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ORIGINAL ARTICLE

Dielectric response as a novel marker for ablation lesion quality: Relation to conventional ablation parameters

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Abstract

Background: The tissue response viewer (TRV) is a novel marker for ablation lesion quality that aims to classify lesions into transmural or nontransmural lesions (high or low dielectric response, HDR or LDR) using dielectric-based tissue assessment. The objective of this study was to gain insight in the TRV by relating its outcomes to conventional ablation parameters.

Methods: Patients that had repeat ablation for atrial fibrillation with a dielectric imaging-based mapping system were enrolled. All ablation data were downloaded from the mapping system and analyzed to explore associations between TRV outcomes and other ablation parameters.

Results: The cohort included 24 patients, in which 58 pulmonary veins and 8 superior vena cavas were targeted. A total of 388 energy applications were applied, resulting in 639 ablation points. The system classified 36% of ablation points as HDR and 44% as LDR. The system did not provide a dielectric response in 20%. The system's ability to provide a dielectric response was related to longer ablation duration and absence of dragging ablation. HDR (versus LDR) was multivariably associated with longer energy applications, higher mean ablation power, and lower wall thickness. Greater impedance drop was univariably associated with HDR.

Conclusion: Outcomes of the TRV are associated with conventional ablation parameters (e.g., duration and power) but also local wall thickness. Catheter stability seems important for successful lesion assessment with the TRV. Further reduction of missing outcomes and validation of the tool are warranted before widespread use.

KEYWORDS
atrial fibrillation, dielectric imaging, dielectric response, electroanatomic mapping, radiofrequency ablation

1 | INTRODUCTION

Application of an adequate dosage of ablation energy is essential for the safety and efficacy of thermal ablation modalities such as radiofrequency (RF) and cryoablation. While cryoablation relies on standardized ablation protocols, various markers for RF ablation lesion quality are available. Widely used markers for lesion quality (i.e., Ablation Index, AI; and Lesion Size Index, LSI) incorporate

time, power, contact force, and impedance data, to provide a real-time index that quantifies the amount of applied ablation energy.[1,2] Clinical use of these indices for catheter ablation of atrial fibrillation is associated with higher rates of acute procedural success and lower rates of arrhythmia recurrence, while having similar rates of complications.[3,4] However, despite the improvements in outcomes, ablation lesion reconnection can be observed in up to 22% of patients.[5] One potential cause of ablation lesion reconnection is the variance in myocardial tissue characteristics (i.e., wall thickness, fibrosis, etc.). As current ablation indices do not account for this tissue heterogeneity, they may promote underdosing of areas that require higher doses of ablation energy, resulting in nondurable ablation lesions, as well as overdosing in other areas, with possibly higher risk of complications.

Recently, an update of a wide-band dielectric imaging system (KODEX-EPD, EPD Solutions, a Philips company, Best, The Netherlands) has enabled a set of features that facilitate dielectric-based assessment of local tissue characteristics (KODEX Vision). This dielectric imaging system enables accurate electroanatomical mapping[6,7] that can be used for complex catheter ablation procedures like pulmonary vein isolation (PVI).[8] With the release of the local tissue assessment features, the system has enabled a novel tool for the assessment of ablation lesion quality: the tissue response viewer (TRV). This tool aims to detect changes in dielectric tissue characteristics to provide an indication of ablation lesion quality. This could potentially enhance ablation lesion quality assessment, which could subsequently result in better outcomes. However, to date, no studies have reported on the clinical application of the TRV feature. In this paper, we present our experiences with the TRV feature and correlate its outcomes to conventional ablation parameters. With these data, we aim to provide insight in the clinical application of dielectric imaging-based ablation lesion assessment.

2 | METHODS

2.1 | Study population

Patients that were scheduled for an ablation procedure with the KODEX-EPD system at our center (St. Antonius Hospital, Nieuwegein, The Netherlands) were consented for participation in a single-center, prospective, observational cohort study. In this study, we included all patients that had a repeat ablation for atrial fibrillation between April 2022 and December 2022. The ablation lesion set could include re-isolation of the pulmonary veins (PVs) and isolation of the superior vena cava. Patients with ablation procedures targeting other arrhythmia were excluded from this study. This study complied with the Declaration of Helsinki and was approved by the local medical ethics committee. Written informed consent was obtained from all patients prior to the ablation procedure.

2.2 | System configuration

The KODEX-EPD system was set up with its body surface patches ('Dielectric Sensors'), a multi-electrode diagnostic catheter (Inquiry™ Quadripolar, Abbott Cardiovascular, Plymouth, MN, USA), a circular mapping catheter (Inquiry™ AFocus II™, Abbott), and a noncontact force-sensing irrigated RF ablation catheter (MapiT® Irrigated, Access Point Technologies EP, Rogers, MN, USA). The latest market released software was used to guide the ablation procedures (version 1.5.1 or 1.5.1a).

2.3 | Dielectric-based local tissue assessment

In addition to conventional electroanatomic mapping, the dielectric imaging system enables dielectric-based local tissue assessment. To perform dielectric-based local tissue assessment, the system generates electrical fields between the electrodes on the catheter tip. The shape of these electrical fields can be affected by the dielectric properties (i.e., conductivity and permittivity) of the tissues that are near the catheter tip. By measuring minute changes in the electrical field strength, the system can establish anatomical information on its immediate surrounding.[9] This technique is used by the system to enable the TRV (Figure 1C) that provides a novel marker for ablation lesion quality. This tool uses local dielectric tissue assessment to detect changes in dielectric properties that occur during ablation. Using these measurements, the system classifies ablation points into high or low dielectric response (HDR or LDR) after each RF application to indicate a likely transmural or nontransmural ablation lesion. Other dielectric-based local tissue assessment features include the tissue engagement viewer (TEV, Figure 1A) and the wall viewer (WV, Figure 1B). The TEV uses dielectric-based measurements to provide an indication of catheter–tissue contact with a noncontact force-sensing catheter. Outcomes are categorized into: No Touch (up to 5.5 g of force), Normal Touch, or High Touch (27.5 g or higher). The WV aims to assess the local thickness of the myocardial wall. The tool provides an indication of wall thickness in millimeters and has already been used to guide ablation of the cavotricuspid isthmus.[10,11]

2.4 | Ablation procedure

The ablation procedures were performed under conscious sedation or general anesthesia. The multi-electrode diagnostic catheter was positioned in the coronary sinus. A single transseptal puncture was performed to position the circular mapping catheter and the ablation catheter in the left atrium. A steerable sheath could be used at the operator's discretion to guide the RF ablation catheter. The KODEX-EPD system was used to generate an electroanatomic map of the left atrium. This electroanatomic map was used, in conjunction with the assessment of local electrograms and pacing maneuvers, to evaluate whether the PVs were isolated.

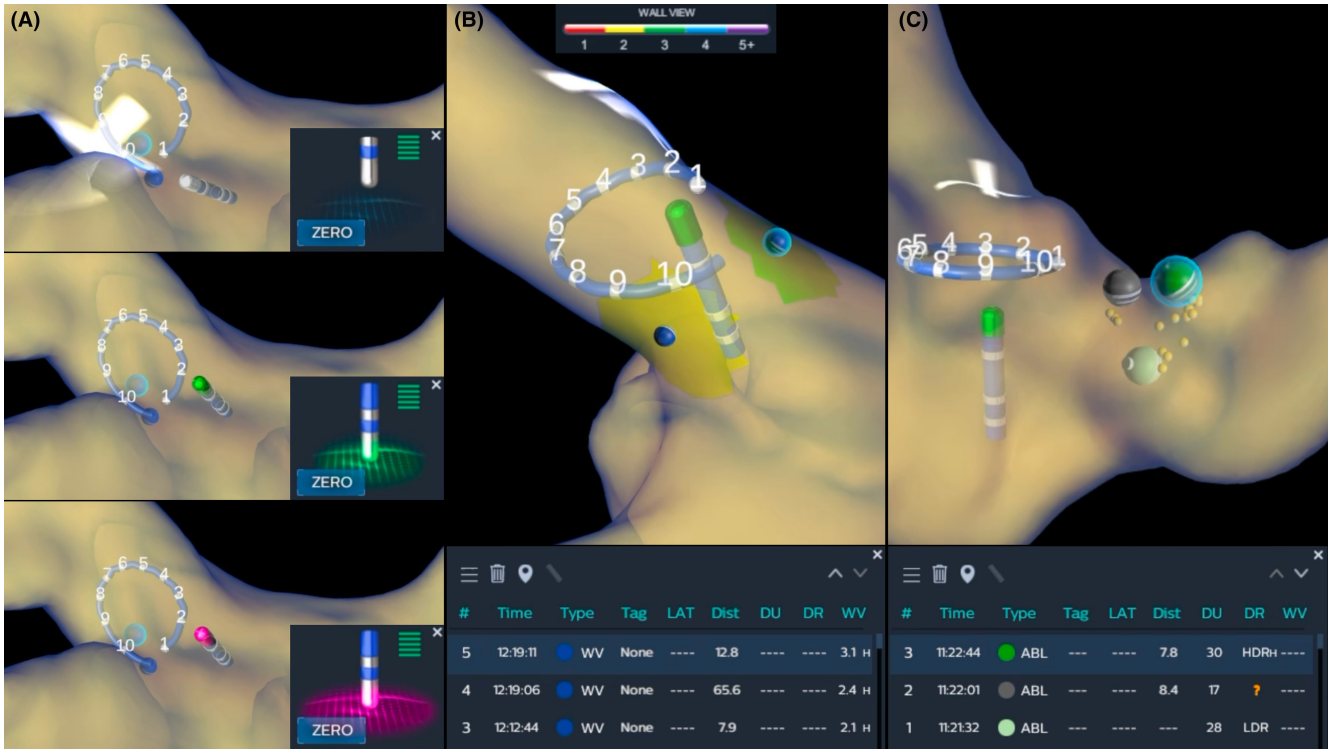

FIGURE 1 KODEX Vision features. Panel A: Tissue Engagement Viewer, No Touch (white catheter tip), Normal Touch (green catheter tip), and High Touch (magenta catheter tip). Panel B: Wall Viewer indicating atrial wall thickness (color legend in figure). Panel C: Tissue Response Viewer indicating No measurement (gray), Low Dielectric Response (light green) or High Dielectric Response (dark green).

If a PV was not isolated, gaps in the prior ablation lesion were targeted using RF ablation. Ablation was performed with power set at 35 W for anterior parts of the PV and 30 W for posterior parts, for a typical duration of 60 seconds. The KODEX-EPD system automatically generated ablation lesion points to mark the locations of ablated sites. Movement of the ablation catheter during an energy application could consequently result in the generation of multiple ablation points by the system. The TEV was used to assess catheter–tissue contact before each energy application. RF ablation was performed until all PVs were re-isolated. In addition to PV re-isolation, the superior vena cava could be assessed for local potentials at the operator's discretion. If local potentials were present, isolation of the superior vena cava was targeted. RF applications for this target typically had a duration of 30 s, with power set at 20–25 W. All other ablation settings were similar to PV re-isolation. Prior to each application, pacing maneuvers were used to assess for phrenic nerve capture. If phrenic nerve capture was present, no RF energy was applied. Ablation was continued until superior vena cava (SVC) isolation or until isolation was deemed not possible due to phrenic nerve capture.

2.5 | Ablation point parameters

The KODEX-EPD system registers various ablation parameters per ablation point, including duration, power, temperature, impedance, local wall thickness, and dielectric response. All ablation point data were downloaded from the KODEX-EPD system with the most recent software version. Subsequently, a custom python script was used to extract all ablation parameters into a single data file for statistical analysis. Dielectric response, local wall thickness, mean power, and temperature were provided for each ablation point by the KODEX-EPD system. Impedance drop was calculated by subtracting the lowest impedance measurement from the impedance at baseline (average of first 0.5 s of ablation). Dragging ablation was defined as one ablation energy application that resulted in multiple ablation points on the electroanatomic map.

2.6 | Statistical analysis

Continuous variables are expressed as mean and standard deviation or median and interquartile range where appropriate. Categorical variables are expressed as counts and percentages. Normally distributed continuous variables were compared using the Student's t test. Categorical variables were compared using χ^2 test. Univariable and multivariable logistic regression modeling were used to explore the association between the dielectric response and other ablation parameters. All ablation parameters were assessed in the multivariable regression model. Missing ablation parameter data was handled using complete case analysis. Multicollinearity was assessed by calculating the variance inflation factor for all ablation parameters in the model. All tests were two-sided, and a $p < .05$ was considered statistically significant.

All statistical analyses were performed using R (version 4.1.2, R Foundation for Statistical Computing, Vienna, Austria) with the following packages: epidisplay, ggthemes, ggpubr, tidyverse, and tableone.

3 | RESULTS

3.1 | Patient and procedure characteristics

Between April 2022 and December 2022, 24 patients had a repeat catheter ablation for atrial fibrillation using the KODEX-EPD system. Twenty (83%) of these patients were male, and the mean age was 65.4 ± 7.8 years (Table 1). The mean left atrial volume (indexed for body surface area) was 28.8 ± 7.7 mL/m^2 (five missing), and mean left ventricular ejection fraction was 58.2 ± 8.4% (four missing). Patients had atrial fibrillation history for a duration of 5.5 [IQR: 2.7–12.0] years, and prior PVI was performed 1.9 [1.3–5.5] years earlier. Prior PVI included catheter ablation with a single-shot RF ablation catheter in 14 (58%) patients, ablation with a single tip contact force-sensing RF catheter in 9 (38%) and single tip noncontact force-sensing in 1 (4%). The pattern of atrial fibrillation was paroxysmal in 20 (83%) and persistent in 4 (17%).

The procedural characteristics are summarized in Table 2. The dielectric imaging system was used to create an electroanatomic map of the left atrium (mapping time 6 [4–8] min). These electroanatomic maps revealed a total of 94 PVs (1 patient with left common pulmonary vein and 1 patient with occluded LSPV due to pulmonary consolidation) of which 58 (62%) were not isolated, with an even distribution between left and right, and superior and inferior PVs. All reconnected veins were targeted with RF ablation, which resulted in successful re-isolation of all PVs. In addition to PVI, the superior vena cava was assessed for local potentials in 11 patients (mapping time 1 [1–2] min). Local potentials were present and targeted in 8/11 (73%) patients, which resulted in successful isolation in 7/11 (64%) patients. In the patient with ablation without SVC isolation, this was due to the vicinity of the phrenic nerve.

TABLE 1 Baseline characteristics.

	Cohort, *n* = 24
Age (year)	65.4 ± 7.8
Male	20 (83)
BMI	27.0 ± 3.7
CHA_2DS_2VASC	1.3 ± 1.3
LAVI (mL/m2)	28.8 ± 7.7
LVEF (%)	58.2 ± 8.4
Class 1 AAD	8 (33)
Class 2 AAD	9 (38)
Class 3 AAD	7 (29)
Class 4 AAD	1 (4)
Class 5 AAD	1 (4)

Note: Continuous: mean ± SD, categorical: *n* (%).
Abbreviations: AAD, anti arrhythmic Drugs; BMI, body mass index; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction.

3.2 | Ablation points

A total of 388 energy applications were applied, resulting in 639 ablation points in the system (556 targeting PV and 83 SVC). The ablation parameters, stratified per target, are presented in Table 3. The WV did not provide an outcome in 14 ablation points. There were no missing values in ablation duration, mean power, mean temperature, and impedance drop.

3.3 | Dielectric response availability

The tissue response viewer did not provide a dielectric response in 128/639 (20%) ablation points. The inability to provide a dielectric response was associated with dragging ablation and shorter energy applications (Table 4, Figure 2).

3.4 | Dielectric response outcomes

The tissue response viewer classified 230/511 (45%) lesions as HDR versus 281/511 (55%) as LDR. A high dielectric response was

TABLE 2 Procedural characteristics.

	Cohort, *n* = 24
Rhythm at procedure start	
Sinus rhythm	21 (88)
Atrial fibrillation	3 (13)
Ablation	
LSPV	16/22 (73)
LIPV	11/23 (48)
LCPV	1/1 (100)
RSPV	13/24 (54)
RIPV	17/24 (71)
SVC	8 (33)
Rhythm at procedure end	
Sinus rhythm, after DCCV	3 (13)
Sinus rhythm, without DCCV	21 (88)
Procedure time (min)	66.9 ± 13.3
Fluoroscopy time (min)	11.8 ± 4.4
Dose area product (Gy*cm^2)	18.9 ± 8.9

Note: Continuous: mean ± SD, categorical: *n* (%).
Abbreviations: DCCV, direct current cardioversion; LCPV, left common pulmonary vein; LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein; SVC, superior vena cava.

associated with longer energy applications, higher mean power, and lower local wall thickness (Table 5, Figure 3). Impedance drop was univariably, but not multivariably associated with high dielectric response.

3.5 | Arrhythmia recurrence

After 10.5 [7.7–12.5] months of follow up, five patients (21%) had recurrence of atrial tachyarrhythmia (all atrial fibrillation, no other supraventricular tachycardia). One patient had a surgical ablation procedure to treat atrial fibrillation recurrence. None of the patients had another repeat catheter ablation procedures. The proportion of ablation points classified as HDR (versus LDR or no DR) was similar among patients with (HDR in 29% [15%–41%] of applications) and without atrial tachyarrhythmia recurrence (HDR in 34% [21%–52%], $p = .68$).

4 | DISCUSSION

This observational study describes the clinical application of a dielectric-based lesion assessment tool for RF ablation. The dielectric imaging-based electroanatomic mapping system was used to guide repeat ablation for atrial fibrillation in this cohort of 24 patients. To gain further insight in the TRV, we analyzed the ablation parameters of all ablation points that were applied in this cohort.

We found that the outcomes of the TRV were associated with conventional ablation parameters and local atrial wall thickness. Greater impedance drop, that was initially used as a marker for ablation lesion quality,[12] was univariably but not multivariably associated with high dielectric response, whereas low local wall thickness, longer duration, and higher mean power of the application were multivariably associated with dielectric response. The correlation with RF power and duration is well known, as both parameters are used in current indices for ablation lesion quality.[1,2] Notably, local wall thickness, as determined by the KODEX WV, appears to have a significant impact on dielectric response. Earlier studies have established a relationship between atrial wall thickness and ablation lesion success,[13,14] but until now no guiding systems have had the capability of real-time atrial wall thickness assessment. Although none of the KODEX Vision features are currently validated, a correlation between local wall thickness and ablation lesion quality seems logical. By accounting not only for conventional ablation parameters but also for local wall thickness and changes in dielectric properties, the TRV could potentially provide a more reliable evaluation of ablation lesion quality.

However, in contrast to conventional ablation indices, the current version of the TRV does not always provide an outcome for dielectric tissue response. Opposed to conventional ablation indices, that rely mostly on catheter outputs (i.e., power, duration, etc.), the TRV also requires local tissue assessments (i.e., wall thickness and local dielectric properties). These local tissue assessments may require a certain level of catheter stability, as we found that dragging ablation and shorter time at an ablation point were associated with missing dielectric tissue outcomes.

The acute procedural characteristics and atrial tachyarrhythmia recurrence rate of this cohort were similar to prior studies on repeat ablation procedures for atrial fibrillation.[15–18] Although these outcomes are encouraging for dielectric imaging-guided repeat ablation, they provide no evidence on the exact impact of the TRV feature, as the dielectric imaging system differs on multiple aspects from other electroanatomic mapping systems (e.g., the TEV and WV features). Similarly, an analysis on the relation between the proportion of ablation points that were classified as HDR (instead of LDR or no DR) and arrhythmia recurrence at follow-up may not provide insights in the potential benefit of the TRV, because outcomes at an ablation point level may not correlate with outcomes on a patient level. For instance, a single nontransmural ablation point could result

TABLE 3 Ablation points.

	Left atrium, $n = 556$	Right atrium, $n = 83$	p
Duration (s)	21.2 ± 12.8	25.5 ± 13.7	.004
Mean power (W)	31.2 ± 2.9	20.3 ± 1.4	<.001
Mean temperature (°C)	32.9 ± 2.1	33.2 ± 1.4	.27
Impedance drop (Ω)	9.6 ± 5.8	10.6 ± 5.3	.14
Wall thickness (mm)	3.0 ± 0.6	2.7 ± 0.5	<.001
NA	14 (3)	0 (0)	
Dielectric response			
HDR	215 (39)	15 (18)	
LDR	230 (41)	51 (61)	
NA	111 (20)	17 (21)	

Note: Continuous: mean ± SD, categorical: *n* (%).
Abbreviations: HDR, high dielectric response; LDR, low dielectric response; NA, not available.

TABLE 4 Factors associated with unavailability of dielectric response (versus dielectric response available).

		Dielectric response	No dielectric response	OR (univariable)	OR (multivariable)
Duration (s)	Mean ± SD	22.8 ± 13.0	17.6 ± 12.2	0.96 (0.95–0.98) p < .001	0.98 (0.96–0.99) $p = .02$
Dragging	Dragging	316 (61.8)	104 (81.2)	–	–
	No dragging	195 (38.2)	24 (18.8)	0.37 (0.23–0.60) $p < .001$	0.53 (0.30–0.94) $p = .03$

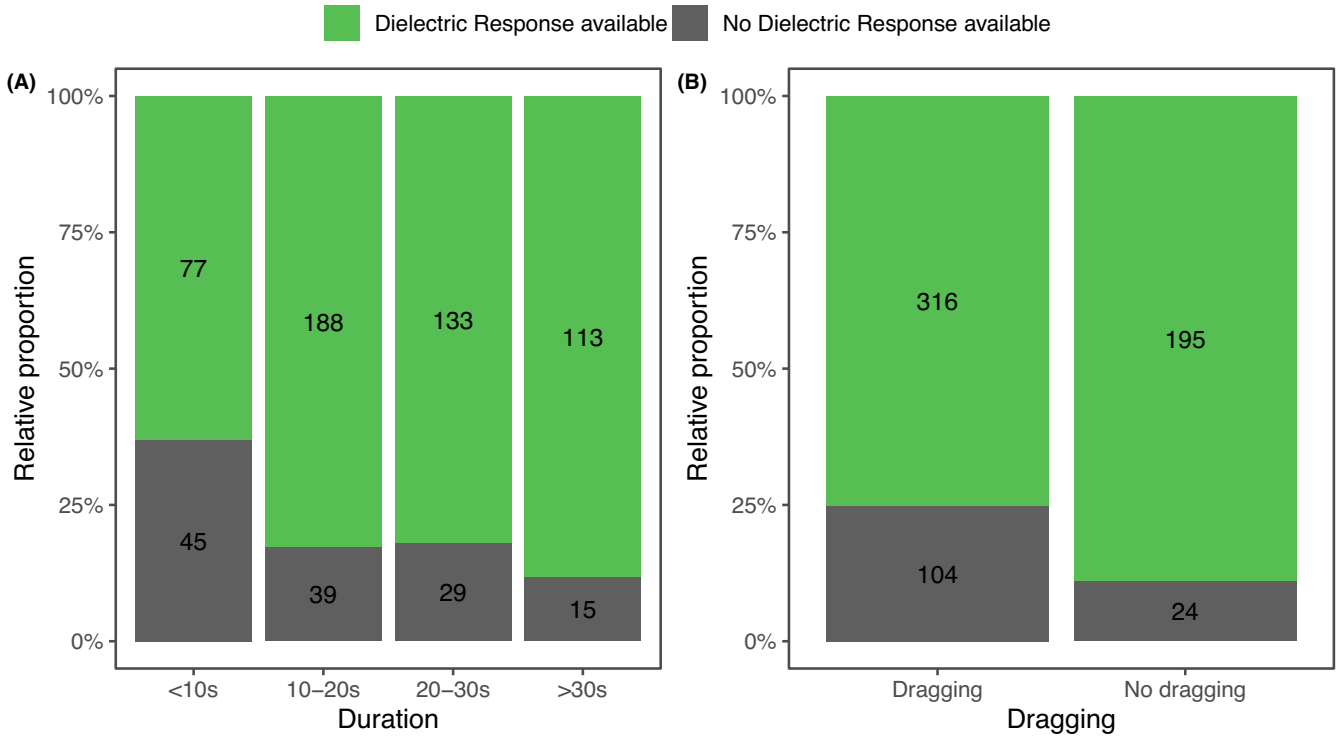

FIGURE 2 Relative proportions of dielectric response availability. Panel A: Categorized by duration of the energy application. Panel B: Categorized by dragging versus no dragging.

TABLE 5 Factors associated with high dielectric response (versus low dielectric response).

		High DR	Low DR	OR (univariable)	OR (multivariable)
Duration (s)	Mean ± SD	31.9 ± 11.8	15.3 ± 8.2	1.20 (1.17–1.24) $p < .001$	1.25 (1.25–1.30) $p < .001$
Mean power (W)	Mean ± SD	30.7 ± 4.0	28.9 ± 5.0	1.09 (1.05–1.14) $p < .001$	1.27 (1.18–1.36) $p < .001$
Mean temperature (°C)	Mean ± SD	33.0 ± 1.7	33.0 ± 2.3	1.00 (0.92–1.09) $p = .97$	0.93 (0.79–1.10) $p = .41$
Wall thickness (mm)	Mean ± SD	2.9 ± 0.6	3.1 ± 0.6	0.58 (0.42–0.79) $p < .001$	0.23 (0.14–0.40) $p < .001$
Impedance drop (Ω)	Mean ± SD	11.1 ± 6.2	9.3 ± 5.4	1.06 (1.03–1.09) $p < .001$	0.99 (0.95–1.04) $p = .71$

in arrhythmia recurrence in a patient with an otherwise high proportion of ablation points classified as HDR.

4.1 | Limitations

This was the first study to present data on the clinical use of dielectric imaging-based ablation lesion assessment using the TRV. Although the study provides an initial insight in the clinical application of this tool, it has several limitations. The most important limitation was the lack of a comparator for the TRV outcomes. Future studies could include a routine repeat electrophysiology study or late gadolinium-enhanced cardiovascular magnetic resonance imaging to correlate the outcomes of the TRV to ablation lesion durability. Alternatively, a future study could include contact force-sensing catheters so that TRV outcomes can be compared with conventional ablation indices (e.g., Force-Time Integral, AI, and LSI). An additional limitation of this study was the selected patient population that focused on repeat ablation procedures for atrial fibrillation. This selection may limit the extrapolation of the outcomes, as previously ablated tissue could theoretically impact the performance of the TRV. However, the observed TRV outcomes were similar for ablation points that targeted isolation of the superior vena cavae, which were not ablated during the initial ablation procedures. Lastly, at present operators did not fully rely on the TRV for guidance on ablation lesion creation, as the tool has not yet been validated and currently displays outcomes only after the energy application. For effective guidance of ablation lesion creation, the TRV should provide its outcome during ablation so that operators can modulate ablation duration accordingly. Future studies should be conducted in which the TRV is effectively used during ablation to evaluate whether the potential benefits of this tool will indeed result in improved clinical outcomes.

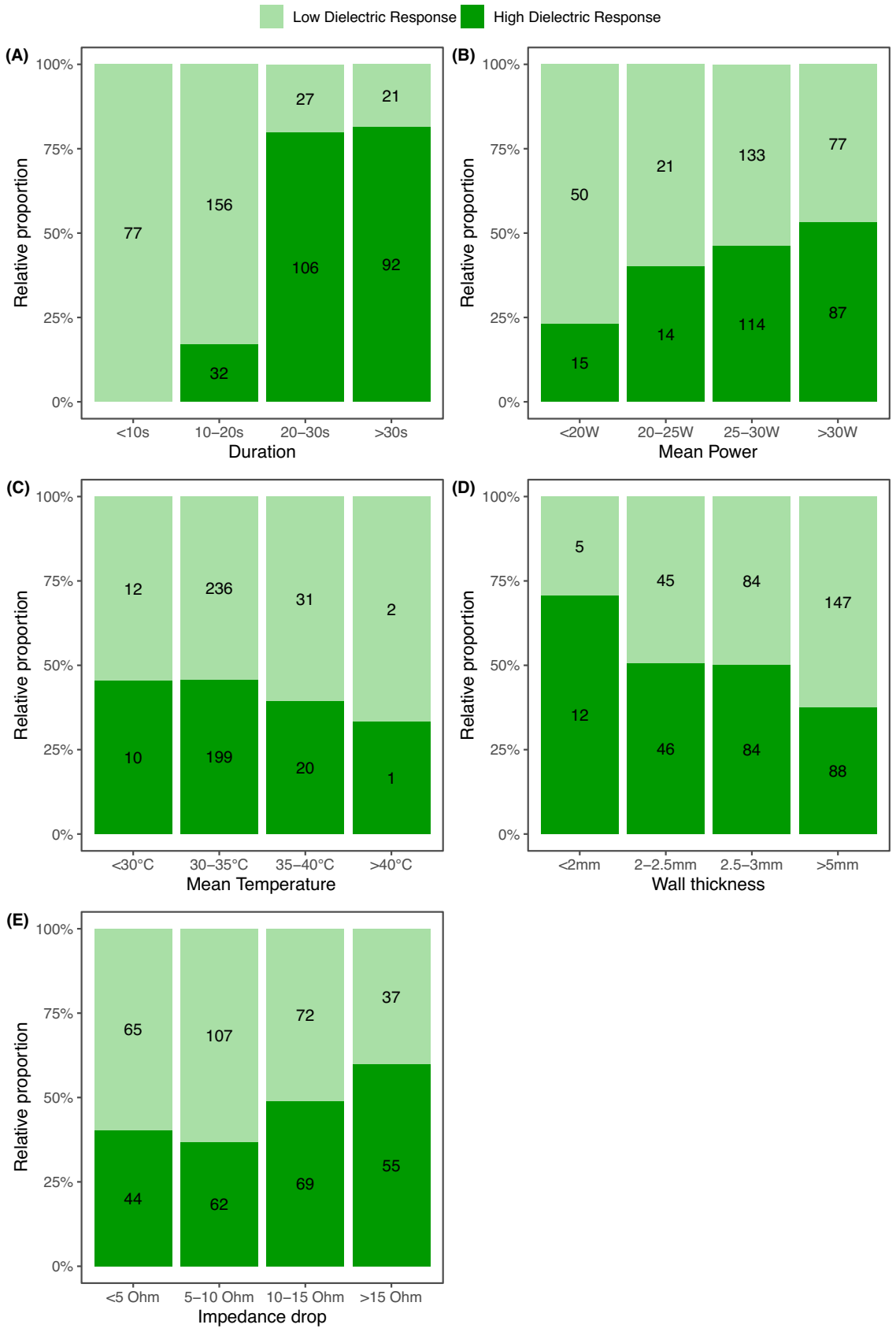

FIGURE 3 Relative proportions of dielectric response outcome. Panel A: Categorized by duration of the energy application. Panel B: Categorized by mean power. Panel C: Categorized by local wall thickness. Panel D: Categorized by impedance drop. Panel E: Categorized by mean temperature.

5 | CONCLUSION

The TRV is a novel dielectric measurements-based marker for ablation lesion quality. Outcomes of the TRV are related to conventional ablation parameters but also local wall thickness. Clinical validation is warranted before widespread adoption of this tool.

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CONFLICT OF INTEREST STATEMENT

VvD and LB are consultants for Philips. All other authors declare they have no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available upon reasonable request.

ETHICS STATEMENT

The study was conducted in compliance with Good Clinical Practice Guidelines and was approved by the Ethics Committee and local institutional review board.

PATIENT CONSENT

All patients provided written informed consent.

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