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Editor's Choice – Validation of the Management of Aortic Graft Infection Collaboration (MAGIC) Criteria for the Diagnosis of Vascular Graft/Endograft Infection: Results from the Prospective Vascular Graft Cohort Study

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WHAT THIS PAPER ADDS

The Management of Aortic Graft Infection Collaboration (MAGIC) criteria have been proposed as a novel diagnostic test for vascular graft/endograft infection (VGEI). The criteria were validated retrospectively in a prospective cohort of patients with definite and suspected vascular graft infections. For a definite VGEI diagnosis, the criteria had a good sensitivity but reduced specificity, owing to suspected VGEI. To improve the accuracy, further modifications of the criteria should be evaluated.

Objective: The timely management of vascular graft/endograft infection (VGEI) is crucial to a favourable outcome, yet can be challenging as there is no validated gold standard diagnostic test. Recently, a new case definition has been proposed by the Management of Aortic Graft Infection Collaboration (MAGIC) to close the diagnostic gap. The aim of this study was to validate the MAGIC criteria as a suggested diagnostic standard for the diagnosis of suspected VGEI in the prospective Vascular Graft Cohort study (VASGRA).

Methods: VASGRA is an open, prospective, observational cohort study. Prospective participants in VASGRA between 2013 and 2019 were included (257 patients; 137 with VGEI). The accuracy of the MAGIC criteria for a diagnosis of VGEI was evaluated retrospectively by calculating the sensitivity and specificity *vs.* the consensually adjudicated VASGRA infection status.

Results: The VASGRA cohort categorised 137 (53.3%) patients as "diseased" and 120 patients as "not diseased"; using the MAGIC criteria, 183/257 (71.2%) patients were considered to be "diseased". Thus, for the MAGIC criteria, a sensitivity of 99% (95% confidence interval [CI] 96–100) and a specificity of 61% (95% CI 52–70) were calculated. Considering suspected VGEI according to the MAGIC criteria as "not diseased" achieved congruent assessments of the VASGRA team and the MAGIC criteria, with a sensitivity of 93% and a specificity of 93%. The accuracy of the MAGIC criteria for the different graft locations were also compared. If the suspected VGEIs were assigned to the "not diseased" group, VGEIs of the thoracic aorta seemed to have a poorer sensitivity (86%; 95% CI 73–95) than the other graft locations.

Conclusion: The current MAGIC criteria offer good sensitivity and specificity in the context of true infections but a reduced specificity for a possible VGEI.

Keywords: Diagnostic accuracy, MAGIC criteria, Sensitivity, Specificity, Validation, Vascular graft/endograft infection (VGEI)
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INTRODUCTION

Vascular infections involving prosthetic graft material cause substantial morbidity, lethality, and high healthcare costs.[1,2] The timely and accurate assessment and diagnosis of vascular graft/endograft infection (VGEI) seems to be crucial for a favourable outcome. A VGEI may be obvious in patients with bacteraemia and abscess formation around a vascular graft. However, a definite VGEI diagnosis is challenging, and usually involves multiple findings rather than one gold standard diagnostic test. Physicians often rely on a diversity

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of clinical symptoms, descriptive radiological imaging, and ambiguous or even missing microbiology, laboratory, or histopathological results. In the absence of a formal case definition, either the rather non-specific Fitzgerald criteria are applied to abdominal or peripheral VGEIs,[3] or the modified Duke criteria to thoracic VGEIs with composite grafts.[4] Recently, criteria for the diagnosis of VGEI have been proposed by the multidisciplinary Management of Aortic Graft Infection Collaboration (MAGIC),[5] and the European Society for Vascular Surgery suggests the use of the MAGIC criteria as a diagnostic standard for all kinds of VGEI (thoracic, abdominal, and peripheral arteries).[2]

The aim of this study was to validate the MAGIC criteria for VGEI diagnosis in the prospective Vascular Graft Infection Cohort study (VASGRA). The accuracy of different VGEI locations was also assessed using the MAGIC criteria.[5]

MATERIALS AND METHODS

Study design and data collection

VASGRA is an open, prospective, observational cohort study, which enrols patients aged $\geq$ 18 years who are receiving vascular graft implantations at the University Hospital Zurich, Switzerland. In VASGRA, standardised data collection forms covering demographic, surgical, clinical, and laboratory information, are completed every three months by physicians and study nurses.[1] Patients are followed prospectively in the vascular surgery outpatient clinic of the hospital with contrast enhanced computed tomography (CECT), and laboratory tests. VGEI incidence and postoperative complications have been documented since 2013. Patients who return to hospital with the suspicion of a VGEI, receive blood and/or tissue cultures, serologies if the culture is negative, laboratory and imaging assessments, ^{18}Fluorodeoxyglucose (FDG; positron emission tomography [PET]/CT), CECT, and a combined imaging approach (contrast enhanced PET [CEPET]/CT). The percentages of CEPET/CECTs among VASGRA suspected/confirmed VGEI and VASGRA rejected VGEI are 89% and 100%, respectively. The Ethics Committee Zurich, Switzerland, approved the study (KEK-ZH-Number 2012-0583). All participants gave written informed consent.

Study patients, internal VASGRA adjudication of infection status, and adjudication by the use of the MAGIC criteria

VASGRA patients presenting with suspected VGEI between April 2013 and September 2019 were included, reviewed, and consensually grouped, in an unblinded manner, into definite, suspected, and rejected VGEI by the multidisciplinary VASGRA team, which includes infectious diseases specialists, cardiac and vascular surgeons, radiologists, microbiologists, and pathologists. For further validation, a group of control patients was also included. For each patient with a VGEI, a control with the same graft location site, a clinic visit, laboratory tests, and an imaging procedure at the same $\pm$ 2 number of weeks between the initial graft surgery and the diagnosis of a VGEI in the respective patient was searched for. Controls were selected only once. Laboratory controls were found for all patients, but information on C reactive protein (CRP) and leucocytes was only available in 80% of the controls.

In detail, the adjudication process was done by two infectious diseases specialists, a nuclear medicine physician/radiologist, and cardiac and vascular surgeons. The following parameters for the VGEI adjudication process were used, whereby a precondition of a diagnosis of VGEI was the presence of at least one clinical, imaging, and laboratory parameter in each category.

Clinical. Pus around the graft; open wound with exposed graft or fistula; graft insertion in an infected site (e.g., in case of endovascular treatment of an infected aneurysm).[3,6,7]

Imaging. CEPET/CECT showing a focal FDG activity combined with at least one CT criterion (e.g., perigraft fluid on CT scan $\geq$ 3 months after insertion, perigraft gas on CT scan $\geq$ 7 weeks after insertion; fat stranding; and contrast enhancement).[8–11] No cutoffs (i.e., for standard uptake value measurements) were defined. Readers scored their confidence in the diagnosis using a previously published four point score.[9]

Laboratory. Positive cultures for bacteria, fungi, or mycobacteria from intra-operative specimens/biopsies/explanted grafts and/or positive blood cultures. To rule out potential contaminant pathogens (e.g., coagulase negative staphylococci, *Cutibacterium acnes*, and *Corynebacterium* spp.), two positive intra-operative specimens or blood cultures, or one positive intra-operative specimen and one positive blood culture were required.[6]

Positive broad range polymerase chain reaction (PCR) and/or species PCR for *Brucella* spp., *Coxiella burnetii, Bartonella* spp., and *Tropheryma whipplei*.[3,12,13]

Serological evidence of infection with microorganisms consistent with VGEI diagnosis (*C. burnetii*, *Bartonella* spp., and *Brucella* spp.).[14,15]

Microorganisms demonstrated by microorganism staining or histopathological examination of perigraft material and, if applicable, postmortem examinations (immunohistology, haematoxylin and eosin stain, Ziehl—Neelsen stain, Grocott stain, periodic acid—Schiff stain.[16,17]

Elevated inflammatory markers (CRP, white blood cell count).[3,7]

The following VGEI locations were distinguished: “thoracic aorta” (intrathoracic part of the aorta, aortic root, and intrathoracic branches; and supra-aortic trunks); “abdominal aorta” (intra-abdominal part of the aorta, including iliac branches); and “peripheral arteries” (groin and lower extremity). The VGEI was further classified according to the Samson classification.[18]

In VASGRA, a VGEI was suspected if there were elevated inflammatory markers and an unexplained fluid collection without focal FDG uptake around the vascular graft ($>$ 3 months after insertion) or positive blood cultures (two for contaminant pathogens; one for “non-contaminant pathogens”) in a patient with a vascular graft. A VGEI was

discounted if, in due course, a diagnosis other than VGEI was confirmed.

In addition, infection status was retrospectively assessed and adjudicated by applying the MAGIC criteria to suspected and confirmed VGEI.[5]

Statistical analysis

Patient and procedure related variables were assessed overall and by infection status using non-parametric tests (Fisher's exact test or the Kruskal—Wallis test, whichever was appropriate). The accuracy of the MAGIC criteria for the diagnosis of a VGEI was evaluated by calculating sensitivity and specificity *vs.* the consensually agreed VASGRA infection status. Sensitivity and specificity estimates with exact binomial confidence intervals (CIs) were provided.

All patients were further grouped based on their adjudicated infection status into "diseased" (definite and suspected VGEI) and "not diseased" (rejected VGEI and control patients) groups. The most challenging group in which no definite diagnosis/rejection of VGEI was possible was then looked at, leading to a status of "suspected VGEI". Those cases were first assigned to the "diseased" group and then to the "not diseased" group, and the accuracy of the MAGIC criteria calculated and compared for both scenarios.

Stata/SE Version 16.1 (StataCorp., College Station, TX, USA) was used for the statistical analyses.

RESULTS

Study participants

Overall, 257 predominantly male (83.7%) participants with a median age of 67 years (interquartile range 59 — 75 years) were included. The VASGRA cohort categorised 137 (53.3%) patients as "diseased" (135 definite VGEI; two suspected VGEI) and 120 patients as "not diseased". The "not diseased" group included 35 patients in whom a VGEI was rejected by consensus and a control group of 85 control patients undergoing routine vascular surgery. Table 1 shows the patient and procedure related variables by infection status and by disease group. With regard to the surgical strategy in patients with VGEIs, 45% received debridement, 34% a total graft replacement, 9% a partial graft replacement, and 12% were managed conservatively.

Distribution of MAGIC criteria within the VASGRA definite vascular graft/endograft infection group

Of the 135 VASGRA definite VGEIs, 102 (75.6%) had at least two major MAGIC criteria. Of these, 26.5% ($n = 27$) had all three MAGIC criteria categories, whereas the other patients either had combined clinical and laboratory major criteria (54.9%; $n = 56$), combined clinical and radiological major criteria (11.7%), or combined radiological and laboratory major criteria (6.9%). In 24 of 135 (17.8%) patients with VASGRA definite VGEI, one major and one minor MAGIC criteria were present. Of these, 14 had a clinical major criterion, while in six patients a radiological and in four patients a major laboratory criterion was present. The remaining eight (5.9%) patients with VASGRA definite VGEI had at least two minor criteria from different categories and were therefore considered to have a suspected VGEI according to the MAGIC criteria. One patient with a VASGRA definite VGEI was rejected as a VGEI according to the MAGIC criteria.

The distribution of all MAGIC major and minor criteria by VASGRA infection status within the "diseased" and "not diseased" groups is shown in Table 2.

Comparison of the MAGIC and VASGRA infection status for definite and rejected vascular graft/endograft infections

Table 3 shows the comparison of the assessment using the MAGIC criteria with the adjudicated VASGRA infection status. All but one rejected VGEIs according to the MAGIC criteria were either VASGRA rejected VGEIs or controls. Among infections, the MAGIC assessment was in line with the VASGRA infection status in 93.3% ($n = 126$), while in 3.7% ($n = 5$) and 2.2% ($n = 3$) the VASGRA team placed the patient either in the group of rejected VGEIs or in the control group, respectively. One patient with a MAGIC definite VGEI remained under suspicion by the VASGRA adjudication team.

Comparison of the MAGIC and VASGRA infection status for suspected vascular graft/endograft infection

The group of suspected VGEIs based on the MAGIC criteria showed a heterogeneous picture. Only one of 48 patients in this group (2.1%) was equally assessed as having a suspected VGEI by the VASGRA team. The majority (52.1%; $n = 25/48$) were considered as not having a VGEI, while 16.6% patients were placed in the definite VGEI group; 29.2% of patients were part of the control group (Table 3).

The current MAGIC criteria offer a reduced specificity for possible VGEI. While only 137 (53.3%) patients were counted as being part of the VASGRA "diseased" group, the MAGIC criteria considered 183 (71.2%) patients as being "diseased" (Supplementary Table 1, Panel A). Based on this association, a sensitivity of 99% (95% CI 96 — 100) and a specificity of 61% (95% CI 52 — 70) were calculated for the MAGIC criteria. The likelihood ratio of a positive test among definite/suspected VGEIs *vs.* rejected VGEI/controls was 2.53 (95% CI 2.03—3.17).

Patients with a non-definite infection status were assigned to the "not diseased" group. In this case, the assessments were congruent (Supplementary Table 1, Panel B). This is also reflected in improved accuracy, as calculated by a sensitivity of 93% (95% CI 88—97) and a specificity of 93% (95% CI 87—97). The likelihood ratio of a positive test among patients with a definite VGEI *vs.* those with a suspected and rejected VGEI and controls was 12.7 (95% CI 6.7—23.8).

Sensitivity analyses

The accuracy of the MAGIC criteria were also compared for different graft locations. Assigning a suspected VGEI to the "diseased'" group showed a poor specificity for VGEI of the

Table 1. Characteristics of 137 patients with and 120 patients without vascular graft/endograft infection (VGEI) by internally adjudicated Vascular Graft Cohort Study (VASGRA) infection status

	VASGRA diseased (n = 137)		VASGRA not diseased (n = 120)		p value
	Definite VGEI (n = 135)	Suspected VGEI (n = 2)	Rejected VGEI (n = 35)	Control patients (n = 85)	
Male gender	114 (84.4)	2 (100)	31 (89)	68 (80)	.67
Age − y	64 (57–73)	71 (67–75)	72 (59–78)	70 (61–75)	.071
Emergency at index surgery	33 (24.4)	0 (0)	8 (23)	4 (4.7)	<.001
Location of vessel					
Abdominal aortal	52 (38.5)	2 (100)	31 (89)	66 (78)	<.001
Thoracic aorta	44 (33.6)	0 (0)	2 (6)	10 (12)	<.001
Peripheral arteries	40 (29.6)	0 (0)	2 (6)	1 (1)	<.001
Samson classification[*]					
III	58 (43.0)	1 (50)	NA	NA	
IV	28 (20.7)	0 (0)	NA	NA	
V	49 (36.3)	1 (50)	NA	NA	1.0

Data are presented as n (%) or median (interquartile range). NA = not applicable.
* Samson criteria:[16] III = involvement of graft body but no anastomosis affected; IV = infection surrounding exposed anastomosis but no bleeding or bacteraemia; V = involvement of a graft to artery anastomosis, septicaemia, and/or anastomotic bleeding.

thoracic aorta (42%; 95% CI 15 — 72), while sensitivities were comparable among the different locations and overall (Table 4). If suspected VGEIs were assigned to the "not diseased" group, VGEIs of the thoracic aorta seemed to have a poorer sensitivity (86%; 95% CI 73 — 95) than other graft locations. For VGEIs of the peripheral arteries, the specificity was substantially lower (67%; 95% CI 9.4 — 99) (Table 4).

Further sensitivity analyses after the exclusion of VASGRA suspected cases (n = 2) or the exclusion of VASGRA control patients are provided in the supplementary material.

DISCUSSION

The MAGIC criteria were assessed retrospectively and validated as the proposed new diagnostic standard for VGEI diagnosis in the prospective VASGRA cohort study. Overall, in patients with VASGRA definite VGEI, the MAGIC criteria offered a good sensitivity but a reduced specificity for diagnosis. Using the MAGIC criteria led to an overestimation of suspected VGEI.

Comparison with other studies and the currently scarce literature is difficult, as neither suitable reference cohorts nor other validation studies in which the initially proposed

Table 2. Management of Aortic Graft Infection Collaboration (MAGIC) major and minor criteria by Vascular Graft Infection Cohort Study (VASGRA) infection status within the "diseased" group of 135 patients with a vascular graft/endograft infection (VGEI)

	VASGRA participants (n = 135)
MAGIC major criteria	
Pus (definite by microscopy) around graft or aneurysm sac at surgery	61 (45.2)
Open wound with exposed graft or communicating sinus	33 (24.4)
Fistula development, e.g., aorto-enteric or aortobronchial	30 (22.2)
Graft insertion in an infected site, e.g., fistula, mycotic aneurysm, or infected pseudo-aneurysm	31 (23.0)
Perigraft fluid on CT scan ≥ 3 months after insertion	43 (31.8)
Perigraft gas on CT scan ≥ 7 weeks after insertion	20 (14.8)
Increase in perigraft gas volume demonstrated on serial imaging	12 (8.9)
Microorganism recovered from an explanted graft	27 (20.0)
Microorganism recovered from an intra-operative specimen	92 (68.1)
Microorganism recovered from a percutaneous aspirate of perigraft fluid	12 (8.9)
MAGIC minor criteria	
Localised clinical features of VGEI, e.g., erythema, warmth, swelling, purulent discharge, and pain	69 (51.1)
Fever ≥ 38°C with VGEI as most likely cause	64 (47.4)
Other, e.g., suspicious perigraft gas/fluid/soft tissue inflammation; aneurysm expansion; pseudo-aneurysm formation; focal bowel wall thickening; discitis/osteomyelitis; suspicious metabolic activity on FDG PET/CT; radiolabelled leucocyte uptake	109 (80.7)
Blood culture(s) positive and no apparent source except for VGEI	51 (37.8)
Abnormally elevated inflammatory markers with VGEI as the most likely cause, e.g., ESR, CRP, and white cell count	126 (93.3)

Data are presented as n (%). CT = computed tomography; FDG PET/CT = fluorodeoxyglucose positron emission tomography/computed tomography; ESR = erythrocyte sedimentation rate; CRP = C reactive protein.

Table 3. Comparison of infection status according to the Vascular Graft Infection Cohort Study (VASGRA) and Management of Aortic Graft Infection Collaboration (MAGIC) adjudication in 137 patients with and 120 patients without vascular graft/endograft infection (VGEI)

MAGIC adjudication	VASGRA adjudication				Total
	Confirmed VGEI	Suspected VGEI	Rejected VGEI	Control patients	
Confirmed VGEI	126 (93.3)	1 (50)	5 (14)	3 (3)	135 (52.5)
Suspected VGEI	8 (5.9)	1 (50)	25 (71)	14 (16)	48 (18.7)
Excluded VGEI	1 (0.7)	0 (0)	5 (14)	0 (0)	6 (2.3)
Control patients	0 (0)	0 (0)	0 (0)	68 (80)	68 (26.4)
Total	135 (100)	2 (100)	35 (100)	85 (100)	257 (100)

Data are presented as *n* (%).

Fitzgerald criteria,[3] the modified Duke criteria,[4,19] or the MAGIC criteria were applied to VGEI were found. One cohort study applied the Fitzgerald criteria as VGEI case definition for a risk factor analysis.[3,6] However, the authors concluded that there were shortcomings challenging the introduction of the criteria as standard in VGEI case definition: two of three criteria were subject to personal judgement and inconsistent interpersonal rating or relied on arbitrarily chosen and not yet validated cutoff values. Moreover, the three rather vague criteria were all weighed equally and thus challenged a firm diagnosis of VGEI.

Neither the Fitzgerald nor the modified Duke criteria were applied to the VASGRA participants and therefore the validation of their performance in VGEI diagnosis cannot be commented upon.[3,4] However, it is worth noting that there were similarities in the development and modification process of the MAGIC criteria and the Duke criteria.[19] The Duke criteria were widely accepted and validated, and showed a high sensitivity and specificity in the diagnosis of infective endocarditis.[19,20] Yet, they were criticised for the "overly broad categorisation of the suspected infective endocarditis group".[4] In fact, the inclusion of additional criteria was suggested to achieve firm definite diagnoses and increase the diagnostic yield. Taking this into account, the modified Duke criteria added more refined imaging techniques (transoesophageal echocardiography in patients with suspected infective endocarditis) and serology methods in culture negative infective endocarditis to the scheme.[4] In 2015, the modified Duke criteria were redefined again, with the inclusion of new imaging modalities like PET/CT, cardiac CT, and magnetic resonance imaging.[4,21]

When new diagnostic criteria are assessed, it is not only the accuracy, but also the direct or indirect effects on patient management that should be considered. In the present study, the diagnostic accuracy of the MAGIC criteria in VGEI assessment was very good in the case of definite diagnoses. In suspected VGEI, there should be a balance between suspected overtreatment with unnecessary surgery and/or antimicrobial therapy, potential patient discomfort, and the undesirable consequence of delayed surgery in the case of a missed diagnosis. Counting suspected VGEI as "diseased" substantially reduced the specificity of the MAGIC criteria *vs.* the assessment of the multidisciplinary team in this study. This was especially true for VGEIs of the thoracic and abdominal aorta. Therefore, the analyses demonstrated the need for additional assessment tools leading to a more tailored application of a diagnostic algorithm for suspected VGEI and different graft locations. With the intention of obtaining an overarching case definition of VGEI, the MAGIC criteria were also assessed for abdominal, thoracic, and peripheral locations separately.[2] Hence, the overall test performance could be less accurate. However, sensitivity analyses were performed and the accuracy for each location calculated separately. Moreover, the likelihood ratios for putting equal weights to sensitivity and specificity were considered and thus accounted for the proportion of individuals with and without the disease. Finally, suitable cutoff values for inflammatory markers were not further elaborated and the availability of PET CT might be reduced or nonexistent in some healthcare settings.

After having applied and validated the proposed MAGIC categories among VASGRA patients, modifications to the criteria are suggested. Radiological findings are one of the three groups of the MAGIC criteria on which a VGEI diagnosis is reliant. CECT is the most commonly used for the diagnosis of VGEI, reaching high sensitivity and specificity, especially in acute infections.[1,7] Suspicious findings on CECT are therefore clearly considered major MAGIC criteria. More ambiguous and undetermined results are found in suspected VGEI. More recently, PET CT and 99-mTC white blood cell scintigraphy with single photon emission CT (SPECT)/CT have been studied as imaging modalities in VGEI.[10,11] Among patients with suspected VGEIs, the combination of the high sensitivity of PET/CT with the high specificity of CECT outperformed standalone imaging and reached very high diagnostic accuracy.[9] In a 2018 meta-analysis, SPECT/CT showed the highest accuracy in VGEI diagnosis.[11] Thus, it is suggested that CECT and PET/CT and/or SPECT are equally important major criteria.

Another part of the MAGIC criteria is the laboratory element. The major criteria include evidence of isolated microorganisms, either from explanted graft material, biopsy, or aspiration of perigraft fluid. In order for a patient to have a major criterion, an intervention must have been performed, which is not necessarily the case, depending on the patient's situation. There is lack of consideration of histopathology and serology in this context, especially in the setting of culture negative VGEI. It is proposed that "microbiological findings" and "laboratory/ histopathology" are categorised separately.

Table 4. Accuracy of Management of Aortic Graft Infection Collaboration (MAGIC) criteria by graft location depending on the composition of "diseased" and "not diseased" groups in 257 patients with or without vascular graft/endograft infection (VGEI)

	Sensitivity (95% CI) − %	Specificity (95% CI) − %
"Diseased" = definite and suspected VGEI; "not diseased" = rejected VGEI and controls		
Overall	99 (96–100)	61 (52–70)
Intracavitary abdominal VGEI	100 (93–100)	62 (51–72)
Thoracic aorta VGEI	98 (88–100)	42 (15–72)
Peripheral arteries VGEI	NA	N/A
"Diseased" = definite VGEI; "not diseased" = suspected VGEI, rejected VGEI, and controls		
Overall	93 (88–97)	93 (87–97)
Intracavitary abdominal VGEI	94 (84–99)	92 (85–96)
Thoracic aorta VGEI	86 (73–95)	100 (74–100)
Peripheral arteries VGEI	100 (91–100)	67 (9.0–99)

CI = confidence interval; NA = not applicable (as there were no patients with a MAGIC score of 0).

This study has several strengths. It was possible to validate the MAGIC criteria[5] in a well established cohort study by comparing the diagnostic criteria with an appropriate reference standard. Moreover, there was a standardised adjudication process based on clear criteria and a final multidisciplinary consensus.

However, the study also has limitations. Firstly, an appropriate standard for comparison is difficult and this cohort study was not designed to validate the diagnostic criteria prospectively. A retrospective evaluation of prospectively collected information from the patients was carried out, and the original MAGIC criteria were published 2016, which may have changed the diagnostic assessment of VASGRA patients in the second part of the study period. However, when comparing the time period before and after 2016, the accuracy did not differ (data not shown). There is no record linkage to other hospitals and hence patients with a rejected VGEI or controls may have presented elsewhere with a subsequent diagnosis of VGEI. However, in VASGRA, there is a median follow up of 4.5 years for both VGEI patients and controls.[22] The long follow up, together with the high number of CEPET/CECT scans, may have contributed to the good agreement among the VASGRA team members on VGEI diagnosis (99%). However, the potential role of SPECT could not be assessed as this is not done routinely at the authors' institution in patients with suspected VGEI. Secondly, a prospective unbiased validation of VGEI criteria is difficult as the evaluation is time sensitive and directly influences the decision process and the need for surgery. Moreover, even with a prospective validation, some criteria like "pus (definite by microscopy) around graft or aneurysm sac at surgery", "microorganism recovered from explanted graft", "microorganism recovered from an intra-operative specimen" or "microorganism from a percutaneous aspirate or perigraft fluid" are difficult to assess. Thirdly, a statement on whether using the MAGIC criteria would allow an earlier diagnosis in real life cannot be made. A retrospective review might lead to an overestimation of VGEI, as the first symptoms of the initial illness might already be interpreted as VGEI symptoms. Further, owing to the retrospective nature of the review, the evaluators were not blinded to results of alternative tests and reference standards. This was accounted for by the involvement of different medical specialties in the consensus review process. According to the Bayes theorem not only the accuracy, but also the pre-test probability of disease in a patient population affects the utility of diagnostic criteria.[23] To overcome this problem, one third of the study population included control patients undergoing routine vascular surgery. However, owing to the stringent criteria, controls could not be identified for all cases. Given the small number of patients, the subgroup analyses on anatomical location and graft material will have to be assessed in prospective multicentre studies.

The MAGIC criteria may be used for a future VGEI case definition. As the MAGIC criteria put some rejected VGEI cases into the suspected or definite category, further modifications are suggested. Owing to the complexity of the disease and the heterogeneity of the affected population, criteria alone will still never suffice. Therefore, multidisciplinary management is a prerequisite for decision making in patients with VGEI.

CONFLICTS OF INTEREST

None.

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APPENDIX A. SUPPLEMENTARY DATA

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