An evaluation of the relative success of internal and external electrical cardioversion of atrial arrhythmias in adults, including a comparison of single and dual coil lead devices

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Abstract

Introduction: Although there is a high prevalence of atrial arrythmias in patients with cardiovascular implantable electronic devices (CIED), few studies have compared the efficacy of cardioversion modalities for the restoration of sinus rhythm. The primary aim of this study is to compare the efficacy of internal and external first-time cardioversion for the treatment of atrial arrythmias in patients with an implantable cardioverter defibrillator (ICD), including the relative efficacy of dual and single coil leads.

Methods: Demographic and clinical information was collected and analysed from consecutive electronic records of patients with a CIED who received atrial cardioversion at a single NHS trust between 2008 and 2023. Non-parametric statistical analyses were undertaken to enable the relative success of first-time cardioversion for different modalities to be determined.

Results: 163 patients were identified, of which 71 received external and 92 received internal cardioversion. External cardioversion had the highest first-time efficacy (90.1%) with a statistically significant difference in first-time success between the external and combined internal cohorts (p=.002). Dual coil leads had superior first-time efficacy (80.4%) compared to single coil leads (56.1%), with a statistically significant difference between them (p=.022).

Conclusions: First-time internal cardioversion success is superior for patients with dual coil leads compared to single coil leads. There is no statistical difference between first time success for dual coil internal and external cardioversions, making an initial attempt at internal cardioversion a potentially credible clinical option for patients with dual coil leads.

Key Words: Atrial arrythmia, Internal cardioversion, External cardioversion, Dual coil, Single coil, Sinus rhythm

Introduction

Cardioversion is considered a safe and effective treatment of shockable atrial arrythmias, the most common and clinically significant of which is atrial fibrillation (AF) [1][2]. The incidence of AF has increased by 50% over the last 50 years, such that one in four adults develop AF in their lifetime [3]. It is often concomitant with an increased risk of heart failure (HF) and cardiomyopathies, and is also associated with a twofold increase in risk of myocardial infarction (MI) in addition to a range of other comorbidities [4]. The most significant comorbidity is stroke [5] and patients with persistent AF have a fivefold increase in risk of thrombus formation [6]. The pathogenesis of all atrial arrythmias can be life-limiting which highlights the need for rapid and effective treatment. Successful treatment in populations where atrial arrythmias are more prevalent is needed to reduce clinical burden and to reduce mortality [7].

Swiryn *et al* identified a close relationship between patients with implanted cardiac devices and atrial arrhythmias, particularly a greater prevalence of AF in patients with a CIED [8]. It was found that 50% of patients with implanted cardiac devices also experienced episodes of atrial arrhythmia following implantation which emphasises the need for effective rate control in patients with CIED [9]. Restoration of sinus rhythm in patients with persistent AF can be provided through first line pharmacological treatment, which if unsuccessful, can be followed by electrical cardioversion [10][2]. Patients with persistent AF and an ICD are eligible for internal cardioversion via their ICD or a standard external cardioversion using defibrillator pads [11].

Internal and external cardioversion

Whilst comparisons of internal and external atrial cardioversion techniques are well documented, there is no standard definition of a 'successful cardioversion'[12][13]. The consensus is that the efficacy of external cardioversion is better than internal, although a recent meta-analysis is contradictory as it suggests there is no difference [14]. Despite this, internal cardioversion is often the primary technique for patients with an ICD due to the perceived risk of damage to the implanted device and leads from external cardioversion [15]. Episodes of acute loss of capture (below 200J) and chronic increases in myocardium thresholds from external shocks (above 200J) have been observed, but are uncommon [16]. In recent studies, cases of pulse generator damage are rarely documented [11], but a study of 2582 patients with a CIED who received external cardioversion concluded there was higher incidence of generator replacement or lead reintervention within the first-year post cardioversion [17]. This contrasts with research focusing on short-term device follow ups in smaller cohorts where no device defects occurred provided defibrillation pads were placed in standard anterior-posterior or anterolateral positions and greater than 8cm from the implanted pulse generator [11]. One study recommends that post-cardioversion device interrogation is unnecessary as no complications were observed 3 to 6 months post-cardioversion [19].

Single and dual coil devices

Studies have theorised differences between dual and single coil leads as an additional factor in determining the success of internal cardioversion [19]. There has been widespread implantation of single coil leads as they have been found to have similar efficacy to dual coil leads in internal cardioversion of ventricular arrythmias [20]. Also, there is greater risk of mortality when dual coil leads are extracted due to the likelihood of the superior vena cava being restricted by lead fibrosis of the proximal coil [21][22]. However, analysis of the relative success of single and dual coil leads in atrial cardioversion has been relatively overlooked and there is an absence of large-scale studies comparing single and dual coil lead efficacy of first-time cardioversion. Studies of small cohorts note the poor efficacy of single coil leads in patients with internal cardioversion when compared to dual

coil leads [19]. It is postulated that this poor efficacy is a result of the shock vector of a single coil lead (RV coil to can) capturing less atrial myocardium than dual coil leads (RV coil to SVC coil).

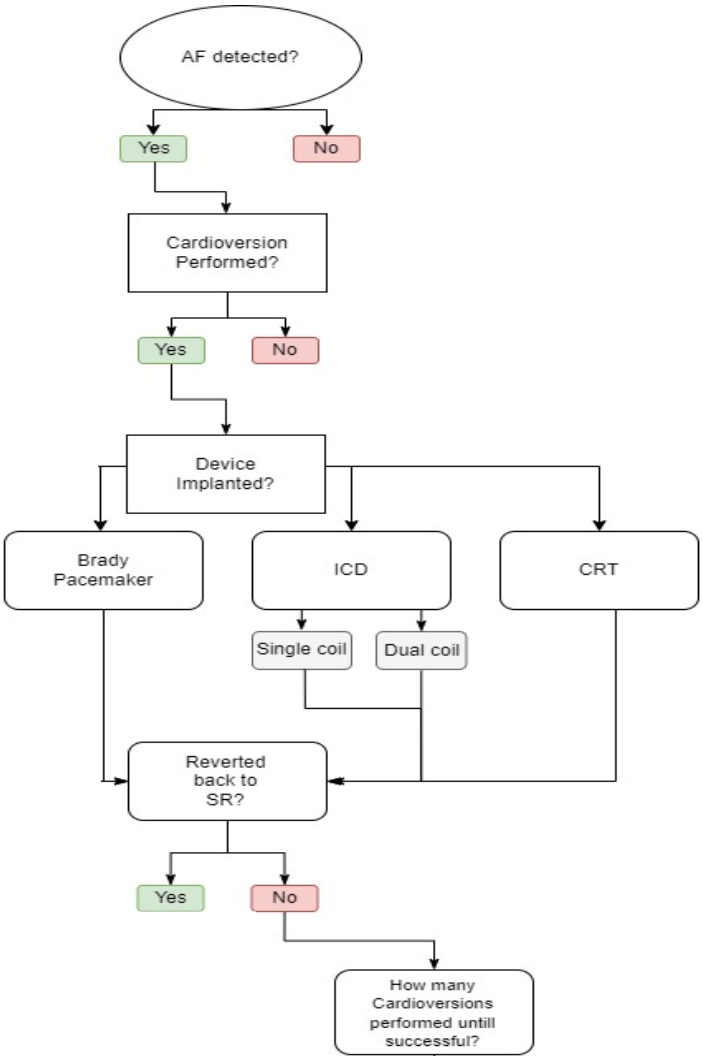
Discrepancies between published studies, along with the lack of NICE guidance on cardioversion in patients with ICDs [10], mean that clinical practice is often based on practitioner judgment. Despite previous studies disputing its effectiveness, and evidence for the superior efficacy of external cardioversion, internal cardioversion for patients with an ICD is routinely used to mitigate the risk of damage to the implanted device/leads by external cardioversion [11]. Therefore, the primary aim of this study is to determine the relative effectiveness of first-time internal and external cardioversion for the treatment of atrial arrythmias in patients with an implanted CIED. The secondary aim is to assess the relative success of internal devices with single or dual coil leads. The objectives are, firstly, to identify variation in first-time cardioversion success for different cohorts of patients with an ICD, and, secondly, to determine the reasons for such variation.

Methods

Following ethics approval, retrospective analysis was undertaken of consecutively sampled patients with CIEDs who had undergone elective electrical cardioversion for atrial arrythmia at a single NHS foundation trust between the January 2008 (the earliest date of an internal cardioversion recorded) and May 2023. This sampling technique enabled the whole population of interest to be included in the study. The electronic records of patients were accessed, anonymised and divided into two cohorts according to cardioversion modality (i.e. internal or external). The type of implanted device was recorded, including the type of ICD shock lead where present. The number of shocks delivered before the patient reverted to sinus rhythm was also noted to enable relative success of cardioversion to be determined (Figure 1). In the external cardioversion cohort, defibrillation pads had been placed in standard anterolateral positions on the right sternal edge off the second intercostal space with the lateral pad placed on the left chest at the fifth intercostal space on the midaxillary line. All cardioversions were delivered using a biphasic waveform with synchronous shock delivery.

High voltage (HV) coil impedance and joules used were recorded to assess whether these variables influenced success of cardioversion. The primary endpoint of a 'successful first-time cardioversion' was defined as the termination of atrial arrythmia and return to sinus rhythm following the first shock delivered from either an ICD or external defibrillator. Termination of atrial arrythmia was defined as the patient leaving the operating room still in sinus rhythm. Demographic data were also collected to describe the sample population. Exclusion criteria for the evaluation included patients under the age of 18 on the day of cardioversion, non-elective cardioversions and patients with non-atrial arrythmias as they were not in scope.

Figure 1: Flow chart showing criteria for selection of patients within inclusion criteria



Data were recorded and analysed in the SPSS software programme (version 29.0). Descriptive statistics for continuous variables were used to describe the sample population. Categorical descriptors were displayed as number and percentages. Non-parametric statistical tests were also undertaken, including the Mann-Whitney U test which was used for continuous variables to compare cohorts. The Fisher's exact test and Chi-squared test of independence were performed to determine whether differences between two categorical variables were statistically significant. A *p*-value of <0.05 was considered statistically significant.

Results

In total, 163 patients met the criteria for this analysis in whom 201 cardioversion shocks were delivered. (Table 1).

Dual coil leads accounted for 31.3% of patients, single coil leads for 25.1% and external cardioversion for 43.6% of patients. Internal cardioversion was delivered to 92 patients (56.4%) via their ICD or CRT-D, whilst 71 (43.5%) patients with an implanted CIED received external cardioversion (Table 1). The remaining external cardioversion patients (66, 40.5%) had a standard bradycardia pacemaker with no implanted shock lead to enable internal cardioversion.

Table 1: Demographic and clinical characteristics of the population by modality of cardioversion performed

Descriptors		Modality Of Cardioversion			
		Internal		External	
		Dual Coil (n= 51, 31.3%)	Single Coil (n= 41, 25.1%)	(n= 71, 43.6%)	Total (n= 163)
Age (Years)	Mean	75.44	69.15	78.70	75.28
	Std. Deviation	9.99	10.78	8.69	10.33
Gender	Male (n)	44	38	49	131
	(%)	86.3%	92.7%	69.0%	80.4%
	Female (n)	7	3	22	32
	(%)	13.7%	7.3%	31.0%	19.6%
Ethnicity (%)	White British	100%	100%	95.8%	98.2%
	White Other	0%	0%	2.8%	1.2%
	Unknown	0%	0%	1.4%	0.6%
Device Type (n)	ICD	21	21	3	45
	CRT-D	30	20	2	52
	PPM	N/A	N/A	56	56
	CRT-P	N/A	N/A	10	10
Device Make (n)	Biotronik	0	0	26	26
	Boston Scientific	4	13	6	23
	Guidant CPI	5	3	0	8
	Medtronic	38	19	13	70
	Sorin	0	0	6	6
	St Jude	4	6	20	30
First Time Cardioversion Success?	Yes (n)	41	23	64	128
	(%)	80.4%	56.1%	90.1%	78.5%
	No (n)	10	18	7	35
	(%)	19.6%	43.9%	9.9%	21.5%
Maximum Joules used (J)	Mean	35.46	37.05	165.49	92.50
	Std. Deviation	2.34	4.15	23.29	66.38
Pre Shock HV Coil Impedance (Ohms)	Mean	42.94	62.20	N/A	51.52
	Std. Deviation	7.92	14.41	N/A	14.73

First-time cardioversion was successful in 128 (78.5%) patients (Table 1). The external cardioversion cohort had the highest percentage of first-time success (90.1%, 64 patients) compared to the combined single and dual coil internal cardioversion cohorts (69.6%, 64 patients). The Fisher's exact test demonstrated that there is a statistically significant difference between first-time success for the combined internal and external cardioversion cohorts (p= .002). Failure to shock, lead dislodgment and device damage were not identified in any of the patients as reasons for failed cardioversion.

Dual coil leads had first-time efficacy of 80.4% with 41 of 51 patients being successfully cardioverted. The first-time efficacy of single coil leads was notably lower (56.1%). The Fisher's exact test showed a notable statistically significant difference success rate between single and dual coil leads (p= .022). To further assess the most successful modality for cardioversion, external cardioversion was compared with internal dual lead cardioversion. There is not a statistically significant difference between external and dual coil internal first-time cardioversion success as demonstrated by the Fisher's exact test (p= .184).

The Mann-Whitney U test shows a statistically significant difference between HV coil impedances of the dual and single coil groups (p= <.001). Figure 2 demonstrates two patients in the dual coil cohort had an out-of-range HV impedance, with one patient not being cardioverted first-time. Figure 3 demonstrates that all patients within the single coil cohort had in-range HV coil impedances.

Figure 2: A scatter plot of patients HV impedance prior to first cardioversion attempt by age for dual coil leads

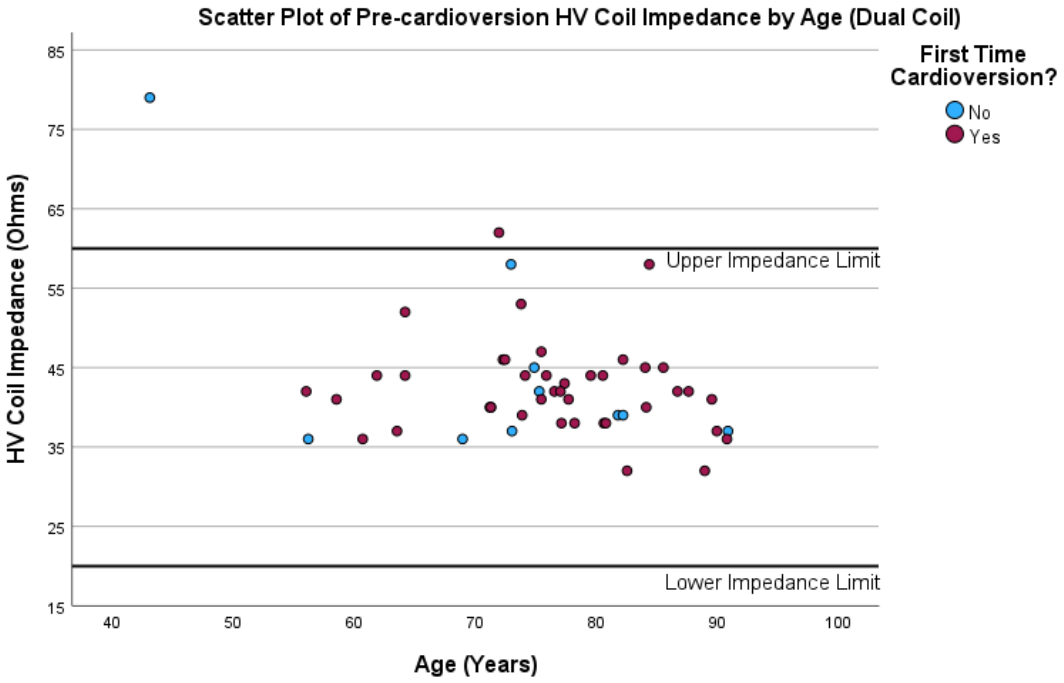
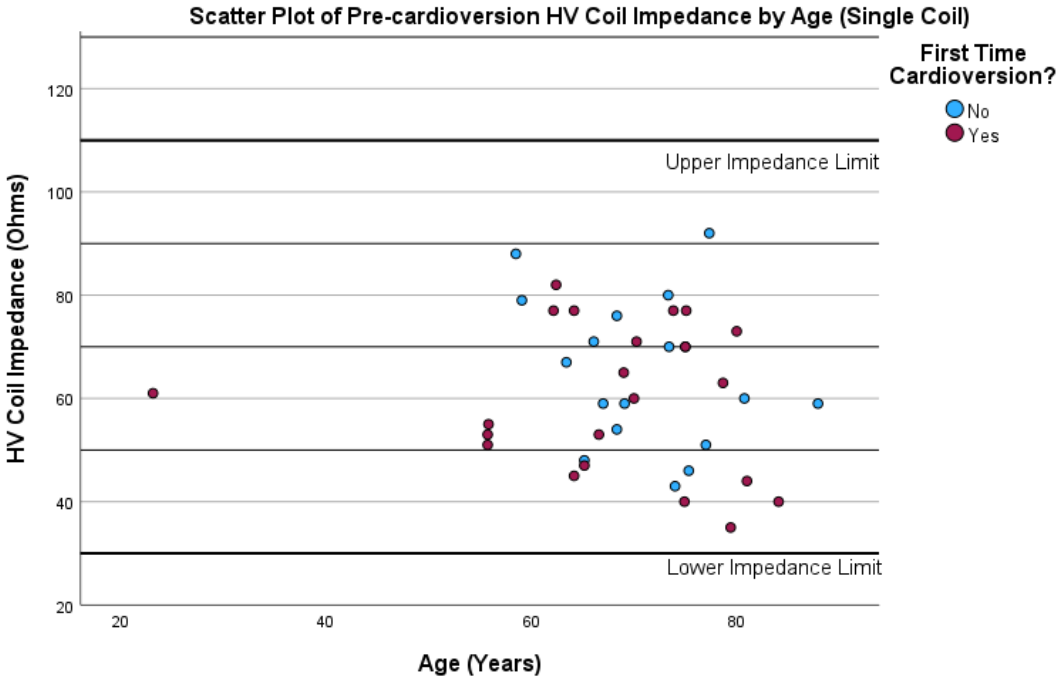
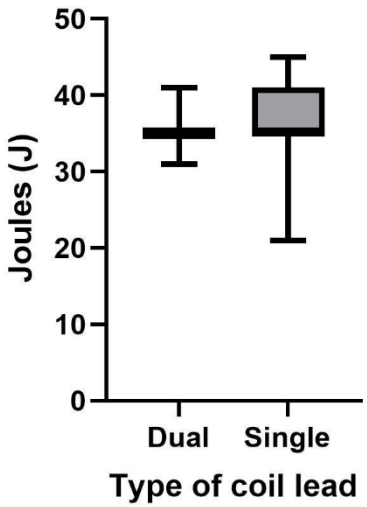


Figure 3: A scatter plot of patients HV impedance prior to first cardioversion attempt by age for single coil leads



The Mann-Whitney U test demonstrated a statistically significant difference between the maximum energy used and each of the modality comparisons. However, Figure 4 demonstrates that, whilst the upper and lower limits for energy used is greater and positively skewed for single coil leads, the median values are similar. Ramping up of joules used was also noted, if first time cardioversion was unsuccessful. A further Chi-squared test of independence indicated no statistically significant association (x^2(6,N=88 , *p*= .094) between the energy used and internal cardioversion success for single and dual coil devices.

Figure 4: Box and whisker plot showing the spread of maximum amount of joules used before successful cardioversion



There was a notable statistically significant difference between the age of combined internal and external cohorts as demonstrated by the Mann-Whitney U test (*p*= <.001) and for the single/dual coil cohorts (*p*= .002). However, this was not the case for the dual coil and external cohorts (*p*= .068). The Fisher's exact test showed a highly statistically significant difference between gender in the combined internal and external cardioversion (*p*= .002) and the external and internal dual coil cohorts (*p*= .032). However, there was no statistically significant difference between gender within the single and dual coil cohorts (*p*= .503). There is no statistically significant difference between ethnicity and any of the cohorts.

Discussion

This study aims to compare the relative effectiveness of first-time internal and external defibrillation for the treatment of atrial arrythmias in patients with an implanted CIED, including the efficacy of single and dual coil leads. This is important as cardioversion is a common procedure, but there is no agreed protocol to support clinical decision-making and maximise the likelihood of first-time success. In addition, use of the most effective modality reduces patient discomfort associated with delivery of unnecessary additional shocks and improved clinical outcomes, as well as device damage and battery depletion from multiple shocks in modalities with low efficacy.

Comparison of combined internal and external cardioversion cohorts

The results indicate that first-time external cardioversion is more successful than for the combined internal cardioversion cohort in patients with a CIED with success rates of 90.1% and 69.6% respectively. This result is statistically significant (p= .002).

These findings align with those of Lüker *et al*. (2019) who concluded that external shock efficacy in a sample size of 230 patients was 93%, compared to 65% for internal [11]. Elayi *et al*. (2020) and Limantoro *et al*. (2013) also draw similar conclusions but from smaller sample sizes and Elgaard *et al* [25] . (2023) suggest that internal cardioversion may be less effective due to high lead impedances, silent lead malfunction or less effective shock vectors [11][17][19]. However, Sugimoto and Taniguchi (2020) dispute the validity of Lüker *et al*.'s findings because Lüker *et al.* compared first-time internal cardioversion with multiple-shock external cardioversion success [11][13]. In contrast, Sunman *et al*. (2016) and Aggarwal *et al*. (2020) conclude there is no statistical difference between internal and external cardioversion success [23][14]. However, the current study supports the proposition that first-time external efficacy is superior to internal for the combined internal cohort.

Whilst external cardioversion is more effective, there may be negative impacts from the high energy associated with external shocks (e.g. patient discomfort, device failure) [15][24][8]. Despite reduced efficacy, cardioversion using an implanted device is easier, less traumatic for patients due to lower amount of energy delivered and carries a lower risk of endocardial damage [23]. NICE (2021) guidance does not specify which modality should be used in patients with a CIED and choice is often left to clinician judgement [10].

Comparison of single and dual coil leads

First-time internal cardioversion for patients with dual coil leads is more successful than internal cardioversion for patients with a single coil lead (80.4% (*n*=41) and 56.1% (*n*=23) respectively). This result is statistically significant (*p*= .022) and suggests that, to maximise the likelihood of first-time internal cardioversion success, it may be more appropriate to implant dual coil leads rather than a single coil lead. However, consideration must be given to other risk factors associated with dual coil leads (e.g. higher mortality in lead extraction)[22]. Additionally, where a single coil lead is implanted, it may be more effective to use external cardioversion to maximise the likelihood of first-time success.

There is a lack of published research with the primary aim of assessing the efficacy of single and dual coil leads in first-time cardioversion of atrial arrythmias. Whilst the primary aim of the study by Limantoro *et al*. (2013) was to compare the efficacy of internal and external first-time cardioversion in 27 patients, the efficacy of single and dual coil leads was investigated as a secondary aim [25]. Limantoro *et al*. (2013) concluded that efficacy of dual coil was 75% (*n*=4), compared to 26% for single coil (*n*=23) [25]. However, their small sample size means these results are not statistically significant. Lüker *et al*. (2019) also compared single and dual coil first-time cardioversion efficacy, but the results were not statistically significant [11].

For the internal cardioversion cohorts, there was no statistical difference between first-time success and the joules used, suggesting this is not a reason for poor cardioversion efficacy. Also, all but two pre-shock HV impedances were in range (Figures 3 and 4) suggesting HV coil impedance was not a reason for poor cardioversion efficacy. Therefore, it can be assumed that the difference in efficacy is due to the type of lead implanted. The contrast in efficacy between dual and single coil leads is perceived to be due to the difference in shock vector between the single and dual coil leads, with more atrial myocardium being captured in cardioversions with a dual coil lead increasing the chance of restoration of sinus rhythm [19].

Comparison of internal dual coil to external cardioversion

The first-time efficacy of dual coil internal cardioversion and external cardioversion was compared which demonstrated there was no statistical significance between their success (p= .184). Published studies have not statistically compared these modalities, so the relevance and applicability of these findings cannot be compared and evaluated. The results suggest that internal cardioversion for patients with dual coil leads could be considered as an alternative to external cardioversion and, for this reason, implantation of dual coil leads should be considered for patients with a high likelihood of future atrial cardioversions.

However, it is important to consider whether other factors influenced the differences between the modality cohorts. There is a statistically significant difference in age between modalities for all three modality comparisons which could introduce bias into the study and provide an alternative explanation for the differences in first-time success efficacy. However, there is a lack of published literature on age and first-time cardioversion success, although Bonfanti *et al*. (2019) suggest that external cardioversion success gradually decreases with increased age, and Ahmed *et al*. (2021) found there was no relationship [26][27]. Consequently, it is not currently possible to assess whether age is a key factor explaining first-time cardioversion success efficacy. Ethnicity did not influence first-time success as there was no statistically significant difference for any of the modality comparisons, as is

the case for gender in the dual and single coil cohorts. However, there is a statistically significant difference between gender for the combined internal/ external cohorts and dual/external cohorts. However, literature on gender and cardioversion success suggests there is no relationship between the two [28][29].

Limitations

Limitations associated with the current study include not being able to assess consistency of practitioner decision making on choice of modality or to compare clinical practice. For example, despite hospital and national guidance, it cannot be determined whether defibrillator pads were placed accurately on each patient. In addition, other factors not assessed in this study can impact the success of cardioversion, including body mass index [30][31]and length of time a patient has been in AF [1] which were not included within this study. Patients with ICDs may also represent different populations in whom the efficacy of cardioversion is lower. The results may not be replicable in larger populations or those with different demographic characteristics. These are areas of potential improvement for future studies.

Conclusion

The efficacy of first-time external cardioversion in patients with atrial arrhythmias was superior for restoration of sinus rhythm when compared to patients in the combined internal cardioversion cohort. Furthermore, first-time internal cardioversion success was superior in patients with dual coil leads, when compared to those with single coil leads. There was no statistical difference between the efficacy of first-time dual coil internal and external cardioversion. This suggests that internal cardioversion for patients with dual coil leads could be considered an alternative to external cardioversion, and, for this reason, implantation of dual coil leads should be considered for patients with a high likelihood of future atrial cardioversions. These findings are important as the predicted increased prevalence in AF and associated implantation of ICDs means that cardioversions will be an

increasingly common procedure. Consequently, to support the development of standardised clinical practice, future research is required to test whether the current results are replicable in larger populations or those with different demographic characteristics.

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