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REVIEW

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Usefulness of sonication in the microbiological diagnosis of cardiovascular implantable electronic device infections: systematic review, meta-analysis and meta-regression

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Abstract

Background Multiple studies have demonstrated the utility of sonication to improve culture yield in patients with cardiovascular implantable electronic device (CIED) infections.

Objective To analyze the usefulness of sonication in the microbiological diagnosis of CIED infections in comparison with traditional cultures.

Methods Systematic database searches were performed to identify studies that provided enough data concerning both sensitivity and specificity of traditional (non-sonicated) and sonicated cultures from CIED samples. The diagnostic accuracy measures were obtained by three different statistical approaches: (i) The univariate model; (ii) The bivariate random; and (iii) The Bayesian bivariate hierarchical model. Heterogeneity was assessed using meta-regression.

Findings Nine studies met the criteria for inclusion in the meta-analysis (1684 cultures). The summary estimates of sensitivity were higher for sonicated cultures (0.756) in comparison with non-sonicated cultures (0.446). On meta-regression, sonication of CIEDs significantly increased the sensitivity ($p=0.001$) as well as the rates of false positive results ($p=0.003$). The final model also showed that the studies that used a threshold for positivity were associated with lower rates of false positive results ($p<0.001$).

Interpretation Our results suggest that sonication improves the microbiological diagnosis of CIED infections in comparison with traditional cultures, but a standardization of processes is necessary.

Keywords Cardiovascular implantable electronic device, Infection, Sonication, Diagnosis

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Introduction

Cardiovascular implantable electronic device (CIED) infections are potentially life-threatening complications associated with significant morbidity, mortality, and costs [1, 2]. Once a CIED infection is diagnosed, a correct microbiological diagnosis is crucial for an appropriate treatment and cure.

According to the international consensus document about how to diagnose CIED infections [3], distal and proximal lead fragments, lead vegetation (if present), and generator pocket tissue should be sent to microbiology laboratories for Gram stain and culture. However, routine diagnostic methods fail to identify the causative microorganisms in many patients. In this sense, Gram stain has been shown to have limited utility in the diagnosis of CIED infections, and cultures may be negative for several reasons, including previous antimicrobial treatment and biofilm formation on the device surfaces [4]. To solve this issue, sonication of explanted CIEDs can be used to separate adherent bacterial colonies embedded in the biofilm, improving microbiological diagnosis [3]. The usefulness of sonication has been previously demonstrated for different clinical samples [5–7], however, the role of sonication in the microbiological diagnosis of CIED infections varies significantly between studies.

To gain insight into the diagnostic usefulness of sonication for routine clinical use, we provide here a systematic review, a meta-analysis and meta-regression of evidence comparing the diagnostic accuracies of traditional culture methods and culture after sonication for the diagnosis of CIED infections.

Methods

Study registration

The protocol was registered at the international prospective register of systematic reviews (PROSPERO) website with number 299917. Institutional ethical approval was not needed because of the nature of this study.

Inclusion and exclusion criteria

This study followed the PRISMA statement and the Cochrane Handbook for Diagnostic Test Accuracy Reviews [8, 9]. We included prospective and retrospective studies that could provide enough data concerning both sensitivity and specificity of traditional microbiological cultures (non-sonicated) and sonicated fluid cultures from CIED samples. Traditional microbiological cultures were categorized as "swab cultures", including sterile swab samples collected from the device surface (generator and/or leads) or from the pocket tissue, and "device cultures", including peri-prosthetic fluids, tissue or devices. Information about the type of swabs was also included.

The studies that incorporated patients with and without clinical diagnosis of CIED infection were included, although the studies that only included patients with clinical diagnosis of CIED infection or without clinical diagnosis of CIED infections were excluded. Case reports and series with a sample size of fewer than 5 records were excluded per recommendations by the Cochrane Statistical Methods Group. Other exclusion criteria included non-English or nor-Spanish articles and epidemiological studies with no clinical characteristics reported.

Study search and data extraction

In the electronic search, we systematically searched Pubmed, EMBASE, Web of Science and the Cochrane Library until June 2023. The following search term was used: ('cardiovascular implantable electronic device' OR 'cardiac implantable electronic device'OR 'cardiac device' OR 'cardiovascular device' OR pocket) AND (sonication OR culture) AND (infection). We also included handsearched published reviews and original studies. Additional information about study search is recorded in Supplementary Table S1.

Search results were entered into Rayyan software (https://rayyan.ai/). After removing duplicates, two investigators (GM-G and CM-P) independently screened the candidate articles by checking title and abstract. For all relevant articles, the full text version was read to determine the presence of the inclusion criteria defined previously. After the screening, articles that were still regarded as candidates at least by one of the investigators, were scrutinized again independently by full-text reading. In case of disagreement in any of the phases of evaluation, a third reviewer was consulted for the final decision (AdA).

The two investigators (GM-G and CM-P) independently extracted the data from the original studies, and after that, data were crosschecked. Again, any disagreements were resolved through the discussion with a third reviewer (AdA).

Quality assessment for bias and applicability

The two investigators (GM-G and CM-P) independently scored the seven domains of the Revised Tool for the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) [10] (Supplementary Table S2). QUADAS-2 has four domains including patient selection, index test, reference standard, and flow and timing. In diagnostic accuracy studies, the index test is the test or intervention being studied, while the reference standard (or gold standard) is the best available method to determine whether participants have the condition. Within these 4 domains, signaling questions are used to assess whether the risk of bias is low, high, or unclear, and the applicability to the original review question is assessed.

Thus, manuscripts were grouped into the following categories: "high quality" (low risk of bias), "moderate quality" (intermediate risk of bias) and "low quality" (clear risk of bias). The final classification was determined after discussion between the two investigators.

Statistical analysis

We obtained the diagnostic accuracy measures and estimates by three different statistical approaches: (i) the univariate model, where the diagnostic odds ratio (DOR) was determined by using the DerSimonian-Laird method, and the estimate area under the curve (AUC) by using the Holling's proportional hazard model. The sensitivity and specificity were determined by using a random-effects model. (ii) The bivariate random model was obtained by using the Zwindermann & Bossuyt Markov chain Monte Carlo (MCMC) procedure, to generate summary points (10.000 iterations), and (iii) The Bayesian bivariate hierarchical model, that was performed by using Integrated Nested Laplace Approximations (INLA) with 10.000 iterations. The penalized complexity priors were chosen believing that the sensitivities or specificities lied in the interval 0.5–0.95 (with probability 0.95), with a negative correlation between sensitivity and specificity of −0.2. The summary receiver operating characteristic (SROC) curves were obtained by the Rutter and Gatsonis's method for both bivariate analyses.

Based on Jones' criteria [11], we interpreted AUC > 0.97, 0.93–0.96, 0.75–0.92, and 0.5–0.75 as "excellent," "very good", "good," and "reasonable," respectively. The heterogeneity among the studies was assessed using chi-square test and I-square (i2) statistics (univariate analysis). A i2 < 40% was considered as "not important" heterogeneity [12]. Sensitivity analysis was performed by the leave-one-out method to find any influential studies.

To investigate factors that contributed to heterogeneity of sensitivity and false positive rates across studies, subgroup analysis and meta-regression was performed. The independent variables for simple meta-regression were type of culture (traditional cultures or sonicated cultures), the use of a culture threshold for positivity (colony forming units per milliliter [CFU/ml]), and the quality of studies according to the risk of bias. To adjust the diagnostic accuracies based on the variables accounting for statistical significance from simple meta-regression, we performed the multivariable meta-regression.

Analyses were carried out in R (version R-4.1.2). We used commands of the statistics software R as follows: "madauni" command for DOR, "phm" command for AUC, and "reitsma" command for the HSROC curve, the summary estimates of sensitivity and specificity, and for meta-regression. The estimates of sensitivity and specificity for the univariate analysis was performed with the function "metareg" from the "meta" package. The Bayesian analysis was performed by using the R package "meta4diag", with the commands "mega4diag", "AUC" and "SROC".

Results

Study search and study characteristics

We identified 3882 studies; 30 were selected for full-text review (Fig. 1). Twenty-one were excluded (for detailed reasons, see Supplementary Table S3), leaving nine studies that met our inclusion criteria [13–21]. Of the nine included studies, seven reported information for both traditional cultures (non-sonicated) and cultures after sonication [14–20], and two of them reported sensitivity and specificity information with two different culture positivity criteria [17, 18]. Finally, there are nine results for cultures after sonication, seven for device cultures, and six for swab cultures.

The number of participants ranged from 40 to 332 with a median of 79. The total number of subjects was 929. This total consisted of 460 patients with CIED infection and 469 without CIED infection. A total of 1684 cultures were performed, including 931 cultures after sonication and 753 non-sonicated cultures (Table 1).

Across the 8 studies that used sonication, the sensitivity ranged from 0.543 to 1 with a median of 0.78, and the specificity ranged from 0.49 to 0.98 with a median of 0.64. Regarding the studies that included device or swab cultures, the sensitivity ranged from 0.09 to 0.81 with a median of 0.46, and the specificity ranged from 0.67 to 1 with a median of 0.88 (Table 2).

Risk of bias

Assessment of study quality using the QUADAS-2 tool is summarized in Fig. 2. We considered one study [21] to be at high risk of bias due to problems with patient selection (case–control study), and three [13, 15, 19] with the reference standard (clinical diagnosis of CIED infections). One study [18] used two different thresholds for positivity from patients with and without CIED infections. These four studies were categorized as "low quality" studies. All the studies were "unclear" in the domain of bias in the index test due to the lack of blindness in the description (information bias).

Sensitivity and specificity

The sensitivity and specificity were calculated from 9 results of 8 studies that used sonication, and from 13 results of 7 studies that used the device or swab cultures (Table 2, Supplementary Figure S1). The results obtained in one study [18] of cultures after sonication and with significant growth (≥ 5 CFU/ml, patients with CIED infection and without previous antimicrobial treatment) were

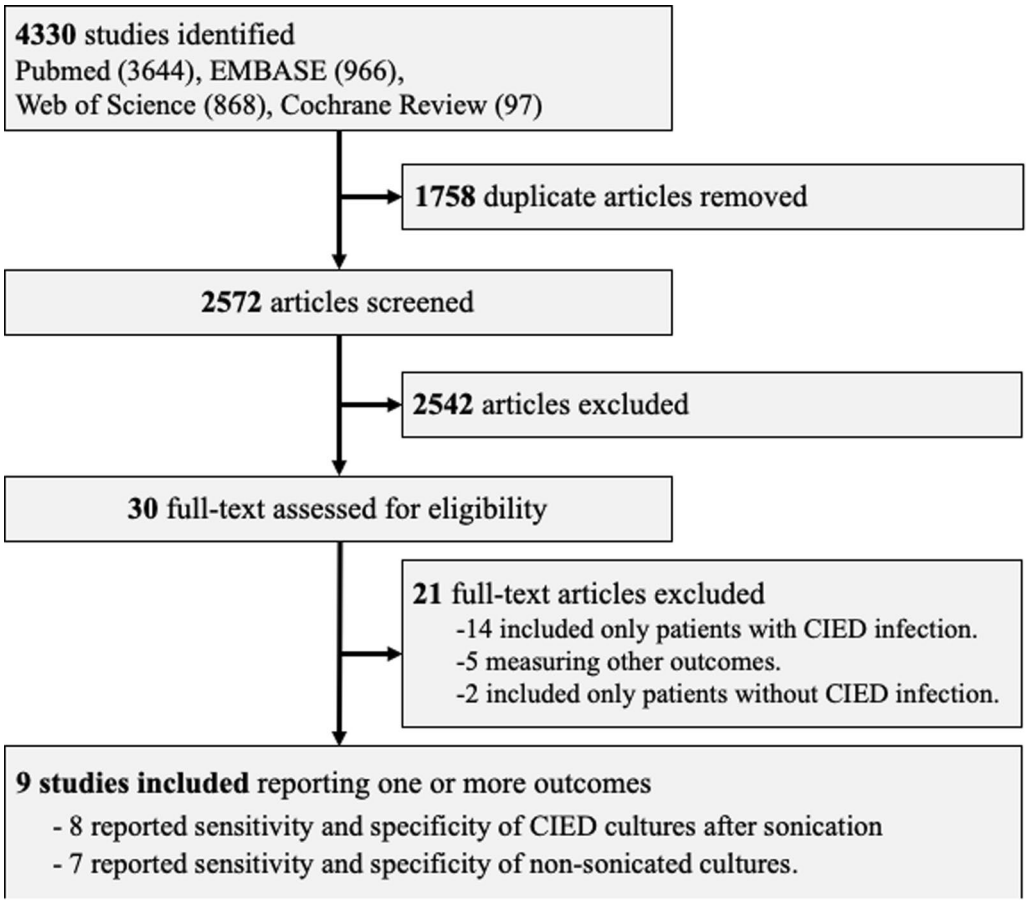

Fig. 1 Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram showing study selection

excluded because only two patients were included in this subgroup. In the univariate analysis, we found substantial heterogeneity for sensitivity and specificity ($i^2 = 91.84\%$ and $i^2 = 91.76\%$, respectively.

The summary estimates of sensitivity and specificity using the random bivariate mode for cultures after sonication were 0.756 (95% confidence interval [CI] 0.677–0.820) and 0.766 (95% CI 0.605–0.874), respectively (Table 3). The sensitivity and specificity for non-sonicated cultures were 0.446 (95% CI 0.310–0.590) and 0.868 (0.795–0.917), respectively. By analyzing the two types of non-sonicated cultures, we can observe a higher sensitivity for device cultures in comparison with swab cultures (0.5 [95% CI 0.287–0.713] vs. 0.374 [95% CI 0.220–0.558]), and lower specificity (0.831 [95% CI 0.723–0.902] vs. 0.908 [0.8–0.96]).

Regarding the Bayesian analysis, the resulting estimates of sensitivity and specificity for cultures after sonication were 0.808 (95% CI 0.704–0.903) and 0.766 (95% CI 0.605–0.874), respectively. For non-sonicated cultures, the estimates were 0.447 (95% CI 0.306–0.599) for sensitivity and 0.887 (95% CI 0.825–0.937) for specificity. Again, a higher sensitivity was observed for devices cultures (0.505 [95% CI 0.281–0.727]) in comparison with swab cultures (0.374 [95% CI 0.227–0.55]), but with lower specificity (0.852 [95% CI 0.757–0.930] vs. 0.909 [0.820–0.965]).

Overall diagnostic accuracy

The results for sensitivity, specificity, DOR and AUC obtained from the univariate and bivariate models are summarized in Table 3. Although subtle differences were observed by the different statistical approaches, our results suggest that sonication increased the diagnostic accuracy in comparison with non-sonicated cultures. In the case of AUC determinations, significant differences were only observed by using the univariate analysis, but higher AUC values were also observed by bivariate analysis. In all cases, good AUC results were obtained with sonication based on Jones' criteria [11], and reasonable/good results for traditional cultures. The Bayesian hierarchical SROC plot is shown in Fig. 3, where it can be observed that there is a higher AUC for cultures after sonication (0.811) in comparison with non-sonicated

Table 1 Summary of study characteristics

Author	Year	Country	Culture type	Positivity culture criteria	Reference criteria	Subjects	Cultures	Quality
Nagpal	2015	EEUU	Sonicated	Any growth and significant growth (≥ 2 CFU/ml)	CLIN + DUKE	77	308	High
			Device					
			Swab					
El-Ashry	2021	Egypt	Sonicated	Significant growth (≥ 20 CFU)	CLIN + DUKE	52	156	High
			Device					
			Swab					
Inacio	2015	Brazil	Sonicated	Any growth (patients with previous antimicrobial treatment)	CLIN + DUKE	83	114	Low
			Device	Significant growth (≥ 5 CFU/ml) (patients without previous antimicrobial treatment)				
Rohacek	2010	Switzerland	Sonicated	Any growth	CLIN + DUKE	123	247	High
			Swab					
Oliva	2013	Italy	Sonicated	Significant growth (≥ 2 CFU)	CLIN + DUKE	40	80	High
			Device					
Mason	2011	EEUU	Sonicated	Any growth	CLIN	82	246	Low
			Device					
			Swab					
Garrigos	2020	EEUU	Sonicated	Significant growth (≥ 2 CFU)	CLIN + DUKE	322	322	Low
Nguyen	2015	Italia	Sonicated	Any growth	CLIN	79	79	Low
Chua	2005	EEUU	Device	Any growth	CLIN + DUKE	71	142	High
			Swab					

Reference criteria: CLIN: Clinical diagnosis of CIED infection based on systemic symptoms and/or local infection signs of CIED pocket/lead; DUKE: Duke criteria

Table 2 Summary of study characteristics

Author and Year	Culture type	Culture criteria	TP	FP	TN	FN	Sensitivity	Sensitivity CI 95%	Specificity	Specificity CI 95%
Nagpal 2015	Sonicated	Any growth	19	2	40	16	0.543	0.366–0.712	0.952	0.838–0.994
		Threshold of 2 CFU/ml	26	17	25	9	0.743	0.567–0.875	0.595	0.433–0.744
	Tissue	Any growth	3	2	40	32	0.086	0.018–0.231	0.952	0.838–0.994
		Threshold of 2 CFU/ml	16	17	25	19	0.457	0.288–0.634	0.595	0.433–0.744
	Swab	Any growth	10	2	40	25	0.286	0.146–0.463	0.952	0.838–0.994
		Threshold of 2 CFU/ml	25	14	28	10	0.714	0.537–0.854	0.667	0.505–0.804
El-Ashry 2021	Sonicated	Threshold of 20 CFU/ml	18	12	21	1	0.947	0.740–0.999	0.636	0.451–0.796
	Tissue		10	5	28	9	0.526	0.289–0.756	0.848	0.681–0.949
	Swab		6	3	30	13	0.316	0.126–0.566	0.909	0.757–0.981
Inacio 2015	Sonicated	Any growth	10	35	33	3	0.769	0.462–0.950	0.485	0.362–0.610
	Tissue	Threshold of 5 CFU/ml	4	0	16	11	0.267	0.078–0.551	1.000	0.713–1000
Rohacek 2010	Sonicated	Any growth	6	44	71	0	1.000	0.421–1000	0.617	0.522–0.706
	Swab		4	30	82	2	0.667	0.223–0.957	0.732	0.640–0.811
Oliva 2013	Sonicated	Threshold of 2 CFU/ml	18	8	12	2	0.900	0.683–0.988	0.600	0.361–0.809
	Tissue		16	4	16	4	0.800	0.563–0.943	0.800	0.563–0.943
Mason 2011	Sonicated	Any growth	15	11	55	1	0.938	0.698–0.998	0.833	0.721–0.914
	Tissue		13	8	58	3	0.812	0.544–0.960	0.879	0.775–0.946
	Swab		11	2	64	5	0.688	0.413–0.890	0.970	0.895–0.996
Esquer 2021	Sonicated	Threshold of 2 CFU/ml	178	1	43	100	0.640	0.581–0.697	0.977	0.880–0.999
Nguyen 2015	Sonicated	Any growth	28	4	39	8	0.778	0.608–0.899	0.907	0.779–0.974
Chua 2005	Tissue	Any growth	24	10	26	11	0.686	0.507–0.831	0.722	0.548–0.858
	Swab		11	8	28	24	0.314	0.169–0.493	0.778	0.608–0.899

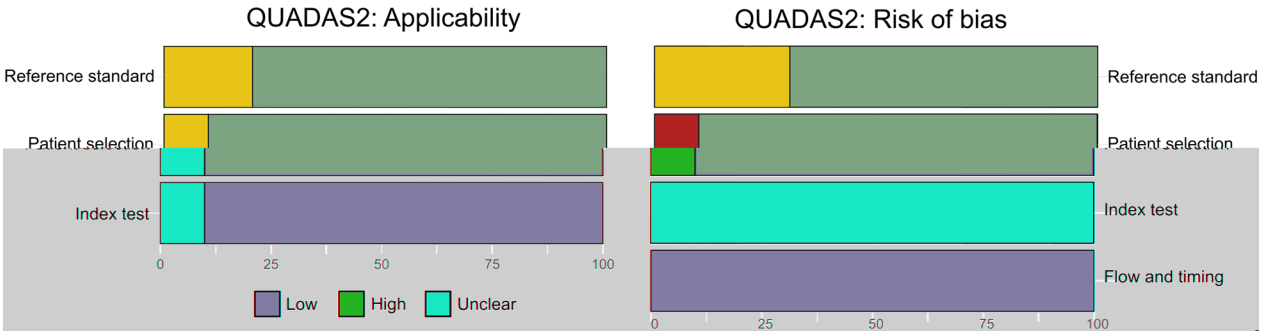

Fig. 2 Quality assessment of diagnostic accuracy studies 2 (QUADAS-2) assessments of included studies. Green = low risk, yellow = level of risk unclear, red = high risk

Table 3 Pooled summary estimates of all studies

	Method	Sonicated cultures		No sonicated cultures	
		Estimate	CI 95%	Estimate	CI 95%
DOR	Univariate DerSimonian-Laird	14.4	6.8–30.7	5.8	3.3–10.4
	Bivariate Zwindermann & Bossuyt	10.6	5.5–18.6	5.5	3–9.3
	Bayesian Bivariate model	14.9	5.13–36.9	6.7	2.9–13.8
AUC	Univariate Holling's proportional hazard	0.889	0.857–0.923	0.723	0.665–0.791
	Bivariate diagnostic random-effects model (*)	0.804	NA	0.771	NA
	Bayesian Bivariate model (**)	0.87	NA	0.78	NA
Sensitivity	Univariate model	0.799	0.702–0.895	0.459	0.321–0.596
	Bivariate diagnostic random-effects model	0.756	0.677–0.820	0.446	0.310–0.590
	Bayesian Bivariate model	0.808	0.704–0.903	0.447	0.306–0.599
Specificity	Univariate model	0.744	0.621–0.867	0.872	0.815–0.929
	Bivariate diagnostic random-effects model	0.766	0.605–0.874	0.868	0.795–0.917
	Bayesian Bivariate model	0.779	0.629–0.895	0.887	0.825–0.937

(*) Partial AUC restricted to observed False Positive Rates and normalized are 0.742 for sonicated and 0.483 for non-sonicated cultures

(**) Partial AUC restricted to observed False Positive Rates and normalized are 0.756 for sonicated and 0.479 for non-sonicated cultures

cultures (0.778). SROCs obtained by the three different statistical methods are shown in Supplementary Figure S2.

Sensitivity analysis

It is commonly held that studies with low numbers of patients might be underpowered to detect an intervention effect. To address this possibility, we performed a sensitivity analysis and found that none of the studies affected the overall pooled results (Supplementary Table S4).

Subgroup analysis and meta-regression

Subgroup analysis and meta-regression analysis were performed to explore the sources of potential heterogeneity. Significant heterogeneity was detected for non-sonicated cultures and quality studies (Supplementary Table S5).

One study [18] was excluded for the meta-regression because the culture threshold for positivity was different for patients with and without CIED infections, and this variable was included as a possible factor that contributes to diagnostic accuracy. Simple meta-regression revealed that sonication of CIED was associated with a higher sensitivity than traditional cultures ($p=0.001$) (Supplementary Table S6). The studies that were classified as "low quality" according to QUADAS2 [10], were associated with lower rates of false positive results ($p=0.060$). In addition, the studies that used a threshold for positivity (≥ 2 CFU/ml) presented lower rates of false positive results ($p=0.089$).

According to multiple meta-regression (Supplementary Table S6), we can confirm that when controlling for the threshold for positivity and the quality of studies, the sonication of CIEDs significantly increased the sensitivity ($p=0.001$) as well as the rates of false positive results ($p=0.003$) in comparison with traditional

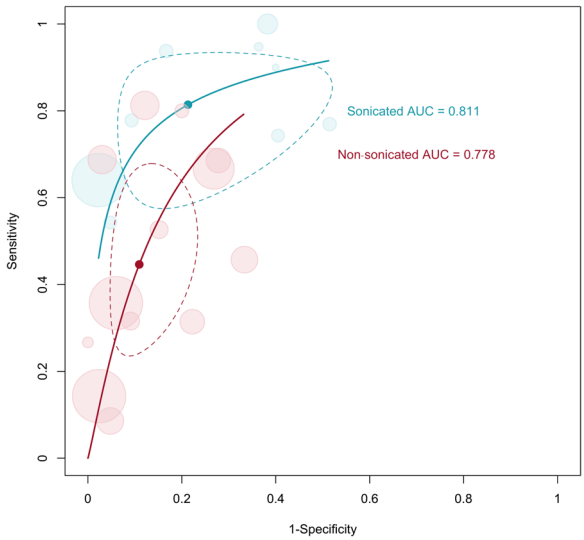

Fig. 3 The resulting Bayesian hierarchical SROC plot: SROC line (green and red solid lines); overall sensitivity and specificity estimates from the Bayesian model (green and red points). Study sizes are indicated by the green and red bubbles

culture. The final model also showed that the studies that used a threshold for positivity and low-quality studies were associated with lower rates of false positive results ($p < 0.001$ and $p = 0.001$, respectively).

Discussion

This diagnostic accuracy review is the first to synthesize the available evidence on the diagnostic accuracy of traditional cultures and sonicated fluid cultures from patients with CIED infections. A pool of nine studies (1838 cultures), showed that the diagnostic sensitivity of cultures after sonication was approximately 0.756, which was significantly higher to that observed for traditional cultures 0.493. However, the use of sonication was also related with higher rates of false positive findings (23.5% vs 16.5%), but we also found that the use of a threshold for culture positivity could decrease false positive rates. Nevertheless, these findings should be interpreted with caution considering the low number of studies on the topic.

The bivariate method is the most statistically rigorous for meta-analysis of diagnostic accuracy studies [22–24]. However, one of the main challenges of bivariate meta-analysis is that often only few studies are available, which may lead to unreliable parameter estimates [25, 26]. Here, we have included nine studies, eight of them including information about de diagnostic accuracy for sonicated cultures. In this situation, data can be analyzed by using the univariate model for meta-analyses [27], but unreliable conclusions may occur. Another approach is to use a Bayesian model, where additional information is incorporated into the model using priors that can stabilize the analysis [25]. For this reason, the robustness of our findings was confirmed by three different statistical approaches, including the univariate model, as well as the bivariate random-effects meta-analysis and the Bayesian approach. Our results suggest that sonication increases the diagnostic accuracy in comparison with traditional cultures, independently of the statistical method used.

It is known that bacteria can colonize the implanted synthetic material of CIEDs without obvious clinical signs of infection [28]. This colonization may occur primarily by introducing the patient's normal skin microbiota into the wound at the time of skin incision [29], or via the hands of those implanting or assisting the procedure [30]. The meta-regression results showed that the use of sonication increased false positive rates. This would be expected since most surgical wounds are polymicrobial in nature [31], and once the wound is colonized, almost immediately planktonic bacteria attach to the device and start biofilm formation [32]. Under this premise, sonication will facilitate removal of the microorganisms from the attached biofilm, increasing false positive rates in cases of device colonization. Despite a presumed high rate of device colonization at the time of implantation, clinical signs and symptoms of infection may not appear for weeks to months later in only a small portion of patients and, noticeably, most colonized devices will not develop an infection (0–7.5%) [14, 15, 33–36]. The progression from colonized medical devices to active infections represents a significant clinical challenge, especially in immunocompromised patients or those with recurrent infections. A comprehensive evaluation of sonication results, integrating patient history, risk factors, and clinical presentation, is essential to accurately differentiate colonization from infection. This distinction is crucial for guiding appropriate therapeutic decisions and avoiding overtreatment of contaminants, while ensuring early intervention for true infections. On the other hand, if contamination occurs during sonication process, which may or may not involve serial passages such as vortexing or centrifugation, positive results may represent false positive results. In these cases, working on aseptic conditions during all the passages required for the sonication method as well as using the right container appear crucial [37]. For these reasons, routine cultures should not be obtained in the absence of signs of infection in which device removal or exchange for other reasons (disfunction or upgrade) is performed.

One option to reduce false positive rates in patients with clinical diagnosis of CIED infection is the use of culture thresholds of positivity that could differentiate colonization from infection. The results obtained from

the meta-regression showed that those studies using a threshold for positivity (≥2 CFU/ml), presented lower rates of false positive results. However, due to the low number of studies that included a threshold for positivity [16–18, 20, 21] these results must be confirmed by largest prospective studies, including different positivity criteria.

The meta-regression analysis also showed that "low quality" studies, according to QUADAS2 [10], were associated with lower rates of false positive results. This paradoxical result might result from the high number of patients included in the study performed by Garrigos et al. [21], which showed a very low number of false positive results in comparison with other studies. Notwithstanding, it should be confirmed by further research.

Most patients with CIED infections received antimicrobial therapy before device extraction, which may lead to negative culture results. Nevertheless, Oliva et al. [38] demonstrated that sonication improved the sensitivity of cultures even in patients that received previous antimicrobial therapy, except those patients that received more than 14 days of treatment before device removal. An interesting strategy to overcome this challenge is the combination of sonication with molecular methods. Thus, Garrigos et al. [21] showed how the use of a 16S ribosomal RNA (rRNA) polymerase chain reaction (PCR) increased the sensitivity to detect pathogens in CIEDs samples compared with sonicated fluids, suggesting that this molecular approach could be considered in cases of suspected CIED infections with negative sonicated cultures.

There are several limitations to this study. First, the available literature on sonication of CIED samples is still limited, and this is reflected by the small number of studies included in this review. Second, variations in the sample collection methods, transport, processing and the positivity criteria of cultures could explain the variable diagnostic accuracy of previously reported values. In this sense, it's noteworthy that sonication has a non-standard methodology. Some research methods include only sonication of CIED samples [15], others use vortex and sonication (without centrifugation) [14], while others use vortex, sonication and centrifugation as a standard method [16]. Furthermore, the time and the frequency necessary for sonication are also unclear, with times ranging from one to five minutes, and frequencies from 20 to 42 kHz. Given the above, a standardization of processes during sonication is crucial to achieve a reproducible and reliable method for the diagnosis of CIED infections.

Another limitation that should be noted is the challenge of clinical diagnosis of CIED infections. The diagnosis includes findings from physical examination, advanced imaging modalities and laboratory and microbiology techniques [3, 4]. However, the inclusion of patients with CIED infections in these studies was based on the physical examination, mainly in local sign of infection, but there is a lack of detailed data about the clinical characteristics of patients. The potential role of previous antibiotic therapy in lowering (and influencing) the colony count is also an important factor that is not adequately addressed. Furthermore, there is no information of the type of swabs used in most of studies included. Only two studies [14, 20] specified that cotton swabs were used for microbiological studies.

In conclusion, this meta-analysis highlights the utility of sonication for the clinical diagnosis of CIED infections, showing higher sensitivity values in comparison with traditional cultures, but with higher false positive rates. However, a standardized sonication protocol is lacking, and a detailed investigation using a large number of studies would be of interest in elucidating the most appropriate procedures. Furthermore, future research should strive to improve the clinical diagnosis of CIED infections by combining sonication with molecular methods.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12941-024-00753-9.

Supplementary Material 1

Author contributions

Conception and design: GM-G, JAL. Literature review and data abstraction from publications: GM-G, CM-P. Risk-of-bias assessment: GM-G, CM-P, AdA. Analysis and interpretation of the data: GM-G, CM-P, AdA, JMO-R. First draft of the manuscript: GM-G, CM-P, AdA, JAL. Critical revision for important intellectual content: GM-G, EG-C, JMO-R AdA, JAL. Reading and final approval of the manuscript: All authors.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This is a systematic review; no ethical approval is required.

Competing interests

The authors declare no competing interests.

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