Systematic Review

Mid-to-long-term recurrence of atrial fibrillation in surgical treatment *vs.* catheter ablation: a meta-analysis using aggregated survival data

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Background: Atrial fibrillation (AF) is the most common cardiac arrhythmia and leading cardiac cause of stroke. Catheter and surgical ablation are two techniques used currently to resolve prolonged disease by limiting the excitatory potential of specific areas of myocardium in the atria of the heart. The aim of this systematic review and meta-analysis was to provide a graphical amalgamation of mid-to-long-term rhythm outcomes following transcatheter and surgical intervention, whether primary or concomitant ablation.

Methods: Three electronic databases were selected to complete the initial literature search from inception of records until April 2023. Primary outcomes were freedom from AF at 12 months, as well as long term time-to-event recurrence data. These data were calculated using aggregated Kaplan-Meier curves according to established methods. The secondary outcome was procedural time for each ablation method.

Results: Following independent screening, 36 studies were included for analysis. A total of 6,700 patients were followed, of whom 4,863 (72.6%) were male. Freedom from AF recurrence at 1, 3 and 5 years for the surgical cohort was 71.7%, 57.6% and 47.6%, respectively. Comparatively, the recurrence rates of the catheter ablation cohort at 1, 3 and 5 years were 71.5%, 56.5% and 50.3%, respectively.

Conclusions: Despite potentially more complex diseases, surgical ablation patients have non-inferior long-term AF recurrence when compared to those undergoing catheter ablation. Recurrence at 12 months as well as procedural time are also similar between these groups. Ultimately, both ablation methods were able to prevent recurrence of AF in approximately 50% of patients at five years following the procedure.

Keywords: Atrial fibrillation (AF); Cox-Maze; catheter ablation; cryoballoon; radiofrequency (RF)

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Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia and leading cardiac cause of stroke, with a worldwide prevalence of 1% and up to 10% in patients undergoing cardiac surgery (1). While predominately due to an underlying cardiac condition, AF is a tachyarrhythmia caused by ectopic neuronal excitation in the atria, usually at a focus surrounding the pulmonary veins as they enter the left atrium. This stimulates unsynchronized electrical impulse firing, leading to irregular atrial contraction and turbulent blood flow. As well as reducing the effective contraction of the myocardium, thrombus formation may occur, especially in the left atrial (LA) appendage, which is responsible for resultant thromboembolic complications.

AF exists in several categories which dictate treatment and prognosis. An initial episode greater than 30 seconds

without a reversible cause is not deemed significant. Two or more of these episodes followed by spontaneous termination defines "paroxysmal" AF. If a single episode persists beyond seven days, it is termed "persistent" AF. This can be further characterized as "long-standing persistent" AF if the arrhythmic episode lasts longer than one year. Finally, in the case of failed or abandoned treatment following this long-standing episode, the patient is deemed to have "permanent" AF (2,3).

While AF is usually managed in an escalatory fashion, from conservative and lifestyle intervention, to pharmacotherapy, cardioversion and finally ablation, each of these treatment modalities differs in clinical success. Within the first year, anti-arrhythmic drug (AAD) therapy has a failure rate of up to 67%, with both AF recurrence and adverse events occurring in spite of treatment (4). Catheter ablation is the next recommended treatment as per European Society of Cardiology (ESC) guidelines, with a class Ia recommendation following failed drug therapy (5). As well as catheter ablation improving quality of life outcomes, when compared to AAD therapy alone, a recent meta-analysis of six randomized controlled trials (RCT) showed only 11.8% recurrence of symptomatic arrhythmias compared to 26.4% in the AAD group (6). Alternatively, the last measure for prevention of AF recurrence is surgical intervention, which instead of disrupting aberrant signals via endocardial tissue disruption, focuses on the epicardial aspect of the heart. This can be carried out in a number of different ways. The Maze procedure, utilizing a "cut and sew" technique, as well as the newer Cox-Maze IV procedure, which instead opts for radiofrequency (RF) ablation to facilitate tissue destruction, both exist as a concomitant treatment alongside planned open surgery via sternotomy. Minimally invasive techniques are also performed, namely a totally thoracoscopic video-assisted ablation or "mini-maze", which does not require concomitant open surgery. A robotic technique has also recently been employed to advance the existing "mini-maze" procedure. Finally, a hybrid approach can also be undertaken, usually involving a staged catheter ablation on the endocardium in the months following a surgical epicardial ablation operation (7).

The aim of this systematic review and meta-analysis was to provide a graphical amalgamation of mid-to-long-term rhythm outcomes following transcatheter and surgical intervention. We sought to directly compare the 12-month freedom from AF recurrence between these two treatment modalities using aggregated Kaplan-Meier (KM) curves.

Methods

Literature search

Three electronic databases were selected to complete the initial literature search, specifically PubMed, Embase and Cochrane Central Register of Controlled Trials, from inception of records until 16th April 2023. The search strategy employed Medical Subject Headings (MeSH) and focused keywords, with the specific input as follows: (atrial fibrillation and (ablation or radio* or catheter or laser or cryo*) and (surgical or thoracop* or robot*)).

After removal of duplicate records and those published before the year 2000, PRISMA guidelines were followed in accordance with pre-written inclusion and exclusion criteria to screen the remaining records (8). Screening was conducted by two authors independently (J.B. and B.T.M.) with any discrepancies being finalized through team discussion, with ultimate ruling by the leading author (B.T.M.). A PRISMA diagram of the search strategy and list of records at each stage is depicted in *Figure 1*. Once full-text review was completed, the reference lists of all included papers were searched to assess for previously missed publications fitting the inclusion criteria.

Inclusion and exclusion criteria

Eligibility criteria was established *a priori*, and focused on inclusion of high-quality prospective studies. Only English language studies were included. Studies were included if they met the following criteria: (I) included data for AF recurrence or return to sinus rhythm at 12 months; (II) were prospective in design; (III) KM graphs of time-to-event data for AF recurrence were present, notably, with numbers-at-risk available; (IV) demographic and operative data was matched to the graphed cohort. Studies were excluded if they: (I) did not provide a KM curve; (II) had a sample size smaller than one hundred patients; (III) had overlapping cohorts with larger included studies. All conference abstracts, reviews, editorials and animal studies were also excluded.

Outcome measures

The primary outcome of this study was mid-to-long-term recurrence of AF following either surgical or catheter ablation for patients undergoing treatment for paroxysmal, persistent or permanent AF. It was a requirement for this data to be graphically depicted in included studies, using a KM

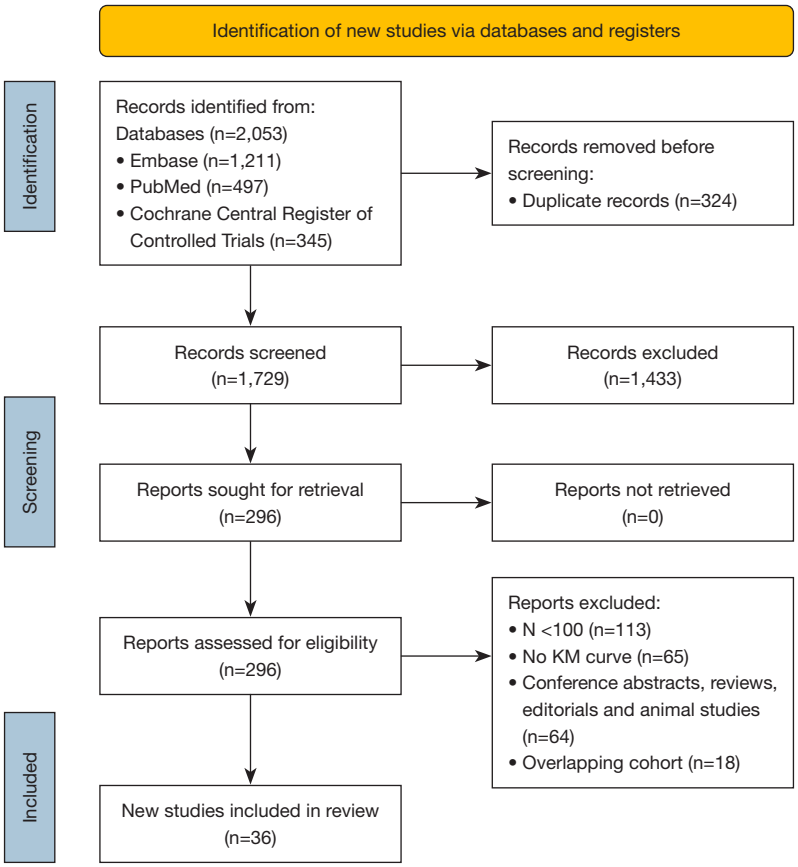

Figure 1 PRISMA flowchart of included studies. KM, Kaplan-Meier.

curve for non-parametric survival estimation. There was no restriction on the length of follow-up for survival analysis.

The secondary outcome was procedural time with comparisons being drawn between the larger categories of surgical *vs.* catheter ablation as well as between subgroups of these interventions. These subgroups include thoracoscopic, cryoballoon and RF procedures.

Quality assessment

The quality of each study was assessed using the modified Canadian National Institute of Health Economics (CNIHE) assessment tool for case series (9). Of a possible total of 20 criteria to be met from the CNIHE tool, a study was considered high quality if it scored 17 or higher, moderate quality if it scored between 13 and 16, and low quality if it scored 12 or below. Study quality was independently assessed by two investigators (B.T.M. and J.B.) with review and consensus completed by the senior author (B.T.M.).

Statistical analysis

Baseline characteristics and operative details were extracted from the text, tables and figures of included papers by two independent authors (B.T.M. and J.B.). Discrepancies were discussed then finally reviewed by the senior author (B.T.M.). Statistical analysis was carried out using Stata (version 17.0, StataCorp, Texas, USA) and R (Version 4.1.1. R Core Team, Vienna, Austria) utilizing meta-analysis of proportions and means with a random-effects model where necessary. Values were considered statistically significant if the reported P value was less than 0.05. For continuous data with central tendency described using median values and interquartile range (IQR), the mean and standard deviation were estimated using calculations described by Wan and colleagues (10). Survival data were calculated using aggregated KM curves collected from included studies, where reported, using the methods described by Guyot and colleagues (11). Digitization of source KM curves was performed using DigitizeIt (version 2.5.9, Braunschweig,

Germany) and in the case where multiple cohorts were represented on the same curve, individual KM curves were first generated then subsequently merged with the rest of the data, to be analyzed together.

Results

Following independent screening, 36 studies were included for analysis, of which 5 described surgical ablation and 31 reported on catheter ablation techniques (*Table 1*). There was considerable overlap between patient population and center-based data in published studies on this topic, and as a result, 18 papers were excluded from analysis prior to inclusion in this review.

Quality analysis using the CNIHE tool found a large majority of high-quality studies fitting all inclusion criteria, revealing 32 publications receiving scores of 17 or more and being classed as high quality. Only four studies were scored as medium quality, whilst zero included studies were low quality (*Table 1*). Therefore, no further sub-group analysis for outcome data or heterogeneity was required as low quality evidence was not a confounding factor in this meta-analysis.

Baseline study characteristics

Baseline cohort characteristics are reported in *Table 2*, along with reporting frequencies for each of the operative methods. A total of 6,700 patients were followed in this systematic review, of whom 4,863 (72.6%) were male. The studies ranged in cohort size from 100 to 611. The mean age of the overall cohort was 61.1±9.2 years with no significant difference between the surgical and catheter groups. Patient comorbidities were not reported in this review. Study details are shown in *Table 1*, with widespread representation from centers in Europe, Asia, North America and Australia. Most studies were multicenter, usually as part of an international clinical trial investigating catheter ablation compared to surgical or medical therapy alone. Notably, the duration of AF before intervention was substantially longer in the surgical cohort over the catheter cohort (54.9 *vs.* 35.6 months, respectively), suggesting a more chronic disease presentation in the surgical group. Other proxies for disease severity are reported in *Table 2*, including the LA diameter and left ventricular ejection fraction (LVEF). Both were more severe in the surgical group, which saw a 2.5-mm larger average LA and a 3.9% further reduced LVEF than the catheter group, at 44.8 *vs.* 42.3 mm and 54.0% *vs.* 57.9%, respectively. The apparent difference in chronicity of patient population is also reflected in the reported category of AF between groups. The surgical repair group was predominately made up of patients with persistent AF, refractive to medical therapy, while the catheter group was more evenly split, with a marginally more dominant proportion of paroxysmal AF patients.

Primary outcome: long-term freedom from AF

Freedom from AF was evaluated through meta-analysis of reported recurrence at the 12-month interval, as well as through aggregated KM survival curves created using techniques by Guyot and colleagues, which extended beyond the 5-year mark. Overall pooled freedom from AF was 71.0% (95% CI: 67.1–74.8%; I^2=91.8%; *Figure 2*) at 12 months, with surgical and catheter subgroups attributing a freedom from AF of 77.2% (95% CI: 66.3–86.5%; I^2=92.4%) and 70.0% (95% CI: 65.7–74.1%; I^2=91.7%), respectively (*Table 3*). No significant difference was found when comparing pooled results between subgroups (P>0.05).

Freedom from AF recurrence at 1, 3 and 5 years for the surgical cohort was 71.7%, 57.6% and 47.6%, respectively (*Figure 3*). When compared to the recurrence rates of the catheter ablation cohort at 1, 3 and 5 years, which were 71.5%, 56.5% and 50.3%, respectively, no definitive conclusions could be made due to the overlapping confidence intervals when curves were superimposed (*Figure 3*).

Secondary outcome: procedural time between groups and subgroups

The pooled procedural times for surgical *vs.* catheter ablation groups were 218.2 minutes (IQR: 193.1–243.4) and 169.0 minutes (IQR: 136.7–185.3), respectively. There was a non-significantly longer procedural time in the surgical group, which can be visualized in *Figure 4*. When comparing subgroups, specifically the type of ablation used, differences were found between the catheter ablation types. Procedural times for thoracoscopic, RF and cryoballoon ablation techniques were 218.2 minutes (IQR: 193.1–243.4), 173.9 minutes (IQR: 145.3–186.5) and 103.5 minutes (IQR: 52.6–159.2), respectively. Differences between subgroups were found to be statistically significant, specifically comparisons of procedural time between thoracoscopic and cryoballoon (P=0.002) and between RF and cryoballoon (P=0.006). *Figure 5* shows the comparative difference between procedural length by subgroup.

Table 1 Study details and quality findings

Author, year	Cohort size (n)	Males (n)	Age (mean), years	Study quality (Delphi)	Country/region	Registry/study name (if relevant)	Years of patient enrolment	Ablation type	Subtype	AF recurrence at 12 months (n)
Surgical ablation										
Ad (12), 2017	133	122	57.3	H	USA		2005–2016	Surgical	Mini	8
Baalman (13), 2022	204	150	58.6	H	Netherlands	AFACT	2010–2015	Surgical	Thoracoscopic	59
DeLurgio (14), 2020	102	80	63.7	H	USA, UK	CONVERGE	2013–2018	Surgical	Hybrid	30
Neefs (15), 2022	442	324	59.8	H	Netherlands		2008–2018	Surgical	Thoracoscopic	142
Saini (16), 2017	109	60	62.7	H	USA		2006–2012	Surgical	Thoracoscopic	24
Catheter ablation techniques										
Boveda (17), 2018	101	75	61.8	H	Germany, France, Greece	CRYO4PERSISTENT	2014–2016	Catheter	Cryo	33
Buist (18), 2018	269	191	58.9	H	Netherlands		NR	Catheter	Cryo =133, RF =136	91
Chun (19), 2021	100	58	65	H	Germany		2017–2019	Catheter	Cryo	20
Deftereos (20), 2014	206	144	62.2	H	Greece		NR	Catheter	RF	83
Di Biase (21), 2016	102	77	62	H		AATAC	2013–2014	Catheter	RF	31
Gal (22), 2014	230	173	56.1	H	Netherlands		NR	Catheter	RF	55
Giannopoulos (23), 2018	166	117	59.6	H	Greece		NR	Catheter	RF	47
Inoue (24), 2021	249	186	66.7	H	Japan	EARNEST-PVI	2016–2019	Catheter	RF	80
Jiang (25), 2022	149	90	59.6	H	China	PAF-AI	NR	Catheter	RF	43
Kang (26), 2014	100	74	55.65	M	South Korea		NR	Catheter	RF	24
Kistler (27), 2023	168	128	65	H	Australia, Canada, UK	CAPLA	2018–2021	Catheter	RF	78
Kuniss (28), 2021	107	76	50.5	H	Europe, Australia	Cryo-FIRST	2014–2018	Catheter	Cryo	15
Lee (29), 2019	105	84	58.6	M	South Korea		NR	Catheter	RF	25
Lee (30), 2018	250	186	55.5	H	South Korea		NR	Catheter	RF	47
Macle (31), 2015	117	87	58.9	H	Australia, Europe	ADVICE	2009–2013	Catheter	RF	51

Table 1 (*continued*)

Table 1 (*continued*)

Author, year	Cohort size (n)	Males (n)	Age (mean), years	Study quality (Delphi)	Country/region	Registry/study name (if relevant)	Years of patient enrolment	Ablation type	Subtype	AF recurrence at 12 months (n)
Marrouche (32), 2022	422	333	63	H	Australia, Europe, USA	DECAAF II	2016–2020	Catheter	RF	163
McLellan (33), 2015	117	75	59	H	Australia, NZ, UK	Minimax	2010–2013	Catheter	RF	35
Packer (34), 2013	163	125	57	H	USA	STOP-AF	2006–2011	Catheter	Cryo	59
Pokushalov (35), 2013	132	101	55	H	Russia, USA		NR	Catheter	RF	61
Rillig (36), 2017	127	85	61.7	H	Germany, USA	Man and Machine	2009–2016	Catheter	RF	23
Spitzer (37), 2023	133	78	63.2	H	USA	REDO-FIRM	2016–2021	Catheter	RF	50
Steinberg (38), 2020	148	91	61	H	Russia, Germany	ERADICATE-AF	2013–2018	Catheter	RF	64
Sun (39), 2022	163	119	61.6	M	China		2017–2020	Catheter	RF	51
Valderrábano (40), 2020	158	124	66.4	H	USA	VENUS	2013–2018	Catheter	RF	98
Wintgens (41), 2021	103	75	60.2	H	Germany, Netherlands	GOLD FORCE	2015–2018	Catheter	RF	27
Wu (42), 2021	327	218	64.8	H	China	CAPA	2012–2014	Catheter	RF	49
Yang (43), 2017	114	92	57.1	H	China	STABLE-SR	2013–2014	Catheter	RF	20
Yao (44), 2020	231	231	57.7	H	Canada	CIRCA-DOSE	2014–2017	Catheter	Cryo/RF	101
Xu (45), 2020	120	80	59.2	M	China	FORCE-PVA	2015–2016	Catheter	RF	17
Yu (46), 2019	222	154	59.4	H	South Korea		NR	Catheter	RF	24
Poole (47), 2020	611	400	68.3	M	USA	CABANA	2009–2017	Catheter	RF	222

Some studies included a small proportion of Extent IV/V or non-TAAA patients. AF, atrial fibrillation; H, high; M, middle; NR, not reported; Cryo, Cryoballoon; RF, radiofrequency; TAAA, thoracoabdominal aortic aneurysm.

Table 2 Baseline cohort characteristics

Variable	Overall	Surgical	Catheter
Patients	6,700 (100.0)	990 (14.8)	5,710 (85.2)
Males	4,863 (72.6)	736	4,127
Age (years)	61.1±9.2	59.9±8.7	61.2±9.2
Atrial fibrillation type			
Paroxysmal	3,222	319	2,903
Persistent	2,696	661	2,025
Reporting frequency (%)	88.3	99.0	86.5
AF duration (months)	39.1±36.0	54.9±53.3	35.6±30.8
Reporting frequency (%)	65.4	79.4	63.0
LA diameter (mm)	42.4±6.2	44.8±7.1	42.3±5.8
Reporting frequency (%)	68.5	55.4	75.4
LVEF (%)	57.0±7.6	54.0±9.3	57.9±7.1
Reporting frequency (%)	70.7	79.4	69.1

Values are n (%) or mean ± SD (weighted average) unless otherwise specified. AF, atrial fibrillation; LA, left atrium; LVEF, left ventricular ejection fraction; SD, standard deviation.

Differences between groups in time taken for each procedure were only found between smaller cohorts in subgroup analysis. Larger cohort comparisons showed no significant differences.

Publication bias

Our objective was to explore the possibility of publication bias using both a funnel plot and Egger's test. However, no indication of publication bias was noted in Egger's test following meta-analysis of outcomes (P=0.468) or in the funnel plot (*Figure 6*). Risk of bias was also assessed for each included study using the RoB2 tool (48) (Figure S1).

Discussion

AF is a potentially life-long condition with a variety of management options, all of varying invasiveness and effectiveness. Usually following the failure of rate control alone, as well as pharmacological rhythm control, the abnormal electrical activity is isolated from the pulmonary veins using a circumferential ablation (49). While many different types of lesion sets have been reported, including both endo- and epicardial ablation, there has been no consensus as to which pattern is most effective. This was shown in the STAR-AF II trial, a high-quality multicenter RCT involving nearly 600 patients, which compared pulmonary vein isolation (PVI) alone to PVI with addition of active areas and PVI with atrial roof ablation, showing no significant difference between lesion sets (50). Due to the variation in the characteristic abnormal electrical activity of AF, current understanding is that the level of ablation should be matched to the individual (51,52).

This meta-analysis summarized all available large prospective studies displaying adequate KM curve data for catheter and surgical cohorts, totaling 6,700 patients and 36 publications. The results of our study showed a non-significant improvement in freedom from AF recurrence at 12 months in surgical patients, with roughly 7% improvement over the endovascular alternative. High heterogeneity (I^2=91.8%) and a stark imbalance in cohort size were two major factors impairing the generalizability of these results. However, patient demographic data and study endpoints were largely similar between included studies, allowing effective comparisons to be made between ablation strategies and subtypes. Due to lack of reporting, further detail into lesion set analysis, including surgical LA appendage occlusion, was not conducted and is a target for future research in this area.

The primary question to be answered in this meta-

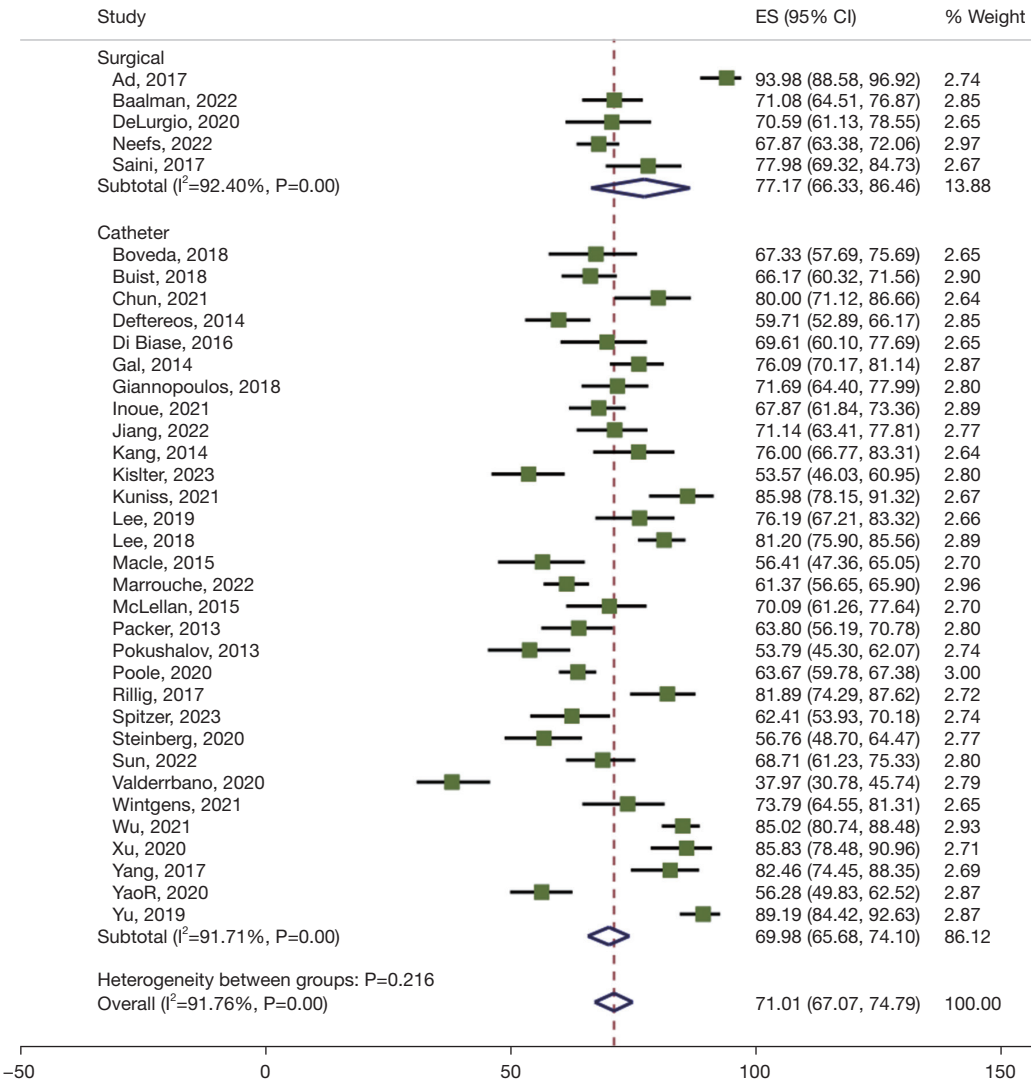

Figure 2 Forest plot showing freedom from atrial fibrillation at 12 months, by subgroup. ES, effect size; CI, confidence interval.

Table 3 Operative outcomes and early morbidity

Operative outcomes	Overall	Surgical	Catheter
Patients, n (%)	6,700 (100.0)	990 (14.8)	5,710 (85.2)
Freedom from AF recurrence at 12 months (%) (95% CI)	71.0 (67.1–74.8)	77.2 (66.3–86.5)	70.0 (65.7–74.1)
I^2 value (%)	91.8	92.4	91.7
Procedural time (min), mean ± SD	163.1±39.9	163.0±39.8	163.6±40.8

AF, atrial fibrillation; CI, confidence interval; SD, standard deviation.

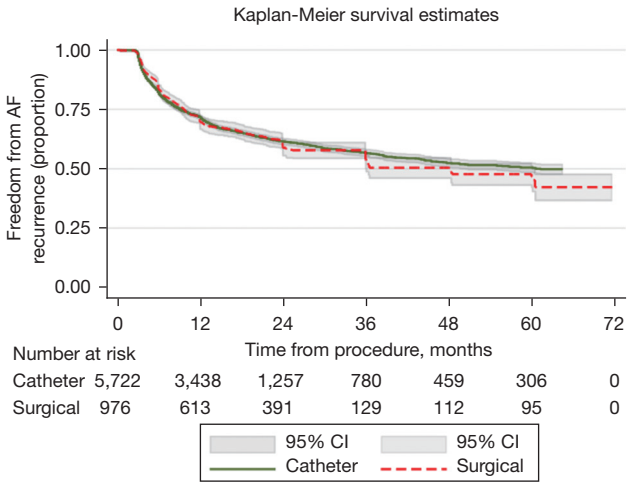

Figure 3 Aggregated Kaplan-Meier curve of freedom from AF recurrence, using methods by Guyot and colleagues (11). AF, atrial fibrillation.

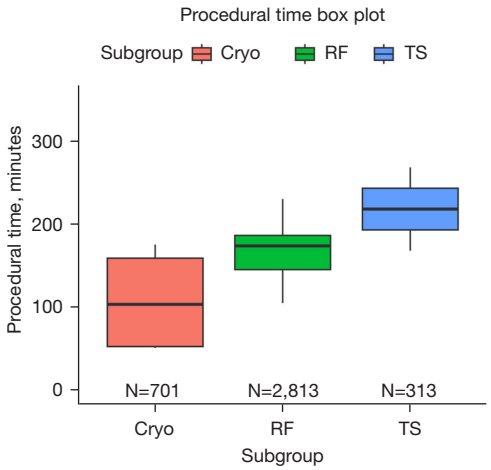

Figure 5 Boxplot showing procedural time by subgroup. Cryo, cryoballoon; RF, radiofrequency; TS, thoracoscopic.

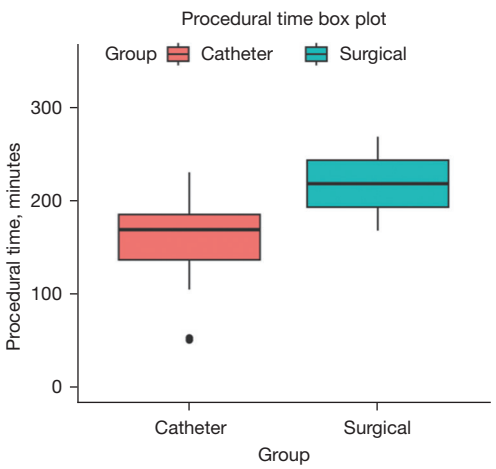

Figure 4 Box plot showing procedural time by group.

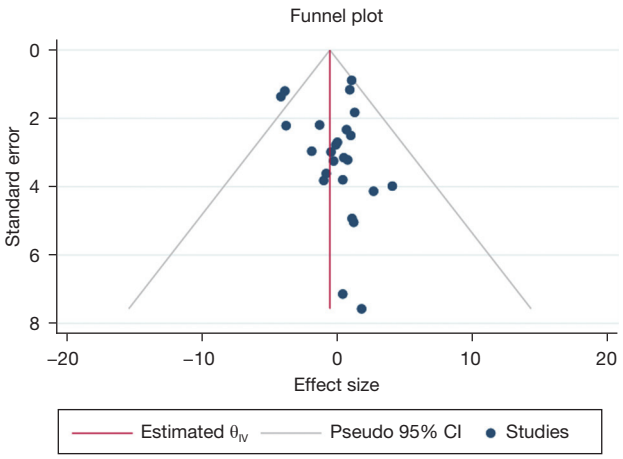

Figure 6 Funnel plot of procedural time following atrial fibrillation ablation (grouped). CI, confidence interval.

analysis was whether an epicardial lesion set showed superiority to an endocardial lesion set in preventing recurrence of AF at 12 months following initial ablation. These lesion sets correlate to surgical and catheter ablation, respectively, both of which come with their own risks and benefits. The indication for each of these approaches vary according to the guidelines published by the ESC and Society of Thoracic Surgeons (STS). According to the 2020 ESC guidelines, ordered treatment sees the implementation of catheter ablation first, recommended for rhythm control after failed drug therapy (Class I), with thoracoscopic ablation only to follow should the percutaneous approach fail (Class II) (5). The 2017 STS guidelines also only give Class I evidence for the use of surgical ablation in combination with concomitant mitral procedures or aortic valve replacement (53). This suggests that surgical ablation patients may have more complex pathology or be subject to additional co-morbidities resulting in initial failure of prior medical and ablative therapy. Catheter ablation, however, received an ESC Class I indication for initial therapy for patients refractory to anti-arrhythmic medication alone, provided the operator was skilled and the procedure was undertaken in an experienced center (5). The implication of these guideline recommendations is reflected

in the results of this meta-analysis, which saw a cohort of surgical candidates with a potentially higher degree of co-morbidities perform just as well as the catheter ablation candidates. Moreover, four of the five included surgical cohorts reported failed previous catheter ablation in a proportion of their patients (12,13,15,16), whereas none of the 31 catheter ablation papers reported this variable. The reported surgical group had a more chronic AF duration, larger LA diameter and poorer LVEF (*Table 2*), yet showed almost identical long-term freedom from recurrence when overlaid on the aggregated KM curve of the catheter group in *Figure 3*. This time-to-event data reconstruction represents the largest in current literature and also provides a graphical comparison of long-term freedom from recurrence between catheter and surgical ablation cohorts.

Despite the potential for more extensive coverage of ablation, the procedural time for surgical ablation was not significantly different to the catheter ablation cohort (*Figure 4*). A previous meta-analysis revealed a difference between these groups in a smaller cohort and with fewer studies selected, however this statistically significant finding was lost when correcting for high heterogeneity in a leave-one-out analysis (54). When isolating length of procedure by ablation technique, the cryoballoon ablation was significantly shorter than both RF and thoracoscopic alternatives (P=0.006 and P=0.002, respectively). This is consistent with findings from Mörtsell *et al.*, who conducted a large analysis of 4,657 patients from Swedish and European Heart Rhythm Association registries, showing a 41-minute reduction in procedural time between cryoballoon and RF cohorts (P<0.001) (55).

It should be noted that a single hybrid ablation study was included under the 'surgical' group in our analysis and aided in the reduction of the overall procedural time for this group. The paper in question, the CONVERGE trial by DeLurgio *et al.*, found that during hybrid procedures conducted in 102 patients, the epicardial ablation time was only 42.9±13.7 minutes compared to the 135.8±49.9 minutes of the endocardial portion of the procedure (14). While this study showed no superiority in AF recurrence over others included in this analysis, at 29.4% at 12 months post-op, it poses an interesting opportunity for future analysis when compared to traditional catheter and surgical ablation techniques. Hybrid ablation may not only be able to more completely isolate conductive tissue in the atria, but also may be able to reach areas, such as Bachmann's bundle, which are more difficult to access without it (56). It appears that hybrid ablation may have benefits for AF-free survival and reduced re-operation rates, however it is yet to be definitively proven in the literature (57).

Limitations

This meta-analysis was not free from limitations, and was most prominently restricted by relative underreporting of surgical patients compared to catheter ablation patients. The discrepancy in patient populations, shown graphically by the wider confidence interval in *Figure 3*, reveals the necessity for further high-quality research to be performed in this cohort. There was also heterogeneity in the ablation technique between studies of the same group for analysis. In the surgical group, included studies used either mini-thoracotomy, thoracoscopy or hybrid ablation, limiting the homogeneity of combined results. In the catheter group, studies reported RF, cryoballoon or mixed cohorts, with similar issues in combined data validity. Finally, when creating the aggregated KM curves, data were obtained from estimated patient data as opposed to real data provided individually by each author. This accounts for the slight error between total patients in *Table 2* and numbers at risk in *Figure 3*.

Conclusions

As depicted in the provided composite KM curve, this systematic review and meta-analysis has shown that despite potentially more complex disease, surgical ablation patients have non-inferior long-term AF recurrence when compared to those undergoing catheter ablation. Recurrence at 12 months as well as procedural time are also similar between these groups, yet with the development of both technologies currently underway and into the future, improvement of these endpoints will likely continue. Ultimately, both ablation methods were able to prevent recurrence of AF in approximately 50% of patients at five years following the procedure.

Acknowledgments

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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Supplementary

Figure S1 RoB2 bar graph and summary for all included studies.

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