2023–9.
5. Durack DT, Lukes AS, Bright DK. New criteria for diagnosis of infective endocarditis: utilization of specific echocardiographic findings. *Duke endocarditis service*. *Am J Med* 1994;96:200–9.
6. Tissières P, Gervaux A, Beghetto M. Value and limitations of the von Reyn, Duke, and modified Duke criteria for the diagnosis of infective endocarditis in children. *Pediatrics* 2003;112 doi:10.1542/peds.112.6.e647
7. Cahill TJ, Prendergast BD. Infective endocarditis. *Lancet* 2016;387:882–93.
8. Koegelenberg CFN, Doubell AF, Orth H, et al. Infective endocarditis in the Western Cape Province of South Africa: a three-year prospective study. *QJM* 2003;96:217–25.
9. De Villiers MC, Vlooien CA, Manning K, et al. The changing landscape of infective endocarditis in South Africa. *S Afr Med J* 2019;109:592–6.
10. Koshy J, Engel M, Carrara H, et al. Long term outcome and EuroSCORE II validation in native valve surgery for active infective endocarditis in a South African cohort. *SA Heart* 2018;18:116–26.
11. Pecoraro AJ, Herbst PG, Doubell AF. Infective endocarditis in Africa: an urgent call for more data. *Lancet Glob Health* 2022;10:e8–9.
12. Pecoraro AA, Herbst PP, Pienaar CC, et al. Bartonella species as a cause of culture-negative endocarditis in South Africa. *Eur J Clin Microbiol Infect Dis* 2021;40:1872–8.
13. Penartaro AJK, Pienaar C, Herbst PG, et al. Causes of infective endocarditis in the Western Cape, South Africa: a prospective cohort study using a set protocol for organism detection and central decision making by an endocarditis team. *BMJ Open* 2021;11:e053169.
14. Pecoraro AJK, Herbst PG, Joubert LH. Echocardiographic features of infective endocarditis in South Africa: a prospective cohort study. *South African Medical Journal* 2022;112.
15. Bartonella Serology Interpretation [Internet]. [cited 2020 Nov 10]. Available: https://www.childrensminn.org/references/Lab/serology/bartonella-antibody.pdf
16. Western Cape Government. City of Cape town 2017, 2017. Available: https://www.westerncape.gov.za/assets/departments/treasury/Documents/Socio-economic-profiles/2017/city_of_cape_town_2017_economic_profile_sep-lg-_-28_january_2018.pdf
17. van Deventer J, Dobell A, Herbst P. Evaluation of the SUNHEART cardiology outreach programme. *SA Heart* 2015;12:82–6.
18. Habib G, Erba PA, Lung B. Clinical presentation, aetiology and outcome of infective endocarditis. *European Heart J* 2019;40:3222–33.
19. Wheeler R, Steeds R, Rana B, et al. A minimum dataset for a standard transoesophageal echocardiogram: a guideline protocol from the British Society of echocardiography. *Echo Res Pract* 2015;2:629–45.
20. Wharton G, Steeds R, Allen J, et al. A minimum dataset for a standard adult transthoracic echocardiogram: a guideline protocol from the British Society of echocardiography. *Echo Res Pract* 2015;2:9–24.
21. Fabrikant H, Baan G, Cahill TJ, Prins RF, Benzinger G, et al. 2017 ESC/EACTS guidelines for the management of valvular heart disease. *European Journal of Cardio-Thoracic Surgery* 2017;52:616–64.
22. Hunter LD, Monaghan M, Lloyd G, et al. Inter-scallop separations of the posterior leaflet of the mitral valve: an important cause of ‘pathological’ mitral regurgitation in rheumatic heart disease screening. *Echo Res Pract* 2018;5:K29–34.
23. Hunter LD, Monaghan M, Lloyd G, et al. Screening for rheumatic heart disease: is a paradigm shift required? *Echo Res Pract* 2017;4:R43–52.
24. Hunter LD, Monaghan M, Lloyd G, et al. Interscallop separations of the posterior mitral valve leaflet: a solution to the ‘borderline RHD’ conundrum? *Open Heart* 2020;7:e001452.
25. Hunter LD, Pecoraro AJK, Doubell AF, et al. Screening for subclinical rheumatic heart disease: addressing borderline disease in a real-world setting. *Eur Heart J Open* 2021;1 https://academic.oup.com/ehjopen/advance-article/doi/25
26. Hunter LD, Doubell AF, Pecoraro AJK, et al. The variable spectrum of anterior mitral valve leaflet restriction in rheumatic heart disease screening. *Echocardiography* 2021;38:729–36.
27. Hunter LD, Lombard CJ, Monaghan MJ, et al. Screening for rheumatic heart disease: the reliability of anterior mitral valve leaflet thickness measurement. *Echocardiography* 2020;37:808–14.
28. Brandão TJD, Januario-da-Silva CA, Correia MG, et al. Histopathology of valves in infective endocarditis, diagnostic criteria and treatment considerations. *Infection* 2017;45:199–207.
29. Mahabadi AA, Mahmoud I, Dykun I, et al. Diagnostic value of the modified Duke criteria in suspected infective endocarditis -The PRO-ENDOCARDITIS study. *Int J Infect Dis* 2021;104:556–61.
30. Tashar D, Raucher-Sternfeld A, Tanir A, et al. Bartonella quintana, an unrecognized cause of infective endocarditis in children in Ethiopia. *Emerg Infect Dis* 2017;23 doi:10.3201/eid2308.161037
31. Gupta M, Lobo FD, Adiga DSA, et al. A histomorphological pattern analysis of pulmonary tuberculosis in lung autopsy and surgically resected specimens. *Patholog Res Int* 2016;2016:1–7.

Pecoraro AJK, et al. *Open Heart* 2022;9:e001856. doi:10.1136/openhrt-2021-001856