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Transvenous Lead Extraction Versus Abandonment of non-Infected, Superfluous Leads—A Meta-Analysis and Systematic Review

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ABSTRACT

Background: Managing non-functional cardiac implantable electronic device (CIED) leads remains controversial. While extraction is standard for infection, it is unclear whether transvenous lead extraction (TLE) or lead abandonment (LA) provides superior outcomes for superfluous leads. Prophylactic TLE may prevent future infection or venous obstruction and avoid complex delayed extraction but carries immediate procedural risk. Conversely, LA avoids upfront risk, though retained leads may predispose to long-term sequelae.

Objectives: To compare procedural and clinical outcomes of TLE versus LA for non-infected leads and assess how pre-existing abandoned leads influence the risks of subsequent extraction.

Methods: PubMed, Embase, OVID, and Cochrane were searched (2000–2025) for studies comparing TLE versus LA and TLE with versus without abandoned leads. Twenty-three observational studies involving 65,760 patients were included. Data was extracted by two investigators using PRISMA guidelines. Primary outcomes included major complications, in-hospital mortality, and clinical success, pooled as odds ratios with 95% confidence intervals using a random-effects model. Subgroup and meta-regression analyses were performed.

Results: TLE was associated with significantly higher odds of major complications (OR 2.07, 95% CI 1.42–3.03) and in-hospital mortality (OR 2.97, 95% CI 1.95–4.53) compared with LA, with no significant long-term difference within limited follow-up. Extraction of previously abandoned leads carried higher risks of major complications (OR 2.51), minor complications (OR 1.79), and mortality (OR 2.06), with lower clinical success (OR 0.24) than functional leads. Recent studies show improved TLE safety.

Conclusion: While TLE carried higher immediate risks, measured long-term outcomes were comparable; however, follow-up was insufficient to capture late abandonment-related sequelae. Extraction of previously abandoned leads carried markedly higher risk, supporting earlier extraction in appropriately selected patients.

Abbreviations: AL, Abandoned Leads; CIED, Cardiovascular Implantable Electronic Device; EHRA, European Heart Rhythm Association; FL, Functional Leads; ICD, Implantable Cardioverter Defibrillator; LA, Lead Abandonment; TLE, Transvenous Lead Extraction.

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1 | Introduction

Pacemakers and defibrillators are crucial and lifesaving medical devices, but some leads have limited lifespans. Over time, pacing and defibrillation leads may fail, become non-functional or superfluous after an upgrade [1].

Unlike with infected leads, where removal is usually mandated, there is an ongoing debate concerning the preferred management strategy for non-infected leads that fail or become redundant [2–4]. Specifically, lead abandonment (LA) may ultimately result in extraction at a longer dwell time. As a result, many experienced centers are moving towards advising patients to have redundant leads extracted [5, 6] rather than abandoned. As the complexity of lead extraction generally increases with lead dwell time, early removal may protect against higher-risk extraction if required at a later date [7, 8]. Early extraction, however, poses a small but significant risk of acute procedural complications, including major vascular or tricuspid valve injury [9–11]. This clinical dilemma is reflected in the 2017 Heart Rhythm Society (HRS) expert consensus paper on lead management and extraction that grants both lead extraction and abandonment a Class IIa indication as appropriate treatment options for leads that are no longer functional or clinically necessary [12].

There are no randomized trials comparing the patient outcomes of these two broad management strategies. In this systematic review and meta-analysis, we review the current evidence concerning whether extracting or abandoning non-infected, redundant leads results in better patient outcomes and fewer complications. We also set out to assess whether the extraction of previously abandoned leads increases procedural complexity and complication rates.

2 | Methods

2.1 | Literature Search

This systematic review was designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [13]. We performed our literature search using PubMed, MEDLINE, Cochrane, EMBASE, ERIC and SCOPUS for original articles from January 1, 2000 to January 31, 2025. Keywords were identified based on research questions and recorded (Table 1). Briefly, these included search terms for the intervention "lead extraction", "abandon*" and target population "superfluous", and "redundant". These terms alongside their variations were combined and searched for using Boolean operators "OR" and "AND".

2.2 | Inclusion and Exclusion Criteria

Studies were screened for inclusion and exclusion criteria, including participants' age>18 years, investigation of abandoned leads, and use of transvenous lead extractions (TLE). Exclusions included patients with congenital heart defects or transplants and non-transvenous extraction approaches. Outcomes included procedural and clinical success rates, major complications, and in-hospital mortality.

2.3 | Selection and Data Collection Process

All titles and abstracts were manually screened by two independent reviewers (KC and PJ) using a custom template through Covidence, who assessed full texts for inclusion based on predefined inclusion and exclusion criteria. Where key information was missing, authors and/or relevant persons for correspondence were contacted in an attempt to gather full data. Any missing summary statistics were either calculated where possible (such as adding the number of males in each group to determine the overall number of males) or not included in data extraction tables. Discrepancies were adjudicated through consultation with the senior author (G.W.).

Data extraction was performed using a pre-defined data extraction checklist. Finally, each included study was critically appraised for its study quality according to the Joanna Briggs Institute Checklist [14].

2.4 | Outcomes and Definitions

The following outcome data was extracted where possible for each study, as per the 2018 EHRA expert consensus statement on lead extraction and the 2017 Heart Rhythm Society expert consensus statement on CIED lead management and extraction [12, 15]:

- Clinical success, defined as the removal of leads with at most retention of small proportions of leads that do not adversely impact procedural outcomes.
- Major complications, defined as any in-hospital, procedure-related outcomes that are deemed as life-threatening or result in death.
- Minor complications, defined as any undesired adverse events that might require medical intervention, including minor procedural interventions, but do not significantly affect the patient's function.
- In-hospital, periprocedural mortality.
- Patient mortality during a variable "long-term" follow-up period ranging from 90 days to 10 years.

2.5 | Data Analysis

Individual study characteristics were reviewed and summarized in Table 1. Outcomes were summarized utilizing odds ratio (OR) with corresponding 95% confidence intervals (CI) as a measure of effect size. Odds ratios were used due to a lack of time-sensitive outcome assessment across most studies. Pooled estimates were calculated utilizing a random-effects model with restricted maximum likelihood (REML) with the Hartung-Knapp adjustment to estimate between-study heterogeneity (I2), thus allowing for study-specific effects. Sub-group analyses were performed by categorizing primary studies according to the country of study and study design (prospective vs. retrospective).

Meta-regression analyses were performed to explore potential between-study continuous variable moderators to the estimated effect size, with p-values <0.05 representing significant interac-

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TABLE 1 | Summary and baseline characteristics of included studies.

First author (Year)	Country	Patients (n =)	Multi-center	Study design	Mean age (years)	Male (%)	Mean lead dwell time (months)	1/2/3 chamber devices (%)	Mean follow-up duration (months)
Studies comparing lead extraction vs. abandonment of non-functional, non-infected leads									
Lee (2024) [16]	United States	172	Yes	Retrospective observational	66.4	65.7	92.4	48/48/4	96
Mar (2023) [17]	United States	152	Yes	Retrospective observational	65	68	87.2	NA	33
Alonso (2021) [18]	France	552	Yes	Prospective observational	60.3	78.6	74.88	45/29/26	19.4
Ayvazyan (2021) [19]	Russia	126	No	Prospective observational	59.2	–	103.2	NA	4.1
Russo (2021) [20]	Italy	105	No	Prospective observational	55	76	48	74/26/0	21
Zeitler (2021) [21]	United States	13144	Yes	Retrospective observational	67	73.7	98.8	93/4/3	1
Mar (2020) [22]	United States	654	Yes	Retrospective observational	64.9	66.5	50.7	40/21/39	34
Alqarawi (2019) [23]	Canada	217	No	Prospective observational	63	83	61.4	NA	55
Pokorey (2017) [24]	United States	6859	Yes	Retrospective observational	79	67.1	36	NA	28.8
Parkash (2016) [25]	Canada	3763	Yes	Retrospective observational	63.4	80.7	NA	17/83/0	106.8
Zeitler (2016) [26]	United States	24908	Yes	Retrospective observational	65.4	72	70.1	NA	14.7
Rijal (2015) [27]	United States	488	No	Retrospective observational	62.7	66.6	33.1	NA	35.8
Bode (2012) [28]	Germany	903	No	Retrospective observational	64.4	80.8	NA	50/28/22	49.1
Amelot (2011) [29]	France	58	No	Retrospective observational	58	100	35.5	46/54/0	38.4
Parkash (2010) [30]	Canada	468	Yes	Retrospective observational	NA	NA	NA	NA	40
Wollmann (2007) [31]	Germany	86	No	Retrospective observational	60.4	77.9	64.8	67/22/9	92.4
Segreti (2020) [32]	Italy	1210	No	Retrospective observational	69	77	66	31/39/31	NA
Bracke (2019) [33]	Netherlands	500	No	Retrospective observational	70.9	77.6	85	NA	NA
Segreti (2019) [34]	Italy	3510	Yes	Prospective observational	68	72.3	72	30/49/21	NA
Jacheć (2019) [35]	Poland	3810	Yes	Retrospective observational	65.2	65.9	86.5	39/47/16	42.2
Merchant (2018) [36]	United States	774	No	Retrospective observational	63.5	68.4	91	NA	27.6
Jacheć (2018) [37]	Poland & Italy	1915	No	Retrospective observational	64.8	57.1	91.3	NA	1
Hussein (2017) [38]	United States	1386	No	Retrospective observational	68.2	74	75.6	NA	1

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tions. Meta-regression analyses were displayed in bubble plots. Potential small-study effects/publication bias were assessed using funnel plots with Egger's test for asymmetry. All statistical analyses were performed using Stata/BE.17 (StataCorp, USA).

3 | Results

3.1 | Literature Search

The initial search strategy yielded 455 papers across all databases searched. 204 duplicates were automatically removed through Covidence, leaving 251 papers for title and abstract screening. On reviewing the titles and abstract, 42 studies were excluded for unrelated subjects, case series, letters and editorials. Full manuscripts for the remaining 209 articles were retrieved and analyzed. This analysis excluded 189 articles based on full-text unavailability or irrelevancy with either the study design, intervention/comparator groups, patient population or outcomes assessed. A total of 23 studies were therefore included in the final analysis.

All steps of the review process up to and including data extraction and quality assessment were performed through Covidence. A PRISMA diagram illustrating the screening process is outlined in Figure 1.

3.2 | Study Characteristics

The Table 1 presents the study characteristics of the 23 studies included in the meta-analysis. All studies were observational in design and published between 2007 and 2024. The number of participants involved ranged from 58 to 24,908 with the total number of participants being 65,760. Sixteen studies compared the clinical outcomes between TLE versus LA for non-infected redundant leads. Seven further studies investigated outcomes of TLE of functional versus abandoned leads (FL & AL). Based on the Joanna Briggs Institute (JBI) critical appraisal tool, a total of 23 studies were evaluated for risk of bias as summarized in Figure S1. Of these, 13 studies (56.5%) were determined to have a low risk of bias, 7 studies (30.4%) had a moderate risk of bias, and 3 studies (13.0%) were assessed as having a high risk of bias. After extracting data from the 23 studies, there were 65,760 patients in total (TLE vs. LA 52,655; TLE of AL vs. FL 13,105), predominantly male (71.82%) with a mean age of 67.16 years and 74.31 months of mean lead dwell time.

3.3 | TLE Versus LA as an Initial Strategy

In this meta-analysis comparing TLE versus LA of non-functioning cardiac leads, 16 observational studies involving 52,655 patients were evaluated. TLE was associated with a significantly increased risk of major procedural complications compared to LA (2.3% vs. 1.1%, odds ratio [OR] 2.07, 95% confidence interval [CI] 1.42–3.03) (Figure 2). In-hospital mortality was also higher among patients undergoing TLE, OR of 2.97 (95% CI 1.95–4.53) (Figure S2). Overall procedural complication rates were not different between the two strategies (OR 1.40, 95% CI 0.90–2.18) (Figure S3).

Subgroup analysis for retrospective studies demonstrated higher all complication rates in the TLE group (OR 2.98, 95% CI 1.95–4.57), while prospective studies did not demonstrate a difference between the two strategies (OR 2.28, 95% CI 0.09–56.27) (Figure S4).

Parkash et al. reported higher procedural complication rates (1.82% vs. 0.83%) and a borderline increase in one-year mortality ($p = 0.06$) with extraction among 3763 Riata advisory leads [39]. In a separate cohort of Sprint Fidelis leads, the same group found a significantly higher complication rate with extraction (19.8% vs. 8.6%, $p = 0.0008$) [30]. Given the unique failure mode of Riata leads and the likely predominance of dual-coil ICD leads, both associated with higher extraction risk, these findings may not generalise to other lead types.

3.4 | TLE of Functional Versus Abandoned Leads

Our study reviewed 7 studies across 13,105 patients which evaluated outcomes of TLE of functional leads (FL) only compared to when abandoned leads were also present. TLE performed with AL present was associated with a significantly lower clinical success rate (OR = 0.24, 95% CI: 0.15–0.37) (Figure 3).

TLE with AL was also associated with a higher risk of major complications OR 2.51 (95% CI: 1.84–3.43) (Figure 4) as well as In-hospital mortality (OR 2.06, 95% CI: 1.14–3.71) (Figure S5).

This was exemplified by the 2024 study by Lee et al. which examined patients with leads dwelling for over 10 years [16]. The study reported higher immediate procedural complication rates in the TLE group (5.5% vs. 3.3%). Notably, however, 9.1% of patients with abandoned leads later went on to require lead extraction in the future, primarily for infection. When extraction was attempted, clinical failure occurred in 40% of these procedures with two patients having a major procedural complication and two patients having retained lead of >4 cm.

3.5 | Meta-Regression and Sensitivity Analyses

Meta-regression comparing TLE versus LA identified "year of publication" as a statistically significant moderator of effect size, with more recent studies showing a trend toward reduced risk associated with TLE, likely reflecting advances in procedural techniques and technology (Figure S6). Other variables, including total sample size, mean patient age and duration of follow-up, did not significantly influence the observed outcomes.

In the analysis comparing TLE of AL versus FL, no study-level variables including mean patient age, sample size, year of publication, or follow-up duration significantly influenced the pooled outcomes.

Sensitivity analyses in both datasets confirmed the robustness of the primary results, showing no significant variation in outcomes when individual studies were excluded, or alternative statistical approaches were applied. This reinforces the consistency and reliability of the observed associations, regardless of analytical assumptions or methodological variation.

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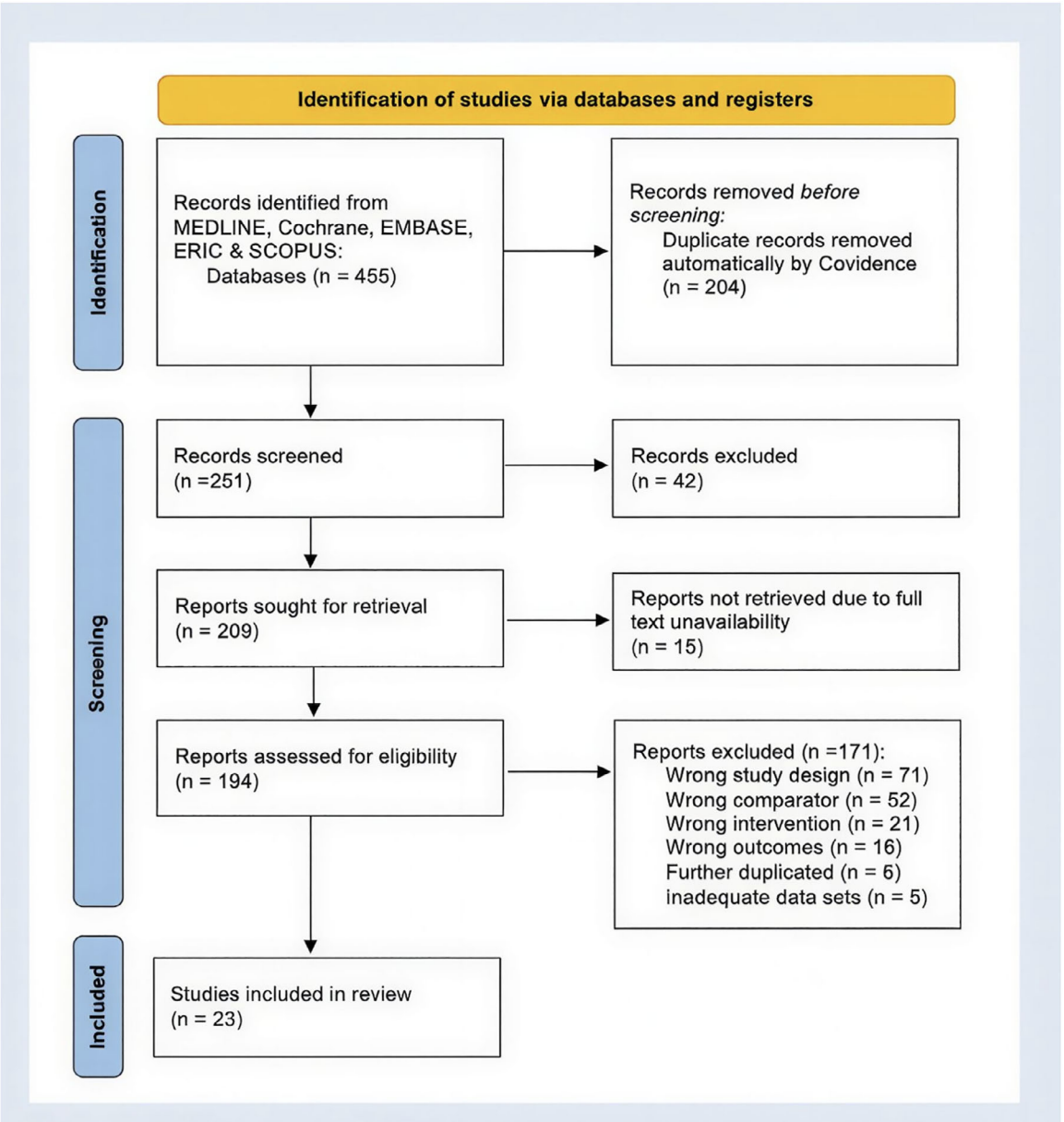


FIGURE 1 | PRISMA flow diagram flow of records through identification, screening, eligibility, and inclusion for this review; reasons for exclusion are shown at each step. PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses; ERIC = Education Resources Information Center. [Color figure can be viewed at wileyonlinelibrary.com]

Finally, there was minimal evidence of small-study effects or publication bias across the two analyses based on funnel plot inspection and Egger's test ($p = 0.3$ and 0.17, respectively) (Figure S7).

4 | Discussion

Transvenous lead extraction (TLE) represents a critical intervention in the management of complications associated with cardiac implantable electronic devices (CIEDs). While lead removal is indicated for infected leads, the decision to extract versus abandon non-infected but redundant leads remains a subject of ongoing debate. In our study, we have evaluated the procedural and clinical outcomes of TLE versus LA as well as the extraction of functional versus previously abandoned leads.

We found that pacemaker LA for non-infected leads had a lower procedural-related risk but that if that AL subsequently needed to be extracted, it added significant procedural risk compared to extraction.

Specifically, TLE doubled the odds of major complications (OR 2.07, 95% CI 1.42-3.03) and almost tripled the odds of in-hospital mortality (OR 2.97, 95% CI 1.95–4.53) when compared to AL. However, there were no significant differences in overall complication rates (OR 1.40, 95% CI 0.90–2.18) or the composite endpoint of long-term complications (OR 0.93, 95% CI 0.76–1.15), suggesting that the elevated procedural risk associated with extraction may

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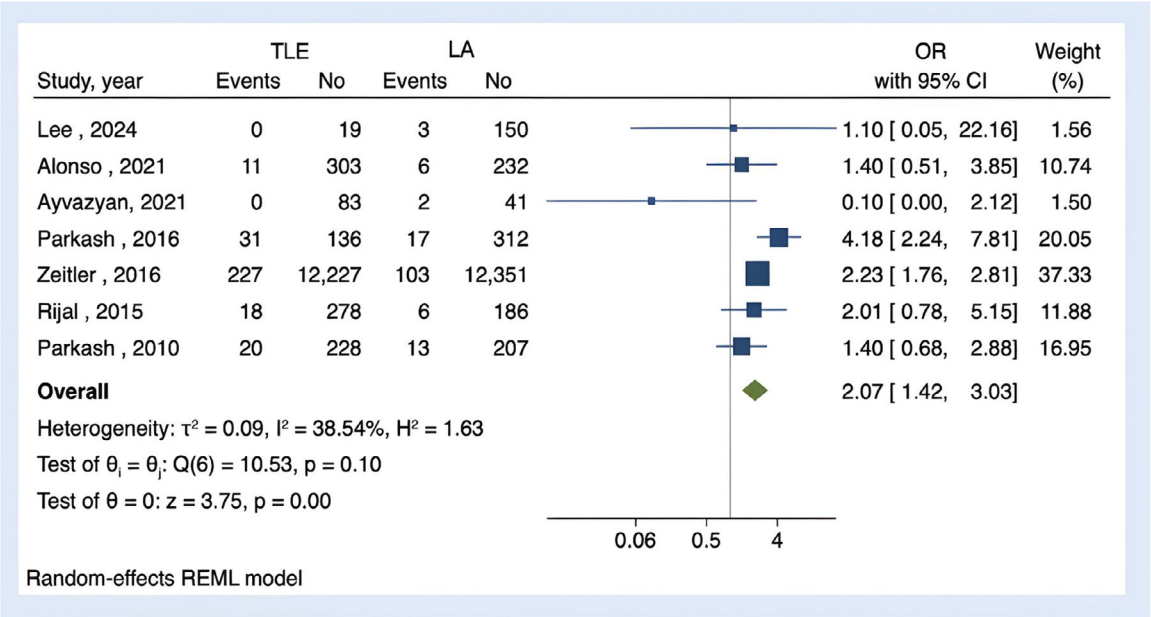


FIGURE 2 | Forest plot illustrating the rates of major complications of transvenous lead extraction versus lead abandonment Forest plot graphically comparing the odds ratio (OR) for major complications between transvenous lead extraction (TLE) and lead abandonment (LA) across multiple studies. TLE = transvenous lead extraction; LA = Lead abandonment. Squares represent study-specific odds ratios (OR) with 95% confidence intervals (CI), with square size proportional to study weight; the diamond indicates the pooled effect estimate using a random-effects restricted maximum likelihood (REML) model.
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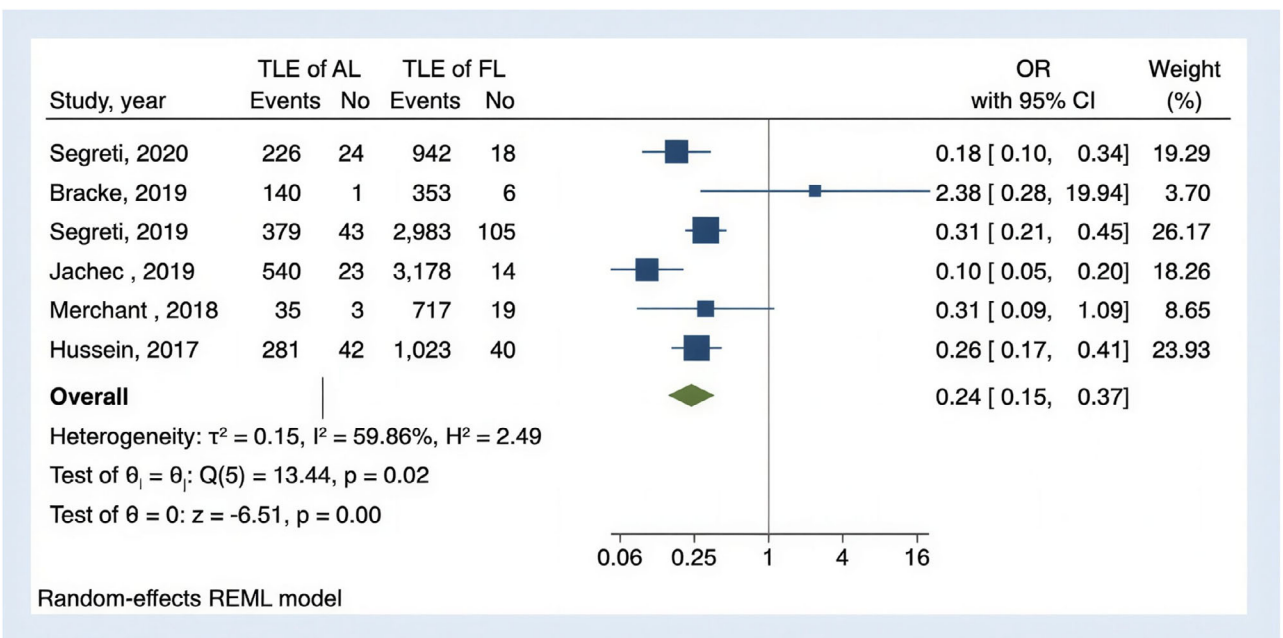


FIGURE 3 | Forest plot illustrating rates of clinical success of transvenous lead extraction of functional leads only versus with abandoned leads present Forest Plot comparing the odds ratio (OR) for clinical success rates of TLE procedures when performed on functional leads (FL) only versus procedures where abandoned leads (AL) are also present. TLE = Transvenous Lead Extraction; AL = Abandoned Leads; FL = Functional Leads. Squares represent study-specific odds ratios (OR) with 95% confidence intervals (CI), with square size proportional to study weight; the diamond indicates the pooled effect estimate using a random-effects restricted maximum likelihood (REML) model.
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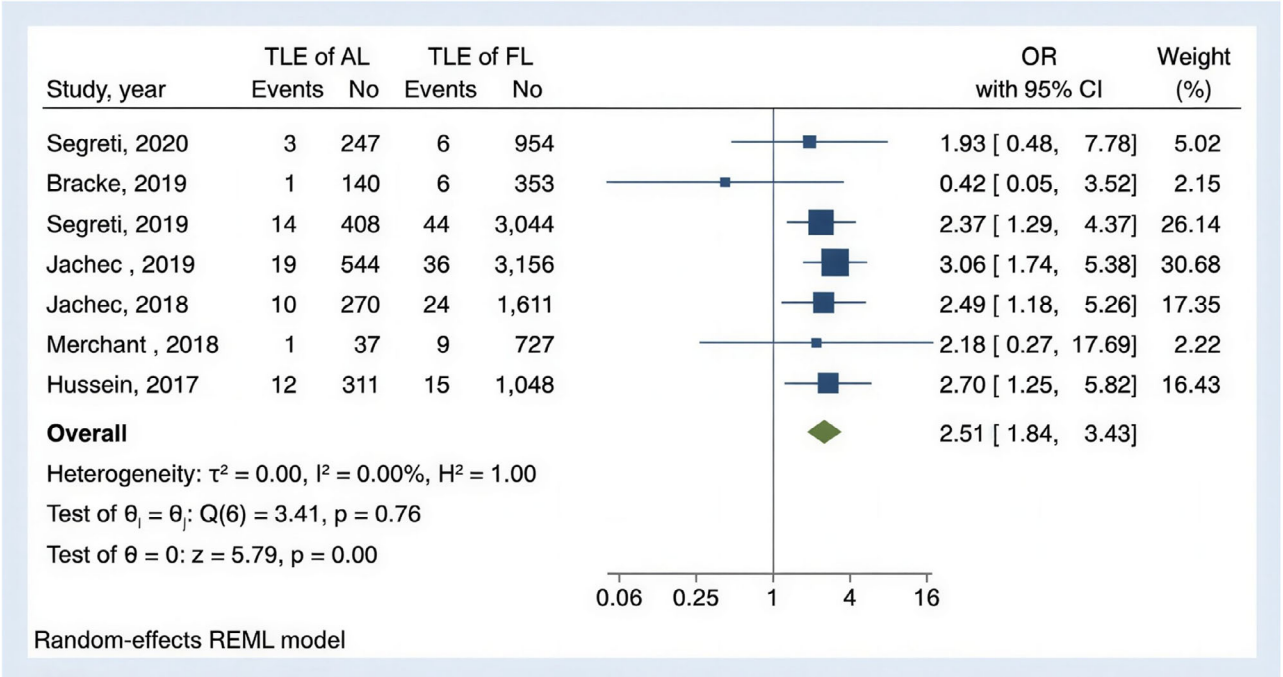


FIGURE 4 | Forest plot illustrating rates of major complications of transvenous lead extraction of functional leads only versus with abandoned leads present Forest plot comparing the odds ratio (OR) for major complications associated with TLE procedures when comparing the cohort with functional leads (FL) only versus the cohort where abandoned leads (AL) are also present. TLE = Transvenous Lead Extraction; AL = Abandoned Leads; FL = Functional Leads. Squares represent study-specific odds ratios (OR) with 95% confidence intervals (CI), with square size proportional to study weight; the diamond indicates the pooled effect estimate using a random-effects restricted maximum likelihood (REML) model.
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be offset by long-term benefits and not translate into long-term differences in adverse outcomes.

In all the studies described above, patients who underwent lead extractions tended to be younger, with shorter lead dwell times and fewer comorbidities than those who underwent abandonment. In part, this is likely to be driven by the fear of being confronted with the need to extract very old leads later in life. Lead extractors generally agree that leads with dwell times of <2 years can often be safely removed with direct traction [40]. The current clinical challenge lies around determining the tipping point at which the risk of complication becomes significant and outweighs the risks of LA.

While most studies assessed leads with dwell times under 10 years, several reviewed substantially older leads. High-volume centres reported procedural success rates over 95% and major complication rates around 3% for leads older than 15 years [41]. Others similarly observed success rates of 96%–98% for leads exceeding 10–20 years [42, 43], and a 95% success with 2% major complications for leads older than 20 years [44].

Our findings revealed that the year of publication significantly moderated the observed effect size, with more recent studies showing lower odds ratios for adverse outcomes, suggesting improvements in extraction techniques over time. These improvements, coupled with increased availability of trained high-volume operators, and the use of endovascular rescue balloons have substantially improved procedural safety, with recent analyses reporting procedure-related mortality as low as 0.08% [45]. These contemporary data highlight a gap between perceived and actual risk, with misperceptions of danger continuing to limit referrals for extraction even in the setting of infection. Another factor that may be relevant is a move from dual-coil to single-coil ICDs [46]. Other factors, including mean patient age, study size, and follow-up duration, were not significant moderators. No evidence of publication bias was detected (Egger's test $p = 0.3$). Importantly, the included studies span 2000–2025, a period of marked evolution in extraction technology, operator experience, and lead design (including a shift from dual-coil to single-coil ICD leads). Pooling data across this era likely overestimates the procedural risk of TLE as performed in contemporary high-volume centres, and the combined ORs should be interpreted with this temporal heterogeneity in mind.

Additionally, sensitivity analyses confirmed the stability of our findings, demonstrating consistent results across different analytical approaches. Subgroup analysis separating prospective and retrospective studies demonstrated higher complication rates of TLE in retrospective studies but showed no significant differences in complications between the two strategies in prospective studies, potentially underscoring the influence of selection bias in retrospective studies for LA.

In addition to these considerations, there is a growing body of evidence linking increasing lead burden across the tricuspid valve with the development or worsening of tricuspid regurgitation. Whilst lead extraction carries a small risk of tricuspid valve damage, lead extraction in carefully selected patients has been shown not only to improve regurgitation severity but also to preserve

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access to the valve in the event that transcatheter tricuspid valve replacement (TTVR) is required in the future [47, 48]. Conversely, abandoned leads may exacerbate tricuspid regurgitation and risk becoming irretrievably jailed if and when TTVR is performed. These evolving observations reinforce that lead management decisions have long-term structural and clinical consequences extending beyond the immediate procedural period.

4.1 | TLE of Functional versus Abandoned Leads

Our meta-analysis provides the most robust evidence currently available, that extraction with the presence of previously abandoned leads is associated with a significantly higher procedural risk and lower success rate. The pooled data demonstrated an increase in major complications (OR 2.51, 95% CI: 1.84–3.43), a higher rate of minor complications (OR 1.79, 95% CI: 1.27–2.53), and in-hospital mortality (OR 2.06, 95% CI: 1.14–3.71) associated with AL extractions. Furthermore, procedural success was higher in the FL group compared to the AL group (OR = 4.16, 95% CI: 2.70–6.66).

The elevated procedural risk observed when extracting cohorts containing abandoned leads is unlikely to reflect abandonment status in isolation. Abandoned leads are likely to be older than concurrent FL, and lead dwell time is among the strongest predictors of extraction complexity. The pooled estimates here, therefore, are unable to conclusively differentiate abandonment from accumulated dwell time, prior procedures and technical difficulty. This potential confounding is directly demonstrated by Jacheć et al. [37]., in whose multivariate analysis lead implant duration, abandoned leads, multiple prior procedures and intraprocedural technical problems were each independently associated with major complications.

4.2 | Follow-up of Abandoned Leads and the Risk for Future Complications

It is important to recognize that most abandoned leads do not ultimately result in clinical complications. The Danish Pacemaker and ICD Register, which included 726 patients with abandoned leads, reported that over an average follow-up of 4.4 ± 3.1 years, 5.5% required subsequent extraction due to device-related infection [49], an incidence that aligns closely with the overall infection rates of the cohort (2.3%–5.0%). More recently, Lee et al. [16]. reported that over 10 years, indications for lead extraction arose in 9.1% of patients managed initially with LA, noting that approximately 29% of these patients ultimately declined extraction due to perceived procedural risk, while among those proceeding, 40% experienced clinical extraction failure. Follow-up in most included studies was restricted to ≤6 years, insufficient to capture the late sequelae of abandonment. As such, outcomes reported may inherently be biased towards abandonment, since upfront extraction risk is well measured while long-term abandonment risks including progressive venous occlusion, worsening tricuspid regurgitation with multiple transvalvular leads, and increased infection risk manifest over decades and are not adequately reflected. The authors highlight that not all patients with abandoned leads who develop lead complications or infection will undergo extraction, especially if the initial abandonment occurred because the extraction risk was considered prohibitively high. Existing studies, therefore, likely underestimate the true risks associated with the extraction of previously abandoned leads.

A commonly cited concern to warrant lead extraction is the accumulation of multiple abandoned leads over the years. However, in all follow-up studies of abandoned leads and their subsequent extraction, more than 2 abandoned leads per patient were present in only 0% to 4.3% of the patients [33, 38, 49–51].

Another argument for extracting redundant leads is for the purposes of MRI compatibility, primarily based on the 2017 HRS consensus paper that excluded patients with abandoned leads from the Class IIa classification provided for MRI nonconditional systems [52]. This was partly due to the insufficiency of data at the time around the safety of abandoned leads for MRI purposes. In light of subsequent clinical reports demonstrating its MRI safety, the 2021 European Society of Cardiology guidelines have labelled abandoned leads a class IIb indication for MRI, it may be considered if no alternative imaging modality is available [53]. Although accumulating evidence supports the safety of MRI in patients with abandoned leads, regulatory labelling and institutional restrictions still may preclude MRI scanning in many centres. This remains a practical disadvantage of abandonment that directly impacts patient care.

Opting for lead extraction over abandonments also poses logistic and financial repercussions. The mean cost of extraction of a superfluous lead is estimated to be $7000 USD [54]. Additionally, the 2017 HRS expert consensus paper states that extraction should only be performed at specialized centres with adequate extraction tools in hybrid theatres with cardiothoracic surgical backup [12]. In contrast, LA can be performed in standard catheterization labs without any specialized equipment.

Taken together, these contemporary observations—a statistically significant temporal reduction in TLE complication rates and a narrowing differential between extraction and abandonment in modern cohorts—indicate that the historical risk–benefit balance for non-infected superfluous leads is shifting. In appropriately selected patients managed at experienced centres, the data therefore support a more proactive consideration of extraction than has traditionally been advocated, as supported by the recently released 2026 HRS/AHA/APHRS/EHRA/IDSA/LAHRS/PACES/STS Expert Consensus Statement Update on CIED Lead Management and Extraction [55], which underscores that decisions should integrate contemporary procedural safety, anticipated lead longevity, and the cumulative downstream burden of retained leads.

4.3 | Limitations

This systematic review and meta-analysis is limited by the observational design of all included studies, introducing risks of selection bias, confounding, and heterogeneity in patient populations and procedural technique. Outcomes are also likely influenced by extraction site and operator experience, which vary substantially between low-volume and specialized high-volume centres [56, 57]. Partial overlap between large European

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registries, particularly Jacheć [35, 37] and Segreti [32, 34], may have contributed to duplication of cases in aggregate analyses.

Comparisons between strategies are further constrained by confounding by indication. Across all studies, patients selected for extraction were consistently younger, had shorter dwell times, and fewer comorbidities than those managed conservatively, a bias that cannot be fully corrected through pooling. Several variables central to guideline-directed decision-making, including number of abandoned leads, cumulative transvalvular lead burden, venous patency, and lead diameter, were inconsistently reported and could not be incorporated into pooled analysis. It therefore cannot be excluded that abandonment cohorts comprised lower-complexity patients, biasing results in favor of the conservative strategy.

A more fundamental, structural limitation is that late complications of abandoned leads, including device-related infection, progressive venous occlusion, lead-related tricuspid regurgitation, and lead migration, may often present at institutions other than the one performing the index procedure, often years to decades later and in different geographic regions. Capturing the true long-term complication rate of abandonment is therefore inherently difficult in conventional cohort studies and can only realistically be achieved through linked national registries combining device, mortality, infection, and admission data, infrastructure that does not currently exist in most jurisdictions. Compounding this, follow-up was often truncated, potentially underestimating subclinical complications that emerge over time. The apparent equivalence in long-term outcomes should therefore not be interpreted as true equivalence, but as a reflection of a limited follow-up horizon: extraction risk is measurable upfront, whereas complications from abandoned leads accrue over decades. Future research should priorities prospective, randomized studies with extended follow-up to better characterize the long-term outcomes of both strategies.

5 | Conclusion

For non-infected, redundant CIED leads, abandonment carries lower immediate procedural risk than extraction. This early advantage must be weighed against the substantially higher complication and mortality rates incurred when abandoned leads later require extraction, and against the long-term burden of retained hardware—progressive venous occlusion, lead-related tricuspid regurgitation, loss of future vascular and valvular access, and ongoing infection risk, that accrues over a horizon longer than current follow-up can measure.

The apparent similarity in long-term outcomes should therefore not be read as therapeutic equivalence: extraction risk is fully measured, whereas the downstream costs of abandonment are systematically under-ascertained. With the historical risk differential narrowing as contemporary extraction safety improves, the balance is shifting toward earlier intervention. In appropriately selected patients managed at experienced, high-volume centres, these observations favor proactive consideration of extraction over default abandonment, while recognizing that the decision remains individualized and consistent with contemporary Expert Consensus recommendations.

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Ethics Statement

This systematic review and meta-analysis utilized data from previously published studies and did not involve direct patient contact or the collection of identifiable patient information. As such, in accordance with local institutional and national guidelines, separate ethics committee approval was not required.

Conflicts of Interest

None of the other Authors have conflicts of interest or disclosures.

Data Availability Statement

All data supporting the findings of this study are available within the paper and its Supplementary Information.

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