Table 2: Continued

Study (year)	Country	Single/ multicentre	N	Mean age (years)	Males (%)	Clinical setting	EF (%)	Mapping system	Mapping type	Acute success/ definition of success	Complications (n)	Catheter	Follow up (months)	Recurrence at follow up (%)	Endo or epi or both	Fluoroscopy time (min) mean±SD
Yamashina et al. (2010)[67]*	Japan	Single	33	45.5	36.4	Outflow tract VT	n/a	CARTO (Biosense Webster)	Activation and pace	87.9% (absence of any spontaneous or induced clinical RVOT arrhythmias and no recurrence of any symptomatic ventricular arrhythmia)	None	NaviStar (Biosense Webster) catheter	2	6.1%	Endo	n/a
Tovia-Brodie et al. (2016)[68]	Israel	Single	18	60	66.7	Idiopathic (77.8%) and ischaemic VT (22.2%) (complete abolition of the clinical ventricular arrhythmia or non-inducibility of ischaemic ventricular tachycardia)	48.6	CARTO Segmentation Module software (Biosense Webster)	Activation, pace and substrate mapping	Idiopathic: 78.6% and ischaemic: 100%	None	3.5 mm open-irrigated catheter (ThermoCool, SmartTouch; Biosense Webster)	n/a	n/a	Endo and epi for ischaemic VT	Ischaemic: 20.9±8.8 min and idiopathic: 22.95±12 min
Verma et al. (2005)[69]	USA	Single	22	41	68	ARVC	55	CARTO mapping system (Biosense Webster Inc.)	Voltage and pace	18 (82%) (non-inducibility of ablated VT or other sustained monomorphic VT)	Cardiac tamponade (1) and femoral haematoma (2)	7F 4 mm-tip deflectable ablation catheter (NaviStar; Biosense Webster Inc.)	37 med	36.4	Endo	83±47
Satomi et al. (2006)[70]	Japan	Single	17	47	76.5	ARVC	n/a	CARTO	Activation, voltage and pace	88%† (no monomorphic VT was inducible)	No major complications	7F mapping/ablation catheter (NAVI-STAR; Cordis-Webstar, Johnson & Johnson)	26	23.5	Endo	n/a
Rhythmia mapping system																
Martin et al. (2019)[71]	EU	Multicentre	27	64.3	85.2	Ischaemic and dilated CMP	36	Rhythmia	Substrate, activation, entrainment and pace	92.3% (non-inducibility)	No complications	Orion mapping catheter (Boston Scientific)	51.6	18.5	Endo–epi	44.4±12.4
Nührich et al. (2017)[72]	EU	Single	22	67	n/a	Ischaemic and non-ischaemic, ARVC	36	Rhythmia 3D electro-anatomical mapping system (Boston Scientific, Marlborough, MA, USA)	Voltage and activation	87% (non-inducibility)	Tamponade (n=1)	ThermoCool, D- or F-Type, 2–5–2 mm spacing (Biosense Webster) or Intella NAV OI; (Boston Scientific)	4	10	Endo–epi	20.7±1.6
Sultan et al. (2019)[73]	EU	Single	32 (VT 15 patients and VE 17 patients)	63	90.6	Different clinical settings including ischaemic CMP and myocarditis	47,2	IntellaMap Orion™ Mapping Catheter (Boston Scientific Corporation) in combination with the Rhythmia™ mapping system (Boston Scientific Corporation)	Activation, pace, substrate and entrainment	100% 9no inducibility)	Femoral haematomas (n=3)	Quadripolar diagnostic catheter (Inquiry™, 5 F, Fa.; Abbott), decapolar diagnostic catheter (Inquiry™, 6 F, Fa.; Abbott)	6	20	Endo	23.4±13.7
Viswanathan et al. (2016)[74]	EU	Single	19 (VT: 12 patients and VE: 7 patients)	64	79	Ischaemic and non-ischaemic CMP, congenital HD, hypertrophic CMP and normal	35	Rhythmia (Boston Scientific Inc.)	Activation	VE: 6/7 (86%) VT procedures: 8/13 (61.5%) complete success (non-inducibility)	Femoral pseudoaneurysm (n=1) and groin haematoma (n=1)	64-electrode mini-basket mapping catheter (IntellaMap Orion™; Boston Scientific Inc.)	10	VT 25% VE: 14.3%	Endo–epi	41.8±17.5
NavX–EnSite–CardioInsight mapping systems																
Lee et al. (2019)[75]	Taiwan	Single	28 (24 PVC and 4 VTs)	48.8	42.9	RVOT PVCs or VT	70	EnSite NavX or Velocity V5.0 3D mapping system (Abbott)	Voltage, pace and activation	78.6% (at least an 80% decrease in PVC burden by 24 h Holter ECGs 3 months later after ablation)	1% pericardial effusion	7F 4 mm quadripolar irrigated ablation catheter or a 7F 4 mm or 8 mm non-irrigated ablation catheter	3	21.4	Endo	n/a

Continued

Table 2: Continued

Study (year)	Country	Single/ multicentre	N	Mean age (years)	Males (%)	Clinical setting	EF (%)	Mapping system	Mapping type	Acute success/ definition of success	Complications (n)	Catheter	Follow up (months)	Recurrence at follow up (%)	Endo or epi or both	Fluoroscopy time (min) mean±SD
Nayyar et al. (2013)[76]	Australia	Single	22	67	95	Ischaemic CMP	32	EnSite NavX (St. Jude Inc.)	Entrainment and pace	64%(no inducible VT after ablation, abolition of ≥1 clinical VTs with other VTs remaining inducible was considered a partial success and the inability to eliminate the clinical VT was considered as a failure)	n/a	3.5 mm tip irrigated ablation (CoolFlex [St. Jude] or ThermoCool [Biosense Webster]), 20-pole catheter (PentaRay; 2–6–2 mm interelectrode spacing) and 1 mm electrodes (Biosense Webster, Inc.)	16	22.7	Endo	n/a
Miyamoto et al. (2010)[77]	Japan	Single	55	52	49%	Organic heart disease: 7 patients and idiopathic VT: 48 patients	n/a	EnSite version 3.0 in 20 patients and version 6.0J in 35 patients	Voltage, substrate, activation and entrainment	95% (sustained VT was VT termination, subsequent non-inducibility of VT for focal VT and non-inducibility for non-sustained focal VT and PVC)	No complications	Quadripolar electrode catheter, 20-pole multielectrode catheters (St. Jude Medical, Minnetonka, MN, USA/Ten-Ten, St. Jude Medical)	21	-	Endo	30±21
Nair et al. (2011)[78]	India	Single	15	44	80	ARVC	n/a	EnSite array mapping and non-contact electroanatomical mapping	Activation, entrainment and pace	86.7% (all of the inducible VTs were successfully mapped and ablated)	No complications	-	25	13.3	Endo	n/a
Hocini et al. (2015)[79]	EU	Multicentre	24	45	58	Idiopathic PVCs and PVCs in the setting of HCM and ischaemic CMP	58.4%	3D mapping technique (ECVUE; CardioInsight Inc.)	Activation	100%	None	Quadripolar mapping catheter) and 4 mm tip ablation catheter (Biosense Webster)	24.7	4.2	Endo	8.8±1.5

**These were similar cohorts and, therefore, were included once in the quantitative synthesis.*
†The percentage refers to the number of successfully ablated VTs.
ARVC = arrhythmogenic right ventricular cardiomyopathy; CMP = cardiomyopathy; EF = ejection fraction; endo = endocardial; Epi = epicardial; F = French; HCM = hypertrophic cardiomyopathy; med = median; n/a = not available; PVCs = premature ventricular complexes; RVOT = right ventricular outflow tachycardia; VE = ventricular ectopy; VT = ventricular tachycardia.

Figure 1: Flow diagram of the search strategy.

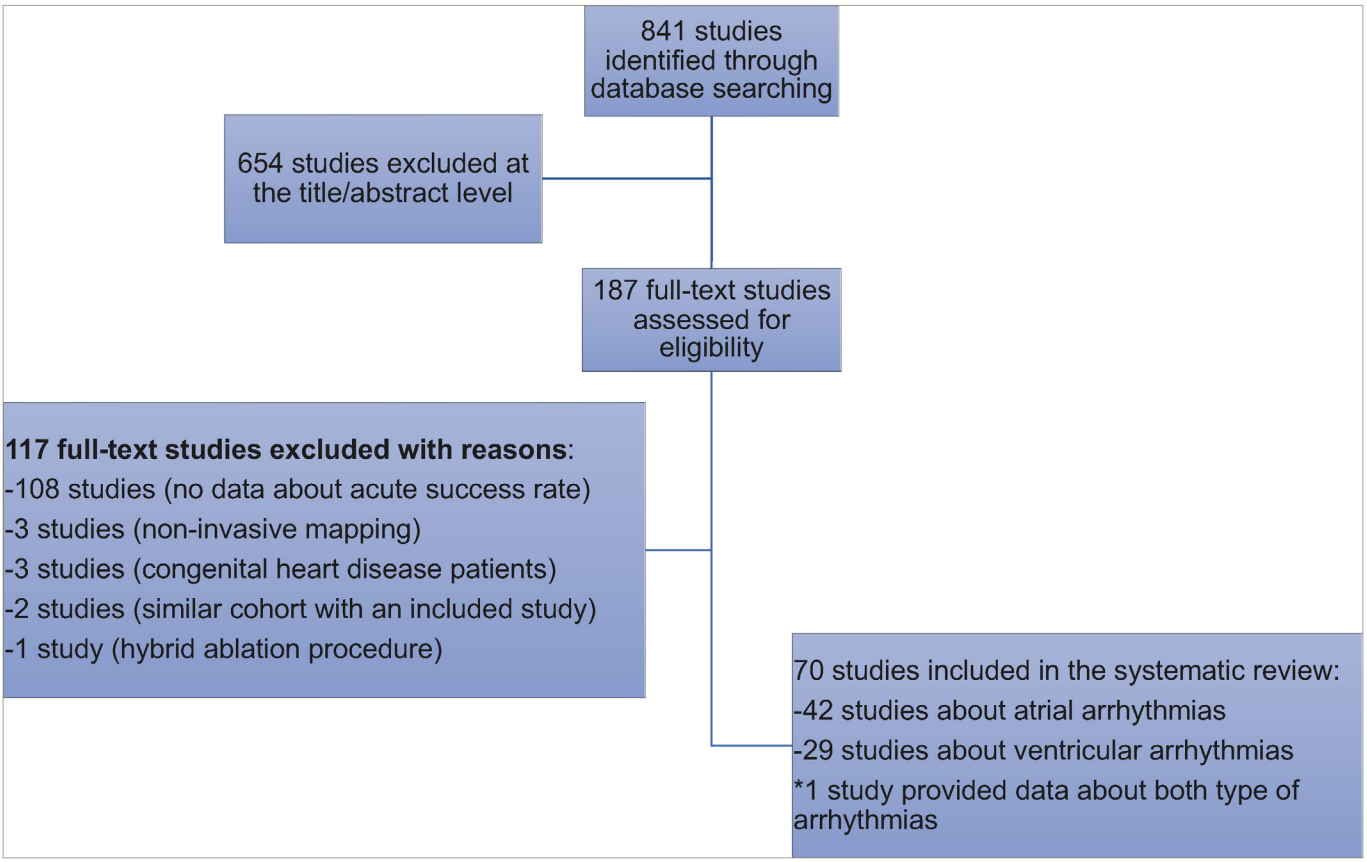
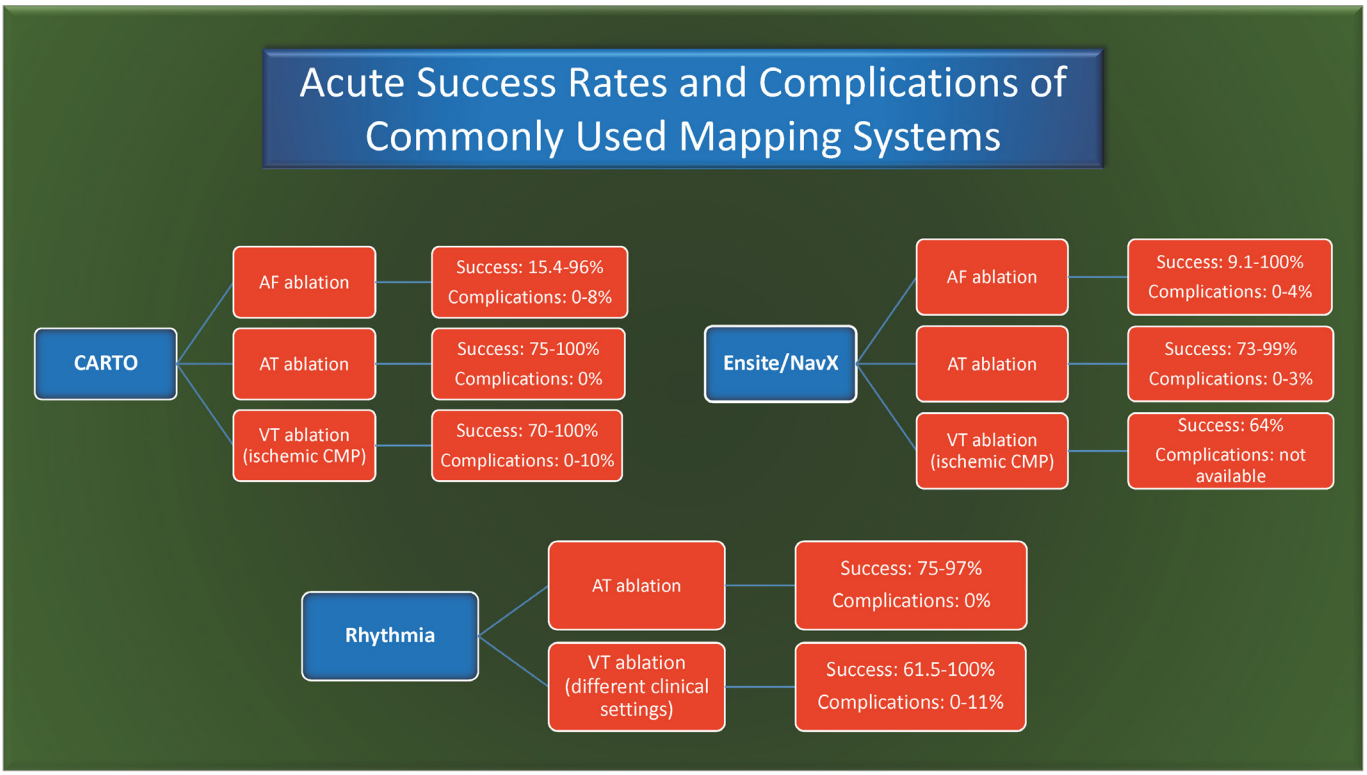


Figure 2: Acute success rates and complications of commonly used mapping systems



AF = atrial fibrillation; AT = atrial tachycardia; CMP = cardiomyopathy; VT = ventricular tachycardia

studies) CA ablation procedures.[52–63] Specifically, the acute success rates are defined as the absence of VT inducibility at the end of the procedure, which ranged from 70 to 100%.[52–63]

Furthermore, the CARTO mapping system showed excellent results with more than 80% acute success rate in outflow tract ventricular arrhythmias and in the setting of ARVC (four and two studies, respectively).[15,65–67,69,70]

Rhythmia mapping system

The search strategy revealed four studies on the acute arrhythmia termination rates using the Rhythmia mapping system in the setting of ventricular arrhythmias (*Table 2*). These studies showed excellent results in abolishing VT and ventricular ectopy in different clinical settings, including ischaemic and non-ischaemic cardiomyopathy, with acute success rates ranging from 61.5 to 100%.[71–74]

EnSite/NavX mapping systems

The search strategy revealed five studies on the success rates of the EnSite/NavX mapping system, mainly in the setting of patients with outflow tract ventricular arrhythmias, ischaemic cardiomyopathy and ARVC (*Table 2*).[75–79] Specifically, acute success rates were found to be 78.6% in patients with outflow tract arrhythmias, 86.7% in patients with ARVC and 64% in patients with ischaemic cardiomyopathy.[75–79]

Discussion

Our review summarizes the acute success rates of the most popular mapping systems across different clinical settings. The existing evidence shows that the most commonly used mapping systems have excellent efficacy regarding acute arrhythmia termination outcomes in both atrial and ventricular arrhythmias, depending mainly on the type of arrhythmia and the clinical setting.

Cardiac mapping is an essential component in the understanding and treatment of arrhythmias through CA procedures. Activation and electrocardiographic signal amplitude mapping are the most frequent modalities in 3D mapping systems, while entrainment mapping can provide additional data in the setting of atrial or ventricular arrhythmias. The commonly used 3D mapping systems such as CARTO (Biosense Webster), EnSite Precision (Abbott) and, more recently, Rhythmia (Boston Scientific) systems have played a major role in enabling and facilitating the high-density mapping of complex arrhythmias.[3] The *in vitro* and *in vivo* accuracy of the CARTO mapping system has been studied since 1997.[84] The CARTO mapping system has been used to guide the ablation procedure in patients with different types of atrial arrhythmias, including AF, AFL and AT.[11–14,16–26,82]

Today, the CARTO 3 system consists of a location pad with three separate low-level magnetic field-emitting coils arranged as a triangle under the patient's body and six-electrode patches positioned on the patient's back and chest. The latest version relies on hybrid magnetic- and current-based localization technologies and has reported an accuracy of less than 1 mm.[3] On the other hand, the current EnSite/NavX navigation and visualization technology consists of a set of three pairs of skin patches and a system reference patch, and uses hybrid impedance-based and magnetic-tracking technologies to create cardiac models or geometries, which display voltage data and activation timing. The Rhythmia mapping system, which uses a hybrid tracking technology using both magnetic- and impedance-based localization features for map creation, was developed as a high-definition system incorporating a high-resolution 64-electrode catheter, 3D ultra-high-density mapping capabilities and an algorithm that automates the signal capture and mapping processes.[3,85]

Each of the mentioned systems, except NavX, uses its catheters for high-density mapping. CARTO 3 uses the PentaRay catheter and the Rhythmia system uses the IntellaMap Orion catheter, while the NavX system allows the operator to use any available catheter.

Single and multielectrode acquisition techniques are clinically effective, whereas a trend towards multielectrode use has been observed in the mapping of complex arrhythmias, such as left AFL and scar-related VT.[86] A pooled analysis of studies that compared fluoroscopy- with non-fluoroscopy-guided ablation of AF and AFL showed that non-fluoroscopic mapping and navigational systems yielded acute success rates not significantly different from fluoroscopy-guided ablation, while navigational systems resulted in a 10% relative reduction in the overall failure rate compared with fluoroscopy-guided ablation for the treatment of AF.[87] Another interesting finding was that mapping systems were shown to reduce the arrhythmia burden and the need for antiarrhythmic drugs in patients with complex arrhythmia following a failed fluoroscopy-guided ablation procedure.[87]

Few studies in the literature have performed direct comparisons of the most commonly used mapping systems. Specifically, Liu et al. performed a direct comparison of CARTO-guided with EnSite/NavX-guided ablation of the PV in AF.[88] They found that compared with the CARTO group, the EnSite/NavX group had a significantly higher acute success rate. Specifically, AF was terminated by radiofrequency delivery in 14 cases (35%) using EnSite/NavX system versus 5 cases (14%) in the CARTO system ($p<0.05$).[88] In addition, complete PV isolation was achieved in 26 cases (65%) in the EnSite/NavX group versus 11 cases (31%) in the CARTO group ($p<0.05$), although contemporary techniques and outcomes have resulted in much higher success rates.[88] On the other hand, Choo et al. did not find a significant difference in acute success rates between CARTO and NavX mapping systems in the setting of paroxysmal or persistent AF CA.[12] In another study, the acute outcomes of AT ablation using standard (CARTO™ and NavX™) versus Rhythmia™ 3D high-density mapping systems were compared; in this setting, acute success rates were found to be similar for any system, leading to around 75% complete and 93% partial acute success rates in a highly selected population.[89] Rottner et al. performed a direct comparison of CARTO and Rhythmia mapping systems in the setting of AF.[90] This study showed that the Rhythmia mapping system had a significantly longer total mapping time, a longer total fluoroscopy time, more delivered RF applications and a longer total RF duration compared with the CARTO system, while there was no difference regarding the total ablation time, total procedure duration and acute procedural success.[90] Another study evaluated the effect of Rhythmia in terms of the outcome of the second ablation for AF compared with the conventional method with an additional anatomical guide by the CARTO system.[91] The authors have found that high-density mapping for the second ablation of AF was superior to the conventional ablation method in terms of the suppression of atrial events.[91] Kaseno et al. evaluated PentaRay®/CARTO® 3 and Orion™/Rhythmia™ in LA voltage mapping.[92] The study showed that the PentaRay map had a shorter procedure time than the Orion map, while a discrepancy in the evaluation of low-voltage areas between PentaRay and Orion maps was revealed.[92]

Finally, it should also be noted that while acute AF termination has been a common goal of AF ablation, in more recent years, the focus is more on a substrate ablation strategy (PVI and often additional ablation), and now the acute completeness of PVI and long-term freedom from arrhythmias are more typical endpoints.[5]

Limitations

We identified only a small number of studies[27–51] on acute arrhythmia termination during CA procedures for the Rhythmia and NavX/EnSite mapping systems, especially in the setting of ventricular arrhythmias. Specifically, no data were revealed by the search strategy about the acute success rates in AF CA procedures using the Rhythmia mapping system, while only one study (Nayyar et al.) provided data about ischaemic VT for the EnSite mapping system.[76] Furthermore, no data on the CardioInsight mapping system were retrieved.

It should be noted that Rhythmia is a more recently developed mapping system compared with CARTO and EnSite; therefore, the studies on Rhythmia included in this analysis are likely to be more recent, compared with studies on CARTO and EnSite and, therefore, could skew the results.

A quantitative synthesis to estimate the pooled success rate of each mapping system was not performed. With regard to AF, beyond PVI, there is no single established strategy; as a result, differences in success rates are also dependent on the ablation strategy. Furthermore, the type of AF (paroxysmal, persistent and long-standing persistent AF) also influences the success rate of the ablation procedure. Similarly, AT ablation is largely dependent on the underlying arrhythmia mechanism, atrial substrate and ablation strategy. With regard to the ventricular arrhythmias, both the type of cardiomyopathy and ablation strategy can influence the ablation outcomes. Ablation for VT is often performed during SR using substrate modification of local abnormal ventricular activities due to the hemodynamic instability associated with the arrhythmia.[93] Therefore, our results cannot be extrapolated to procedures using substrate modification for ventricular arrhythmias.

We chose not to provide data about the procedural time presented in each study because this parameter is dependent on not only the technical characteristics of each system but also the operator's skills. In addition, this review did not focus on the long-term arrhythmia recurrence rate because this marker is highly dependent on patients' comorbidities, post-procedural medications, echocardiographic findings, follow-up strategy for the identification of arrhythmia recurrence, etc. It should be noted that acute success definitions differ slightly among the included studies (*Tables 1 and 2*), and this is an additional limitation that prevents the comparison of the efficacy of the different mapping systems in all clinical settings. Another cause of the noted discrepancy in success rates for each mapping system among the included studies could be related to the new features that were incorporated into each system and the different catheters that were used in the last few years.

Conclusions

Mapping systems have played a crucial role in high-density mapping and the observed high procedural success rates of atrial and ventricular CA procedures. More data are needed about the comparative efficacy of the different mapping systems across different clinical settings. ❑

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