

RESEARCH

Use of the CHA₂DS₂VASc score to reduce utilisation of transoesophageal echocardiography prior to ablation for atrial fibrillation

Charlotte Atkinson MSc, Jonathan Hinton MRCP, Edmund B Gaisie BMBS, Arthur M Yue DM FRCP, Paul R Roberts MD FRCP, Dhruvo J Rakhit PhD FRCP FACC and Benoy N Shah MD MRCP FESC

Department of Cardiology, University Hospital Southampton, Southampton, UK

Correspondence should be addressed to B N Shah
Email
benoy.shah@uhs.nhs.uk

Abstract

Transoesophageal echocardiography (TOE) is frequently performed prior to atrial fibrillation (AF) ablation to exclude left atrial appendage (LAA) thrombus. However, patients undergoing AF ablation are usually anticoagulated, thus making the presence of thrombus unlikely in most cases. This study aimed to determine whether the CHA₂DS₂VASc scoring system can be used to identify patients that do not require TOE prior to AF ablation. In this single-centre retrospective study, local institutional and primary care databases and electronic patient records were searched to identify patients that had undergone TOE prior to AF ablation. Patient demographics, CHA₂DS₂VASc score, TOE findings and anticoagulation status were collected for analysis. Over a 7-year period (2008–2014), 332 patients (age 57 ± 10 years; 74% male) underwent TOE prior to proposed AF ablation. CHA₂DS₂VASc scores of 0, 1, 2 and >2 were found in 39, 34, 15 and 12% of patients, respectively. The prevalence of LAA thrombus was 0.6% (2 patients) and these 2 patients had risk scores of 2 and 4. No patients with a score of 0 or 1 had LAA thrombus. Patients that are classed as low risk by the CHA₂DS₂VASc score do not require a pre-ablation TOE to screen for LAA thrombus provided they are adequately anticoagulated. This would lead to a significant reduction in health care expenditures by reducing unnecessary TOE requests and thereby improve patient experience.

Key Words

- ▶ transoesophageal echocardiography
- ▶ atrial fibrillation
- ▶ ablation
- ▶ anticoagulation
- ▶ thrombus

Introduction

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia in the Western world and is associated with significant morbidity and mortality (1). The presence of AF portends a significant risk of thromboembolism, which can cause ischaemic stroke. Clinical risk scores such as the CHADS₂ and the CHA₂DS₂VASc score have been validated for the use of thromboembolic risk stratification in patients with non-

valvar AF (2). Lip and coworkers (3) showed that the CHA₂DS₂VASc score was superior to the CHADS₂ score at identifying truly low-risk patients – no patients with a CHA₂DS₂VASc score of 0 suffered thromboembolic events, whereas 1.4% of the patients with a CHADS₂ score of 0 did. Accordingly, the CHA₂DS₂VASc has replaced the CHADS₂ score in daily clinical practice when estimating stroke risk.

Patients with symptomatic AF, which is resistant to at least one anti-arrhythmic medication, may be considered for AF ablation. One of the procedural risks of AF ablation is thromboembolic stroke (4) and one potential mechanism for this is dislodgement of thrombus present in the atria by catheters and wires used during the procedure. The thromboembolic risk during an AF ablation procedure is reportedly 0.5–1.5% (5, 6). Heart Rhythm Society (HRS)/European Heart Rhythm Association (EHRA)/European Cardiac Arrhythmia Society (ECAS) recommendations for AF ablation (7) state that patients who are in AF at the time of the ablation should undergo a pre-procedural transoesophageal echocardiogram (TOE) despite anticoagulation status. TOE is the gold standard for thrombus screening in the left atrium (LA) and particularly the left atrial appendage (LAA); TOE has a 93–97% sensitivity and 100% specificity for imaging LA/LAA thrombus when compared to surgical findings (8).

Several studies have shown an increased risk of left atrial thrombus with increasing CHADS₂ score. A large single-centre study on 1058 patients correlated CHADS₂ scores with LA appendage findings: the investigators found a significantly increased risk of thrombus with high CHADS₂ score, no low-risk patients (score of 0) with thrombus, but there were four patients with a score of 1 (intermediate-risk) where thrombus was found (9).

However, there are a paucity of data relating the CHA₂DS₂VASc score, which is superior to the CHADS₂ score (and has replaced it in clinical practice), to LAA appearances on TOE and thus need for pre-ablation imaging. TOE is not performed universally prior to AF ablation procedures; factors that may affect use of TOE include available resources, potential risks of a semi-invasive test and overall low likelihood of thrombus formation in anticoagulated patients. The aim of this study was to determine whether the CHA₂DS₂VASc score can successfully predict the risk of LA/LAA thrombus as identified by TOE. Our hypothesis was that the CHA₂DS₂VASc score could be used in the future to obviate the need for TOE prior to AF ablation on selected low-risk patients, thus improving patient experience and also reducing health care costs.

Methods

Consecutive patients who underwent TOE in preparation for AF ablation in our institution between 2008 and 2014 were included in this study. Patients were excluded if they did not have a pre-procedural TOE, if TOE

images were not available for review or if there were incomplete demographic data to calculate risk scores. Patient demographics, relevant medical history, cardiac medication and TOE data were reviewed using hospital electronic databases retrospectively and CHA₂DS₂VASc and CHADS₂ scores calculated for the time point at which TOE had been performed.

Standard two-dimensional TOE imaging was performed on all patients using commercially available equipment (Philips ie33 ultrasound systems, Eindhoven, Netherlands) and a multi-plane phase array transducer prior to AF ablation. Standard oesophageal intubation, image acquisition and measurements were performed as per European TOE guidelines (10). The LA and LAA were assessed in multiple mid-oesophageal views. Pulsed-wave Doppler imaging was used to measure LAA emptying velocities and colour Doppler imaging used to assess blood flow within the LAA. All TOEs were reviewed and reported by experienced echocardiologists.

The following data were collected from the TOE studies and reports: cardiac rhythm during the study, presence of LA/LAA thrombus and/or spontaneous echo contrast (SEC) in the LA/LAA and LAA emptying velocities. Thrombus was defined as a uniformly echodense intra-cavity mass distinct from the endocardium and pectinate muscle and present in more than one imaging plane; SEC was defined as dynamic ‘smoke-like’ echoes with characteristic swirling motion; and low LAA emptying velocities were less than 40cm/s (11). An abnormal LA/LAA was defined as the presence of one or more of the aforementioned pathologies. The TOE reports were also reviewed for presence of significant mitral valve disease (moderate or severe regurgitation or stenosis) and any impairment of LV systolic function. When thrombus was identified, the ablation was cancelled and the patient treated appropriately as decided by the patient’s cardiologist.

Prior to AF ablation, all patients were anticoagulated with either warfarin or novel oral anticoagulants (NOAC). Patients taking warfarin required a target INR of between 2.0 and 3.0 four weeks prior to ablation. Patients taking NOACs must have been doing so for at least four weeks prior to ablation. All patients included in this study that were taking NOACs stopped their anticoagulation prior to ablation and LMWH was used up until the ablation.

Statistics

Data were reported as mean±s.d., percentage of total population or median and interquartile ranges. To

determine inter-observer variability, twenty TOE studies were selected randomly and retrospectively reviewed independently by two specialist cardiologists who were blinded to the initial report. The TOE studies were assessed for the presence of LA/LAA SEC or thrombus and low LAA emptying velocities. Cohen's kappa statistic was used to describe agreement.

Ethics statement

In accordance with UK guidance from the National Research and Ethics Service (NRES), this study was registered with our NHS Trust as a Service Evaluation for which local institutional approval was sought and obtained.

Results

A total of 346 patients underwent TOE prior to proposed AF ablation, of which 14 patients were excluded due to incomplete data, resulting in a total of 332 patients. The mean age was 57 ± 11 years, 73% were male and 68% of patients had paroxysmal AF: full patient demographics are listed in Table 1. The majority (94.6%) of patients were anticoagulated with warfarin with the remainder (5.3%) with NOACs. Most patients were low-risk, as identified by the CHA₂DS₂VASc score, which can be seen in Fig. 1; over a third of patients had a score of 0 and almost three quarters patients had a score of <2 (i.e. 0 or 1). No patients had a score ≥ 6 .

Thrombus was found in two patients (0.6%). Both patients were female, had persistent AF and had high-risk CHA₂DS₂VASc scores. One patient, aged 63 years, had a score of 2, due to a history hypertension and female gender.

The other patient, aged 56 years, had a score of and 4 on account of a previous TIA, history of diabetes and female gender. Neither of these patients had significant mitral valve disease although one patient had mild LV systolic dysfunction and the other had a history of hypertrophic cardiomyopathy. Both patients were anticoagulated with warfarin; however, one of the patients had a sub-therapeutic INR of 1.5 at the time of the TOE. Images of the thrombus found in the LAA can be seen in Fig. 2. In addition to thrombus, as expected, both patients also had SEC and reduced LAA emptying velocities seen on TOE.

Despite only 2 patients having thrombus identified, there were in total 28 patients (8%) that had SEC and 80 (24%) that had reduced LAA emptying velocities. The majority of patients (73%) had a completely normal LA/LAA as assessed by TOE. There were 89 patients that had an abnormal LAA (either SEC and/or reduced LAA emptying velocities) but without evidence of thrombus. Only 19 patients (6%) had a degree of LV systolic dysfunction and 7 (2%) had an abnormal mitral valve. Table 2 demonstrates the abnormal echo findings according to CHA₂DS₂VASc score.

There were two patients diagnosed with peri-procedural thromboembolic events during the study period. Both patients were anticoagulated with warfarin and both had therapeutic INR readings in the preceding 4 weeks prior to the ablation procedure. Although both patients had SEC in the LA appendage, neither patient had thrombus on their pre-procedural TOE.

Inter-observer variability

To determine the inter-observer variability, 20 patients were selected randomly and the echocardiographic data were re-assessed. Two independent imaging cardiologists

Table 1 Baseline patient demographics.

Demographics	All patients (n=332)	Warfarin (n=315)	NOAC (n=17)
Age (years; mean \pm s.d.)	57.4 \pm 9.8	57.4 \pm 9.8	58.2 \pm 10.5
Male	245 (73%)	228 (72%)	15 (88%)
Congestive heart failure	3 (1%)	3 (1%)	0 (0%)
Hypertension	97 (29%)	91 (29%)	6 (35%)
Diabetes mellitus	16 (5%)	15 (5%)	1 (6%)
Previous stroke/TIA	39 (12%)	36 (11%)	3 (18%)
History of vascular disease	18 (5%)	17 (5%)	1 (6%)
CHA ₂ DS ₂ VASc score (median + IQR)	1 (0–2)	1 (0–2)	1 (0–1)
CHADS ₂ score (median + IQR)	0 (0–1)	0 (0–1)	1 (0–1)
Paroxysmal AF	227 (68%)	213 (68%)	12 (71%)
Persistent AF	105 (32%)	102 (32%)	5 (29%)
Previous AF ablation	92 (28%)	88 (28%)	4 (24%)

AF, atrial fibrillation; IQR, interquartile range; NOAC, novel oral anticoagulant; PAF, paroxysmal atrial fibrillation; s.d., standard deviation; TIA, transient ischaemic attack.

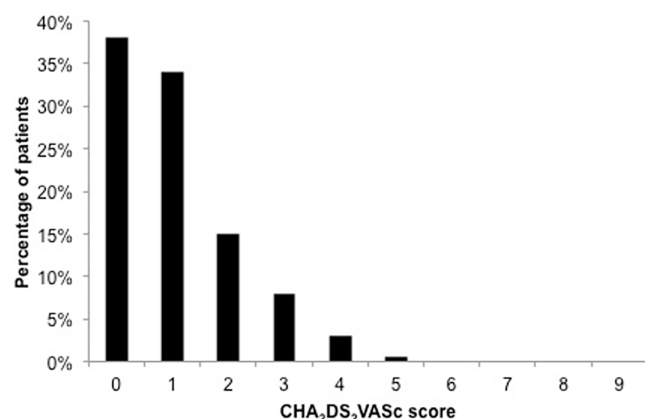


Figure 1

CHA₂DS₂VASc scores (n332). 39% (128 patients) scored 0; 34% (113 patients) scored 1; 15% (50 patients) scored 2; 8% (27 patients) scored 3; 3% (12 patients) scored 4; 0.6% (2 patients) scored 5 and no patients had a score of 6 or more.

retrospectively reviewed the TOEs in a blinded manner for LA/LAA thrombus, SEC and reduced LAA emptying velocities. The overall agreement for the presence of thrombus was excellent (100%, $k=1.00$).

Discussion

The principal findings of this study are that thrombus prevalence in anticoagulated patients undergoing TOE prior to AF ablation is very low (0.6%) and that no patients with a CHA₂DS₂VASc score of 0 or 1 had LA/LAA thrombus. All patients with LA/LAA thrombus had a high-risk (≥ 2) CHA₂DS₂VASc score which, therefore, had a 100% sensitivity for prediction of LA/LAA thrombus.

The presence of LA/LAA thrombus is associated with thromboembolic events, particularly stroke and TIA, in patients with AF (12). One of the most significant risks associated with AF ablation is that of thromboembolism. This study has demonstrated a very low prevalence (0.6%) of LA/LAA thrombus in patients undergoing AF ablation. These results are consistent with other studies with similar cohorts of patients (mean age 57–60 years, majority (64–80%) male, all undergoing TOE prior to AF ablation, with similar anticoagulation protocols) who also found thrombus prevalence to be between 0.5% and 2.3% (9, 13, 14).

There have been studies that have found much higher thrombus prevalence; however, in these studies, the patient cohort and anticoagulation protocols were different. For example, a study by Yarmohammadi and coworkers (15) found a thrombus prevalence of 11.8% in a study of 541 patients awaiting cardioversion, but these patients had no anticoagulation at all. Similarly, a further study by Yarmohammadi and coworkers (16) identified a thrombus prevalence of 6% in a group of 2369 patients undergoing cardioversion who had been anticoagulated with warfarin but many had a sub-therapeutic INR. In this current study, all patients received oral anticoagulation for at least 4 weeks prior to TOE, with a target INR of between 2.0 and 3.0. These differences in thrombus prevalence, despite differences in patient cohorts, highlight the importance of appropriate anticoagulation when considering LA/LAA thrombus.

Nevertheless, from this study and others, it is evident that despite therapeutic anticoagulation, there is still a slim chance of thrombus formation in certain AF patients. One patient in this study with LA/LAA thrombus had a

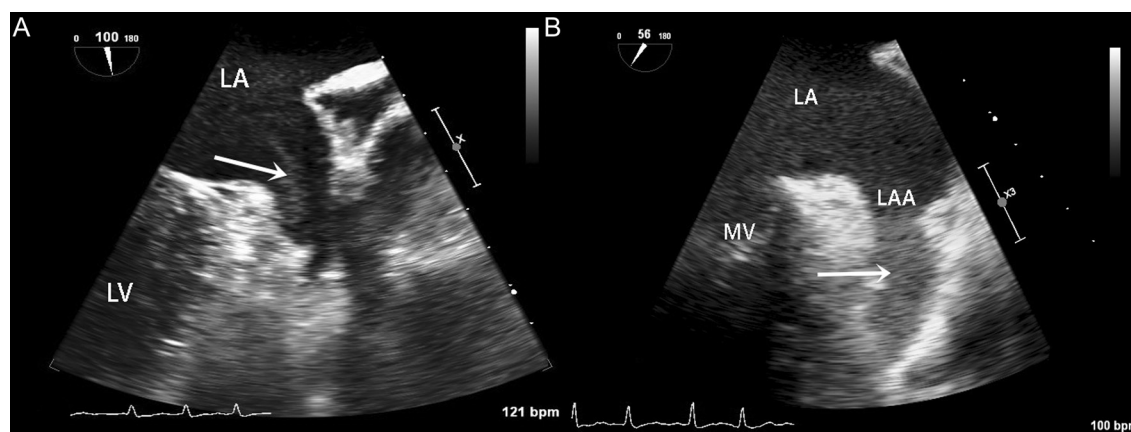


Figure 2

LA appendage appearances on TOE from both patients with thrombus (arrows) in the study. LA, left atrium; LAA, left atrial appendage; LV, left ventricle; MV, mitral valve.

Table 2 Table of abnormalities by CHA₂DS₂VASc score.

CHA ₂ DS ₂ VASc score	n	Thrombus	Spontaneous echo contrast (%)	Reduced LAA velocity (<40 cm/s) (%)	LV systolic dysfunction (%)	Abnormal MV structure/function (%)
0	128	0	8	24	5	3
1	113	0	4	19	10	5
2	50	1	12	38	8	4
3	27	0	7	22	7	11
4	12	1	33	25	8	8
5	2	0	50	0	100	0

LAA, left atrial appendage; LV, left ventricle; MV, mitral valve.

sub-therapeutic INR (1.5) at the time of TOE. However, the other patient had a therapeutic INR of 3.1 and LA/LAA thrombus was still present. Puwanant and coworkers (9) demonstrated similar findings in their study of 1058 patients where 6/8 patients with LA/LAA thrombus had a sub-therapeutic INR, whilst the other two patients with thrombus had INRs of 2.5. These data demonstrate that therapeutic anticoagulation with warfarin, although important, does not eliminate the risk of thrombus formation in patients with AF.

Although most patients were anticoagulated with warfarin, 5.3% (17 patients) were taking NOACs. The safety and efficacy of NOACs and their use prior to AF ablation is well established (17, 18, 19) and guidelines currently recommend at least three weeks of NOAC therapy prior to ablation (20). None of the patients in this study taking a NOAC had LA/LAA thrombus; their demographics were comparable to the rest of the population, and the CHA₂DS₂VASc scores ranged from 0 to 5, similar to the population on warfarin. This finding is consistent with other studies that have shown that the incidence of thrombus in patients undergoing pre-ablation TOE is either similar (21) or less (22) than those patients on warfarin.

In addition to anticoagulation, most patients in this cohort were classed as either low (39%) or intermediate-risk (34%) with a CHA₂DS₂VASc score of 0 or 1, respectively. This is consistent with data from studies by Scherr and coworkers (23), Puwanant and coworkers (9), and Herring and coworkers (14) who all found that nearly half of their patients (50, 47 and 42.5% for each study, respectively) undergoing TOE prior to AF ablation had a CHADS₂ score of 0.

In our study, both patients with LA/LAA thrombus had persistent AF. There is no clear consensus on whether type of AF (i.e. paroxysmal vs. persistent) can be used to determine need for TOE. The 2007 HRS Task Force (7) suggested that TOE should always be performed in patients with persistent AF despite anticoagulation status,

whereas patients with PAF and in sinus rhythm during the ablation would not require a TOE. However, the results from the large study by Puwanant and coworkers (9) identified two patients with LA/LAA thrombus or sludge who had PAF and were in sinus rhythm at the time of the TOE. These results highlight that simply using the clinical history of AF and the rhythm at the time of the ablation is not sufficient to exclude the risk of LA/LAA thrombus. Unfortunately, due to conflicting results in recently published studies (14, 23, 24, 25), the updated HRS guidelines (26) were not able to offer further evidence-based clarification on these guidelines.

The current study has demonstrated that there were no patients with a CHA₂DS₂VASc score of 0 or 1 with LA/LAA thrombus; this agrees with several other studies (14, 27, 28) as listed in Table 3. A study by Nishikii-Tachibana looked at 541 Japanese patients undergoing TOE before AF ablation and demonstrated that there were no patients with a CHA₂DS₂VASc score of 0 with LA thrombus; however, there were four patients (2.8%) with a CHA₂DS₂VASc score of 1 with LA/LAA thrombus, despite therapeutic oral anticoagulation with warfarin (29). Interestingly, this study found a relatively high thrombus prevalence of 6.4%, which they attribute to a higher proportion of patients with persistent AF than other studies; however, it is relatively similar to those reported in this study (38% and 32%, respectively). It is more likely that their population had a larger proportion of high-risk patients (58% have CHA₂DS₂VASc score ≥2, compared to this study with 28%), due to differences in local AF ablation guidelines.

Clinical implications and recommendations

There are currently no clear guidelines on which patients require a TOE prior to AF ablation. The 2007 HRS/EHRA/ECAS (7) guidelines for AF ablation recommend that TOE may not be required in patients with PAF in sinus rhythm at the time of the procedure. Subsequent HRS AF guidelines

Table 3 Summary of studies that have examined LA/LAA thrombus in patients undergoing TOE prior to AF ablation and their CHA₂DS₂VASc scores.

Authors	n	Scoring system	Mean age ± s.d. (years)	Proportion of patients with score of 0	Thrombus prevalence	Thrombus scores	
						CHADS ₂	CHA ₂ DS ₂ VASc
Floria <i>et al.</i> (27)	681	CHADS ₂ and CHA ₂ DS ₂ VASc	57.0 ± 11.0	Not available	7 patients (1.0%)	14% with thrombus had a score of 1, 86% with thrombus had a score ≥ 2	100% with thrombus had a score ≥ 2
Willens <i>et al.</i> (28)	167	CHADS ₂ and CHA ₂ DS ₂ VASc	66.3 ± 11.6	CHADS ₂ : 16 (9.6%)	5 patients (3.0%)	100% with thrombus had a score ≥ 2	100% with thrombus had a score ≥ 3
Herring <i>et al.</i> (14)	586	CHA ₂ DS ₂ VASc	59.9 ± 0.4	CHA ₂ DS ₂ VASc: 11 (6.6%) CHADS ₂ : 249 (42.5%)	3 patients (0.5%)	100% with thrombus had a score ≥ 1	100% with thrombus had a score ≥ 2
Nishikii-Tachibana <i>et al.</i> (29)	543	CHADS ₂ and CHA ₂ DS ₂ VASc	61.9 ± 9.9	CHA ₂ DS ₂ VASc: 123 (21.0%) CHADS ₂ : 161 (29.7%)	35 patients (6.4%)	100% with thrombus had a score ≥ 1	11% with thrombus had a score of 1 89% with thrombus had a score ≥ 2

produced in 2012 (26) reported conflicting opinions on this matter and provided no clear recommendations. More recently, the EHRA have suggested that the CHA₂DS₂VASc score may be useful in determining which patients require a TOE, particularly when the score is ≥ 2 (20), which this study supports.

From the current study, taking into consideration the guidance documents and all other studies available, we suggest that all (anticoagulated) patients with a CHA₂DS₂VASc score of 0 or 1 do not require a TOE prior to AF ablation, provided they are therapeutically anticoagulated for at least 4 weeks with either warfarin (with a stable INR of between 2.0 and 3.0) or a NOAC, regardless of cardiac rhythm. If this guidance were followed, it would significantly reduce the need for TOE (73% or 241 patients over a 7-year period in our study) and would not have missed a single patient with thrombus. Indeed, since these results were presented to our local electrophysiologists, we have amended our institution's policy and, with an initial desire to be 'cautious' rather than 'cavalier', we no longer perform TOE routinely in patients with a CHA₂DS₂VASc score of 0 awaiting AF

ablation: this has led to a 35% reduction in TOE requests in the first 6 months following the introduction of this policy.

To the best of our knowledge, there have been no patients in any of the published studies with a CHA₂DS₂VASc score of 0 where LA/LAA thrombus has been identified. These results are summarised in Table 3. This reduction in TOE would provide significant cost savings for the health service and, in addition, the reduction in TOEs would improve patient experience markedly, because although low risk, TOEs can be an unpleasant experience for patients.

Study limitations

This was an observational, retrospective, single-centre study. All data were collected retrospectively using patient records and therefore subject to potential misclassification. The patient cohort consisted of mostly low-risk patients with few co-morbidities (only 26% had a CHA₂DS₂VASc ≥ 2, 12% had a history of stroke/TIA, and 1% had CHF) and thus may not be generalisable to other populations.

Importantly, there were very few patients with LA/LAA thrombus identified, likely due to the anticoagulation protocols and low-risk patient cohort. Finally, the number of patients anticoagulated with NOACs in the study was small. As the use of NOAC agents continues to increase, further larger studies on patients anticoagulated with NOACs will be required.

Conclusion

Patients with a CHA₂DS₂VASc score of zero or one (a significant proportion of patients awaiting AF ablation) can safely undergo ablation without the need for pre-procedural TOE. This would lead to a significant reduction in health care expenditures, reduce burden of clinical waiting lists and improve patient experience by removing requirement for a semi-invasive test in these patients.

Declaration of interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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References

- 1 Camm AJ, Kirchhof P, Lip GYH, Schotten U, Savelieva I, Ernst S, Van Gelder IC, Al-Attar N, Hindricks G, Prendergast B, *et al.* 2010 Guidelines for the management of atrial fibrillation. *Europace* **12** 1360–1420. (doi:10.1093/europace/euq350)
- 2 NICE 2014 NICE guidelines (CG180) Atrial fibrillation: the management of atrial fibrillation. London, UK: NICE. (available at: <https://www.nice.org.uk/guidance/cg180>)
- 3 Lip GYH, Nieuwlaet R, Pisters R, Lane DA & Crijns HJGM 2010 Refining clinical risk stratification for predicting stroke and thromboembolism in atrial fibrillation using a novel risk factor-based approach: The Euro Heart Survey on Atrial Fibrillation. *Chest* **137** 263–272. (doi:10.1378/chest.09-1584)
- 4 Oral H, Chugh A, Özyaydin M, Hansen PR, Tolstrup JS, Lindhardtsen J, Reich S, Igic P, Elmouchi D, Tschopp D, *et al.* 2006 Risk of thromboembolic events after percutaneous left atrial radiofrequency ablation of atrial fibrillation. *Circulation* **114** 759–765. (doi:10.1161/CIRCULATIONAHA.106.641225)
- 5 Bertaglia E, Zoppo F, Tondo C, Colella A, Mantovan R, Senatore G, Bottoni N, Carreras G, Corò L, Turco P, *et al.* 2007 Early complications of pulmonary vein catheter ablation for atrial fibrillation: a multicenter prospective registry on procedural safety. *Heart Rhythm* **4** 1265–1271. (doi:10.1016/j.hrthm.2007.06.016)
- 6 Bhargava M, Marrouche NF, Martin DO, Schweikert RA, Saliba W, Saad EB, Bash D, Williams-Andrews M, Rossillo A, Erciyes D, *et al.* 2004 Impact of age on the outcome of pulmonary vein isolation for atrial fibrillation using circular mapping technique and cooled-tip ablation catheter: a retrospective analysis. *Journal of Cardiovascular Electrophysiology* **15** 8–13. (doi:10.1046/j.1540-8167.2004.03266.x)
- 7 Calkins H, Brugada J, Packer DL, Cappato R, Chen SA, Crijns HJG, Damiano RJ Jr, Davies DW, Haines DE, Haissaguerre M, *et al.* 2007 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for personnel, policy, procedures and follow-up. A report of the Heart Rhythm Society (HRS) Task Force on Catheter and Surgical Ablation of Atrial Fibrillation. *Europace* **9** 335–379. (doi:10.1093/europace/eum120)
- 8 Romero J, Cao JJ, Garcia MJ & Taub CC 2014 Cardiac imaging for assessment of left atrial appendage stasis and thrombosis. *Nature Reviews Cardiology* **11** 470–480. (doi:10.1038/nrcardio.2014.77)
- 9 Puwanant S, Varr BC, Shrestha K, Hussain SK, Tang WHW, Gabriel RS, Wazni OM, Bhargava M, Saliba WI, Thomas JD, *et al.* 2009 Role of the CHADS₂ score in the evaluation of thromboembolic risk in patients with atrial fibrillation undergoing transesophageal echocardiography before pulmonary vein isolation. *Journal of the American College of Cardiology* **54** 2032–2039. (doi:10.1016/j.jacc.2009.07.037)
- 10 Flachskampf FA, Wouters PF, Edwardsen T, Evangelista A, Habib G, Hoffman P, Hoffmann R, Lancellotti P & Pepi M 2014 Recommendations for transoesophageal echocardiography: EACVI update 2014. *European Heart Journal: Cardiovascular Imaging* **15** 353–365. (doi:10.1093/ehjci/jeu015)
- 11 Wazni OM, Tsao HM, Chen SA, Barrett C, Hao S, Patel D, Di Biase L, Martin DO, Kanj M, Arruda M, *et al.* 2006 Cardiovascular imaging in the management of atrial fibrillation. *Journal of the American College of Cardiology* **48** 2077–2084. (doi:10.1016/j.jacc.2006.06.072)
- 12 Stoddard MF, Singh P, Dawn B & Longaker RA 2003 Left atrial thrombus predicts transient ischemic attack in patients with atrial fibrillation. *American Heart Journal* **145** 676–682. (doi:10.1067/mhj.2003.91)
- 13 Zoppo F, Brandolino G, Berton A, Frigato, N, Michieletto M, Zanocco A, Zerbo F, Bacchiega E, Lupo A & Bertaglia E 2012 Predictors of left atrium appendage clot detection despite on-target warfarin prevention for atrial fibrillation. *Journal of Interventional Cardiac Electrophysiology* **35** 151–158. (doi:10.1007/s10840-012-9707-0)
- 14 Herring N, Page S, Ahmed M, Burg MB, Hunter RJ, Earley J, Sporton SC, Newton JD, Sabharwal NK, Myerson SG, *et al.* 2013 The prevalence of low left atrial appendage emptying velocity and thrombus in patients undergoing catheter ablation for atrial fibrillation on uninterrupted peri-procedural Warfarin therapy. *Journal of Atrial Fibrillation* **5** 28–35. (doi:10.4022/jafib.761)
- 15 Yarmohammadi H, Varr BC, Puwanant S, Lieber E, Williams SJ, Klostermann T, Jasper SE, Whitman C & Klein AL 2012 Role of CHADS₂ score in evaluation of thromboembolic risk and mortality in patients with atrial fibrillation undergoing direct current cardioversion (from the ACUTE Trial Substudy). *American Journal of Cardiology* **110** 222–226. (doi:10.1016/j.amjcard.2012.03.017)
- 16 Yarmohammadi H, Klostermann T, Grewal G, Alraies MC, Varr BC, Lindsay B, Zurick I, Shrestha K, Tang WHW, Bhargava M, *et al.* 2013 Efficacy of the CHADS₂ scoring system to assess left atrial thrombogenic milieu risk before cardioversion of non-valvular atrial fibrillation. *American Journal of Cardiology* **112** 678–683. (doi:10.1016/j.amjcard.2013.04.047)
- 17 Di Biase L, Lakkireddy D, Trivedi C, Deneke T, Martinek M, Mohanty S, Mohanty P, Prakash S, Bai R, Reddy M, *et al.* 2015 Feasibility and safety of uninterrupted periprocedural apixaban administration in patients undergoing radiofrequency catheter ablation for atrial fibrillation: Results from a multicenter study. *Heart Rhythm* **12** 1162–1168. (doi:10.1016/j.hrthm.2015.02.028)

- 18 Nairouz R, Sardar P, Pino M, Aronow WS, Sewani A, Mukherjee D, Paydak H & Maskoun W 2015 Meta-analysis of risk of stroke and thrombo-embolism with rivaroxaban versus vitamin K antagonists in ablation and cardioversion of atrial fibrillation. *International Journal of Cardiology* **187** 345–353. (doi:10.1016/j.ijcard.2015.03.323)
- 19 Rillig A, Lin T, Plesman J, Heeger CH, Lemes C, Metzner A, Mathew S, Wissner E, Wohlmuth P, Ouyang F, *et al.* 2016 Apixaban, rivaroxaban, and dabigatran in patients undergoing atrial fibrillation ablation. *Journal of Cardiovascular Electrophysiology* **27** 147–153. (doi:10.1111/jce.12856)
- 20 Sticherling C, Marin F, Birnie D, Boriani G, Calkins H, Dan GA, Gulizia M, Halvorsen S, Hindricks G, Kuck K, *et al.* 2015 Antithrombotic management in patients undergoing electrophysiological procedures: a European Heart Rhythm Association (EHRA) position document endorsed by the ESC Working Group Thrombosis, Heart Rhythm Society (HRS), and Asia Pacific Heart Rhythm Society (APHRS). *Europace* **17** 1197–1214. (doi:10.1093/europace/euv190)
- 21 Kawabata M, Goya M, Sasaki T, Maeda S, Shirai Y, Nishimura T, Yoshitake T, Shiohira S, Isobe M & Hirao K 2017 Left atrial appendage thrombi formation in Japanese non-valvular atrial fibrillation patients during anticoagulation therapy – warfarin vs direct oral anticoagulants. *Circulation Journal* **81** 645–651. (doi:10.1253/circj.CJ-16-1089)
- 22 Wyrembak J, Campbell KB, Steinberg BA, Bahnson TD, Daubert JP, Velazquez EJ, Samad Z & Atwater BD 2017 Incidence and predictors of left atrial appendage thrombus in patients treated with nonvitamin K oral anticoagulants versus warfarin before catheter ablation for atrial fibrillation. *American Journal of Cardiology* **119** 1017–1022. (doi:10.1016/j.amjcard.2016.12.008)
- 23 Scherr D, Dalal D, Chilukuri K, Dong J, Spragg D, Henrikson CA, Nazarian S, Cheng A, Berger RD, Abraham TP, *et al.* 2009 Incidence and predictors of left atrial thrombus prior to catheter ablation of atrial fibrillation. *Journal of Cardiovascular Electrophysiology* **20** 379–384. (doi:10.1111/j.1540-8167.2008.01336.x)
- 24 McCready JW, Nunn L, Lambiase PD, Ahsan SY, Segal OR, Rowland E, Lowe MD & Chow AW 2010 Incidence of left atrial thrombus prior to atrial fibrillation ablation: Is pre-procedural transoesophageal echocardiography mandatory? *Europace* **12** 927–932. (doi:10.1093/europace/euq074)
- 25 Calvo N, Mont L, Vidal B, Montserrat S, Andreu D, Tamborero D, Pare C, Azqueta M, Berrueto A, Brugada J, *et al.* 2011 Usefulness of transoesophageal echocardiography before circumferential pulmonary vein ablation in patients with atrial fibrillation: is it really mandatory? *Europace* **13** 486–491. (doi:10.1093/europace/euq456)
- 26 Calkins H, Kuck KH, Cappato R, Brugada J, Camm AJ, Chen SA, Crijns HJG, Damiano RJ Jr, Davies DW, DiMarco J, *et al.* 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design. *Europace* **14** 528–606. (doi:10.1093/europace/eus027)
- 27 Floria M, Roy LD, Xhaet O, Blommaert D, Jamart J, Gerard M, Dormal F, Deceuninck O, Ambarus V, Marchandise B, *et al.* 2013 Predictive value of thromboembolic risk scores before an atrial fibrillation ablation procedure. *Journal of Cardiovascular Electrophysiology* **24** 139–145. (doi:10.1111/j.1540-8167.2012.02442.x)
- 28 Willens HJ, Gómez-Marín O, Nelson K, Denicco A & Moscucci M 2013 Correlation of CHADS₂ and CHA₂DS₂-VASc scores with transesophageal echocardiography risk factors for thromboembolism in a multiethnic united states population with nonvalvular atrial fibrillation. *Journal of the American Society of Echocardiography* **26** 175–184. (doi:10.1016/j.echo.2012.11.002)
- 29 Nishikii-Tachibana M, Murakoshi N, Seo Y, Xu DZ, Yamamoto M, Ishizu T, Atsumi A, Machino-Ohtsuka T, Kuroki K, Yamasaki H, *et al.* 2015 Prevalence and clinical determinants of left atrial appendage thrombus in patients with atrial fibrillation before pulmonary vein isolation. *American Journal of Cardiology* **116** 1368–1373. (doi:10.1016/j.amjcard.2015.07.055)

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