Catheter-tissue Contact Force Determines Atrial Electrogram Characteristics Before and Lesion Efficacy After Antral Pulmonary Vein Isolation in Humans

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Abstract

Introduction: Electrogram (EGM) characteristics are used to infer catheter-tissue contact.

We examined if (a) atrial EGM characteristics predicted CF and (b) compared the value of CF versus other surrogates for predicting lesion efficacy.

Methods and Results: Twelve paroxysmal AF patients underwent pulmonary vein isolation using radiofrequency (RF) ablation facilitated by a novel CF-sensing catheter. Operators were blinded to CF. EGM amplitude, width and morphology were measured pre and post RF. At each RF site, average CF, force-time integral (FTI), impedance fall, time to impedance plateau, maximum power, catheter tip temperature and total energy delivered were recorded. An effective lesion was defined based on previously validated EGM criteria for transmural lesions. There was a moderate correlation between CF and EGM amplitude ($r=0.19$) and EGM width ($r=-0.22$). Pre-RF, EGM amplitude and width had modest to poor discriminative capacity for identifying pre-ablation CF (e.g., EGM amplitude identified $CF>20g$ with sensitivity and specificity of 67% and 60%, respectively). Pre-ablation CF, FTI and total energy delivered during RF were the only independent predictors of effective lesion formation. Neither pre-RF EGM amplitude/width nor power, temperature and impedance changes during RF predicted effective lesion formation. An average $CF>16g$ or $FTI>404 g*s$ had excellent sensitivity and specificity ($>80\%$) for identifying an effective lesion.

Conclusions: EGM characteristics do not reliably predict either CF before the onset of RF, nor do they predict the likelihood of an effective lesion. CF parameters were superior to power, temperature and impedance changes during RF in predicting lesion efficacy.

Keywords

Catheter-tissue contact force; Catheter ablation; Atrial electrogram; Atrial fibrillation; Lesion efficacy; Radiofrequency; Average contact force; Force-time integral; Impedance; Energy; Tip temperature; Maximum power.

Introduction

Since the advent of real-time contact force (CF) sensing technology, a number of pre-clinical studies have demonstrated the robust association between catheter-tissue CF and radiofrequency (RF) ablation lesion size, depth and volume.^{1, 2} Human studies have since shown a clear correlation of catheter-tissue CF with procedural parameters such as amount of RF required to achieve pulmonary vein isolation (PVI) or bidirectional cavotricuspid isthmus block, likelihood of subsequent acute reconnection and long-term freedom from AF.^{3, 4, 5}

In the absence of real-time CF measurements, surrogate markers of catheter-tissue contact such as catheter motion on fluoroscopy, impedance (both baseline and fall with ablation), maximum tip temperatures, electrogram (EGM) quality and abatement with ablation are utilized. Catheter motion and impedance have been shown to have limited predicted value for real-time CF.^{6, 7, 8} Although EGM characteristics such as amplitude and width are used to differentiate “good” from “poor” CF, the predictive value of these markers for real-time CF remains unknown. Furthermore, the ability of CF compared to other post-ablation parameters for predicting an effective RF lesion post ablation remains unknown. This study aimed to (i) characterize the predictive value of atrial EGM characteristics for real-time CF and (ii) compare CF with other post ablation parameters for predicting lesion efficacy in paroxysmal atrial fibrillation (AF) patients undergoing catheter ablation using a novel CF-sensing catheter.

Methods

This was a prospective study, which recruited patients undergoing antral pulmonary vein isolation (PVI) for paroxysmal AF under general anesthesia. The study was approved by the Melbourne Health Human Research Ethics Committee.³

Pulmonary vein isolation procedure

Our procedural approach for PVI has been detailed previously.^{3, 6, 7} In brief, the procedure was performed with double transseptal punctures, systemic anticoagulation with heparin (activated clotting time of >350 seconds) and use of pre-procedural CT scan merged with detailed left atrial (LA) geometry collected during the procedure using a 3-D mapping system (Ensite, NavX, St Jude Medical Minneapolis, MN, USA). PVI was facilitated by the use of a circular mapping catheter. Point-by-point RF lesions of 30 seconds duration were delivered at the PV antra with a power of 30 Watts (W) at the anterior, superior and inferior PV quadrants and 25 W at all posterior sites with temperature limited to 48°C for each lesion.⁶ Wide encirclement of the ipsilateral pairs of PV antra was performed without additional adjunctive left atrial ablation. PVI was confirmed by demonstration of entrance and exit block. Intravenous adenosine was combined with a waiting time >30 minutes for each vein to uncover dormant PV reconnection.

Ablation catheter

A CF-sensing catheter and viewing platform were used for ablation (TactiCath; Endosense SA, Meyrin/Geneva, Switzerland, distributed by Biotronik, Berlin, Germany). The CF-sensing catheter is an open-irrigation, quadripolar, 7 Fr catheter with a 3.5-mm tip electrode and 2mm -5mm -2 mm spacing. It contains a tri-axial sensor located between the second and third electrodes, which measures the force of the contact between the tissue and the catheter-tip electrode.^{1, 2, 4, 5, 9, 10} The CF sensor has a resolution and sensitivity of 1 g in a bench test.

Ablation protocol

Ablation was performed with the use of “traditional” markers of catheter-tissue contact such as catheter tip motion and stability on fluoroscopy and on the 3-D mapping system, EGM quality and abatement with ablation, baseline impedance and impedance fall with ablation. The operators were blinded to CF-data. In all procedures, the operator systematically delivered point-point ablation lesions for 30 seconds. RF was terminated prematurely (before 30 seconds) if one of these factors were absent or if the operator felt that a significant lesion was created based on EGM attenuation. Lesions where there was inadvertent abrupt movement of the catheter from the original site of energy delivery were excluded.

CF-sensing data

CF (in grams, g) was measured for 5 seconds immediately before and 5 seconds immediately after the onset of RF. During RF, average CF and the force-time integral (a product of average CF and RF duration in seconds, measured as grams*seconds; g*s) was recorded. For the purposes of the present analysis, CF was categorized into ≤ 10 g, 11-20g and >20 g and FTI into ≤ 500 , 501-1000 and >1000 g*s.

Impedance, tip temperature, maximum power and energy data

An RF generator (Stockert 70, Biosense Webster, Diamond Bar, CA, USA) was used to deliver RF current as described previously.^{7,9} Impedance (recorded every 200 ms), maximum power delivery, peak tip temperature and total energy delivered for each lesion was recorded and displayed on a computerized digital amplifier system (EPMed Systems, West Berlin, NJ, USA). For impedance, we recorded the maximal impedance fall and time to impedance plateau, as described previously.⁷ The plateau

was identified by viewing the impedance RF cycle data curves. Plateau time point was confirmed if the impedance reading within a 2 second period before or after this point were within 2 Ω of each other.⁷

Lesion inclusion criteria

The following entry criteria were set in order for the lesion to be included in the present analysis (Figure 1A):

- (1) delivery in sinus or paced rhythm (to minimize beat to beat variability in EGM amplitude that is exaggerated in AF);¹¹
- (2) non-overlapping lesion (distance >4 mm from adjacent lesion on surface geometry on NavX; Figure 1B);
- (3) no catheter macro-movement as detected on fluoroscopy or NavX;
- (4) no catheter micro-movement defined as paradoxical increase in EGM amplitude post RF ablation compared to pre-RF ablation;¹²
- (5) minimal deviation in CF (<5g) when comparing the CF at the start and at the end of RF ablation to allow a valid comparison of EGM amplitude/width before and after ablation, whilst keeping CF constant (Figure 1C).

EGM analysis

Bipolar intracardiac EGMs 12-lead surface ECG were recorded simultaneously on a computerized digital amplifier system (EPMed Systems, West Berlin, NJ).

Intracardiac EGMs were filtered between 30 and 500 Hz. Bipolar EGMs were analyzed offline at a sweep speed of 600 mm/s by two observers who were blinded to CF data. For each lesion, the following data were immediately before onset of RF and immediately after the termination of RF ablation:

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- (1) positive, negative and total EGM amplitude (Figure 1D);
 - (2) EGM width (Figure 1D);
 - (3) EGM morphology as QS, QR, QRS, R, RS or RSR;
 - (4) Percentage reduction in EGM amplitude with ablation (pre EGM amplitude – post EGM amplitude/Pre EGM amplitude x 100).

To minimize error the mean of 5 consecutive EGMs were immediately before and 5 EGMs immediately after ablation were measured for each site.

Definitions for lesion effectiveness and transmural

We defined an effective lesion using established criteria for lesion transmural, which are based on bipolar EGM morphology before and after RF ablation.¹³ A transmural (or effective) lesion can be differentiated from a non-transmural (or ineffective) lesion with the sensitivity and specificity approaching 100% using the following criteria: (i) complete abolition of positive deflection when pre-ablation QR present; (ii) $\geq 75\%$ attenuation of the positive deflection when pre-ablation QRS present; and (iii) complete elimination of R' when pre-ablation RSR' present (Figure 2).¹³

Study endpoints

This study assessed the following:

- (1) the correlation between CF and EGM amplitude/width, and the ability of EGM amplitude/width to predict real-time CF;
- (2) whether CF and EGM amplitude or width before the onset of RF predicts the creation of effective lesions after RF at that site;
- (3) the predictive value of post ablation parameters such as FTI, impedance

(maximum fall and plateau), maximum power, maximum tip temperature, and total energy delivered for the creation of effective RF lesions;

(4) CF parameters required to create effective RF lesions;

Statistical Analysis

The Statistical Package for the Social Sciences for Windows (release 15.0; SPSS, Inc, Chicago, IL) was used for analysis. Continuous variables were expressed as mean $\pm$ standard deviation if normally distributed; median and interquartile range_{25-75%} (IQR_{25-75%}) were used if the data was clearly skewed. Where normal distribution was not present, log transformation of the raw values was performed to meet the assumption of homogeneity of variance. Mean values were compared using the Student t-test. Independent samples Mann-Whitney U test or log transformed values were used for continuous variables where normal distribution was not present. To test for associations between categorical variables, χ^2 -tests or Fisher's exact test were used.

Linear regression analysis was used to evaluate the relationship between two continuous variables and the strength of correlation (R) reported. Receiver Operating Characteristic (ROC) curves and the Youden's index ($J = \text{sensitivity} + \text{specificity} - 1$) were used to examine: (a) the predictive value of EGM characteristics for real-time CF and (b) optimal "cut-offs" values for post-ablation parameters required for creation of effective lesions. A larger area under curve is considered better at discriminating an effective RF lesion from an ineffective one. An area under curve of 1 was considered perfect and 0.5 as non-discriminating which performed no better than chance.¹⁴ The Youden's index has minimum and maximum values of -1 and +1, respectively, with a value of +1 representing the optimal discriminative ability.¹⁵

A binary logistic regression model was created to determine pre-ablation predictors (EGM amplitude, width and CF) of effective RF lesions. A separate binary logistic regression model was created to determine post-ablation predictors of effective RF lesions. A 2-tailed P value < 0.05 was considered statistically significant. Graphs were constructed by using Prism, version 5.0d (GraphPad Software, Inc, La Jolla, CA).

Results

Baseline characteristics

Twelve patients with no structural heart disease and paroxysmal AF undergoing antral PVI were recruited. Mean age was 51 ± 11 years (33% females) with mildly dilated left atria (area 24 ± 4 cm²), and normal left ventricular function ($63 \pm 5\%$) and AF duration for a mean of 3 ± 1.8 years. Of 980 antral PV lesions, 567 lesions met inclusion criteria (median 48 lesions per patient, range 24-78 lesions) with a mean RF duration of 25 ± 9 s.

CF and EGM amplitude/width

Increasing CF was moderately associated with increasing EGM amplitude and narrower EGM width ($R = 0.19$ and -0.22 , respectively, $P < 0.001$; Figure 3A, B). Although there was a significant increment in median EGM amplitude and decrement in EGM width with increasing category of CF, there was large degree of overlap in amplitude and width recorded between different CF categories (Figure 3C, D). EGM amplitude and width had modest to poor discriminative capacity for identifying CF of different categories with sensitivity ranging from 52-81% and specificity from 36-83% (Table 1).

CF parameters and effective lesions

Each increment in FTI category was associated with greater percentage reduction in EGM amplitude (Figure 4A). Of 567 lesions, 287 (51%) were classified as effective and 280 (49%) as ineffective based on EGM criteria for transmural. While 100% of lesions with an FTI >1000g*s were effective, only 21% of lesions with an FTI $\leq$ 500g*s were effective (Figure 4B). ROC analyses showed that an FTI and average CF had excellent discriminative capacity to identify an effective lesion (Figure 4C, D). An FTI >404g*s or an average CF >16 g had the best sensitivity and specificity for identifying an effective lesion (for FTI 88% and 90%, respectively, for average CF 84% and 84%, respectively).

Predicting pre-ablation CF with EGM characteristics

Given that a pre-ablation CF>16g best identified an effective lesion, we determined the if pre-ablation EGM amplitude and width could identify this CF. Pre-ablation EGM amplitude could predict a pre-ablation CF>16g with only modest sensitivity (64%) and specificity (61%, AUC = 0.62, $P < .001$, maximum J = 0.25). Similarly, pre-ablation EGM width predicted a CF>16g with sensitivity of 59% and specificity of 62% (AUC = 0.64, $P < 0.001$, maximum J = 0.21).

Parameters predicting effective lesions

Pre-ablation CF independently predicted subsequent creation of effective lesions after ablation on multivariable analysis (Table 2). Neither pre-ablation EGM amplitude nor width did not predict formation of effective lesions post RF.

Of all post ablation parameters, FTI and total energy delivered during RF were

the only independent predictors of an effective lesion on multivariable analysis (Table 2). Maximum tip temperature, maximum power, maximal impedance fall and time to impedance plateau did not predict the formation of effective lesions post ablation. FTI had the best discriminative capacity for predicting an effective lesion (Figure 5).

Relationship between effective lesions and acute PV reconnection

Of 567 lesions studied, PV reconnection occurred at sites distinctly corresponding to 25 lesions. Three of the 287 (1.1%) lesions deemed effective on EGM criteria had PV reconnection, whereas 22/287 (7.9%) of lesions deemed ineffective on EGM criteria had evidence of PV reconnection (odds ratio 8, 95% confidence interval 2-27, $P < .001$ for PV reconnection with an ineffective lesion).

Discussion

Main findings

This prospective study examines the predictive value of atrial EGM characteristics for real-time CF and compares the ability of CF compared to various post ablation parameters in predicting lesion efficacy during catheter ablation for AF in humans.

The main findings were:

1. Increasing pre-ablation CF was associated with increasing EGM amplitude and narrower EGM width but the strength of this relationship was moderate. This effect was attributed to the large degree of overlap in EGM amplitude/width between different CF categories;
2. Increasing FTI was associated with greater degree of EGM amplitude reduction and higher incidence of effective RF lesions based on previously validated EGM criteria for transmural;

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3. An FTI > 404 g*s or average CF > 16 g had the best sensitivity and specificity (both >80%) for predicting an effective RF lesion;
 4. Before the onset of ablation, EGM amplitude and width could predict a CF of >16g with only modest sensitivity and specificity (~60%);
 5. Before the onset of ablation, real-time CF rather than EGM amplitude or width predicted the subsequent formation of an effective lesion post ablation. Post ablation, FTI was the strongest independent predictor of effective RF lesion formation compared to all post ablation parameters such as impedance, maximum power, maximum tip temperature and total energy delivered.

These findings highlight, first, the limitations of using EGM amplitude/width alone as surrogate markers for catheter-tissue CF, which were found to be only modest predictors. Second, the findings demonstrate the superiority of CF parameters over other markers such as impedance fall, maximum tip temperature, and total energy delivered in predicting lesion efficacy. These findings underscore the importance of real-time CF measurements for optimizing lesion efficacy.

Surrogate markers to predict catheter-tissue CF and lesion efficacy

In the absence of real-time CF data, catheter-tissue contact is inferred from surrogate markers such as catheter motion on imaging,^{8, 16} catheter-tip temperatures, impedance fall,^{1, 7, 9, 17-23} baseline EGM amplitude and abatement with ablation.^{12, 16, 17, 24, 25} We have previously shown that the combined use of all “traditional” surrogate markers and tactile feedback to guide catheter ablation results in marked variability in real-time catheter-tissue CF within and between different anatomic segments of the PV antra.⁶ The present study extends these observation by examining the predicting value of EGM characteristics for CF and compares the utility of various post ablation

parameters for lesion efficacy. We used established bipolar EGM criteria for lesion efficacy which have been shown to have near perfect sensitivity and specificity for discriminating a histopathologically transmural from a non-transmural lesion.¹³

Kalman *et. al* in a canine study showed that despite good contact inferred from fluoroscopic catheter stability (in relation to cardiac borders and with cardiac and respiratory motion) and EGM stability (stable morphology and $\leq 10\%$ deviation in EGM amplitude), up to 30% of lesions were observed to have poor contact as visualized on intracardiac echocardiography, resulting in lower efficiency of heating index and smaller lesion size.⁸ Intracardiac echo-guided ablation resulted in a significant increase in proportion of lesions with good contact (94%), higher efficiency of heating index and greater lesion size. However, *that* study did not have real-time CF measurements.

Similar to our study, Okumura *et. al* demonstrated small differences in mean bipolar EGM amplitude with a large degree of overlap between increasing categories of CF from minimal (CF ~5g: 3.5 ± 2.6 mV) or consistent contact (10g: 4.5 ± 2.9 mV) and tissue tenting (25g: 4.6 ± 3.2 mV). However, that study was performed in animals, used CF-sensing technology incorporated into a robotic remote-control navigation system and did not determine the predictive value of EGM amplitude for real-time CF. Strickberger *et. al* in a human study, differentiated “firm” from “poor” contact on the basis of bipolar capture threshold and found 2.4 times higher ventricular EGM amplitude with firm contact although direct CF measurements were not available at that time.¹⁷ In the current human study using direct contact force measurements, we demonstrate the limited predictive value of atrial EGM characteristics for real-time CF. We found that EGM amplitude and width had only modest value for predicting pre-ablation CF. Importantly, pre-ablation CF, rather than

EGM characteristics predicted lesion efficacy post RF ablation, underscoring the importance of CF measurements in optimizing ablation efficacy.

Despite a number of pre-clinical studies demonstrating that baseline impedance and subsequent fall with ablation correlated with imparted CF and lesion and volume,^{1, 9, 19-22} we recently demonstrated that impedance changes had at best, modest efficacy as surrogates of real-time CF.⁷ De Bortoli et al also found a moderate correlation of impedance fall with CF ($\rho = 0.54$, $P < 0.01$).²³ The present study extends these observations and demonstrates that CF was superior to impedance measurements in discriminating an effective from an ineffective lesion. We also affirm the accepted limitations of catheter tip temperature for assessing lesion size. Previous studies have shown that tip temperature is an imprecise tool during irrigation tip ablation where registered catheter tip temperatures inadequately reflect actual tissue heating.²⁶⁻²⁸ Indeed, Yokoyama *et. al* showed a lack of increase in tip temperature with increasing categories of CF despite significant increases in tissue temperature.¹ Consistent with these observations, we found that tip temperature did not predict lesion efficacy and had limited discriminative capacity for identifying effective RF lesions. Of all post ablation parameters used in clinical practice including maximum impedance fall, impedance plateau, maximum power, maximum tip temperature, we found that only FTI and total energy delivered were independent predictors of an effective lesion. Moreover, FTI was superior to all other parameters including total energy delivered in identifying an effective lesion. Our use of previously validated EGM criteria for lesion transmuralty¹³ was justified as lesions deemed ineffective on EGM criteria were 8 fold more likely to have acute PV reconnection compared to sites deemed effective.

The present study showed that FTI strongly correlated with percentage

amplitude reduction, which is known to be a marker of lesion transmurality.^{12, 24, 25}

Furthermore, a higher incidence of EGM-based transmural lesion were noted with increasing category of CF. We also defined the optimal CF and FTI for the creation of effective lesions. An FTI >404 g*s identified an effective lesion with sensitivity and specificity over 80%. This value was consistent with recent observation that an FTI > 400 g*s conferred a lower risk of gap formation and long term freedom from AF recurrence.⁵

Study limitations

We chose to assess lesion efficacy based on bipolar EGM criteria for lesion transmurality. Further studies assessing lesion characteristics using magnetic resonance imaging may strengthen these findings.

Conclusions

EGM amplitude and width have modest to poor predictive value for real-time CF during antral PVI in humans. Pre ablation, CF rather than EGM amplitude or width predicted effective lesion formation. Post ablation, FTI rather than other post ablation parameters independently predicted effective lesion formation with excellent sensitivity and specificity. An FTI > 404 g*s appears to be optimal for the creation of an effective lesion.

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Table 1: Best sensitivity and specificity for EGM amplitude and width to predict real-time CF at different categories.

CF cut off	EGM amplitude			EGM width	
	Sensitivity (%)	Specificity (%)	Area under curve	Sensitivity (%)	Specificity (%)
>2g	54	83	0.71	79	60
>10g	60	65	0.65	65	64
>20g	67	60	0.64	52	67
>40g	67	58	0.6	81	36

AUC = 0.5 indicates no discriminative and AUC =1 indicates perfect discriminative capacity respectively. All *P* values <0.001. CF-

Table 2: Ablation parameters that before and after ablation that predicted an effective lesion

	Univariable		Multivariable
	OR (95% CI)	P value	OR (95% CI)
Pre-ablation			
CF (each 1g increment)	1.089 (1.072-1.106)	<0.001	1.088 (1.069-1.106)
EGM amplitude (each 1mV increase)	1.277 (1.071-1.522)	<0.001	-
EGM width (each 1ms increase)	0.983 (0.966-1)	0.05	-
Post-ablation			
Average CF during RF (each 1 g increment)	1.264 (1.216-1.313)	<0.001	-
FTI achieved during RF (each 1g*s increment)	1.012 (1.010-1.014)	<0.001	1.012 (1.009-1.014)
Maximum tip temperature (every 1° increase)	1.454 (1.319-1.601)	<0.001	-
Total energy delivered (each 1 J increment)	1.002 (1.001-1.003)	<0.001	0.997 (0.995-0.999)
Maximum power (each 1 W increase)	1.031 (0.986-1.078)	0.18	-
Maximal impedance fall (each 1Ω fall)	1.18 (1.139-1.223)	<0.001	-
Time to impedance plateau (each 1 increment)	1.261 (1.21-1.314)	<0.001	-

Figure 1: Study methodology

(A) Entry criteria for inclusion of RF lesion for analysis; (B) method of antral PVI; (C) Real-time CF curves of each RF lesion were exported and analyzed in graphical form. To minimize the impact of variability in CF on EGM amplitude before vs. after ablation, only those lesions with a starting and ending CF within 5g of each other were included in the analysis; (D) method of analyzing bipolar EGMs for amplitude of the positive (A_p), negative (A_n), total (A_t) deflections and EGM width (W).

Figure 2: Definition of “effective” and “ineffective” lesions

Criteria for lesion transmuralty as defined by Otomo et. al and applied to the present study (permissions pending).¹³ EGM morphology before and after RF ablation were used to classify lesion as transmural (TL, termed “effective” as in the present study) or non-transmural (non-TL, termed “ineffective” as in the present study). (A) For sites with a pre-ablation QR, loss of the positive deflection (A_p) could differentiate TL from non-TL sites with a sensitivity (Se) and specificity (Sp) of 100%, respectively; (B) for sites with a pre-ablation QRS, $\geq 75\%$ loss of the A_p could differentiate TL from non-TL sites with Se and Sp of 85% and 95%, respectively; for sites with a pre-ablation RSR', loss of the second positive deflection could differentiate TL from non-TL sites with a Se and Sp of 100%, respectively.

Figure 3: Pre-ablation CF and EGM characteristics

(A, B) EGM amplitude and width had a modest positive and modest negative correlation respectively with increasing pre-ablation CF; Median EGM amplitude increased (C) and median EGM width decreased (D) with increasing pre-ablation CF category but note the large degree of overlap in values with different CF categories.

Figure 4: Relation of FTI with %EGM amplitude reduction and lesion efficacy

Percentage reduction in EGM amplitude (A) and percentage of effective lesions based on transmurality criteria (B) increased with each increment in FTI category. ROC analysis curves showed that an FTI was $>404\text{ g}\cdot\text{s}$ (boxed value, A) and an average CF $>16\text{ g}$ (boxed value, D) had the best sensitivity and specificity for identification of an effective lesion. *AUC*- area under curve.

Figure 5: ROC curves and analyses comparing various post ablation parameters that allowed differentiation of effective from ineffective lesions

Curves that are further away from reference line indicate greater area under curve (AUC) and better predictive value for the measure tested. A Youden's index (J) of +1 represents optimal discriminative value. Note FTI had the strongest discriminative capacity. ROC for maximum power is not shown as it did not have discriminative capacity (AUC = 0.53, $P = 0.18$)

Max.-maximum, Se-sensitivity, Sp-

specificity

Parameter	Value with best "cut off"	AUC (max. J)	Se (%)	Sp (%)
FTI	>404 g*s	0.94 (0.78)	88	90
Impedance plateau	>10 s	0.83 (0.52)	84	68
Max. impedance fall	>13 !	0.77 (0.42)	74	68
Max. tip temperature	>41°	0.7 (0.32)	38	94
Total energy delivered	>383 J	0.61 (0.21)	76	44

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