Characterization of Contact Force During Endocardial and Epicardial Ventricular Mapping

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Background—The optimal contact force (CF) for ventricular mapping and ablation remains unvalidated. We assessed CF in different endocardial and epicardial regions during ventricular tachycardia substrate mapping using a CF-sensing catheter (Smartouch; Biosense-Webster) and compared the transseptal versus retroaortic approach.

Methods and Results—In total, 8979 mapping points with CF, and force vector orientation (VO) were recorded in 21 patients, comprising 13 epicardial, 12 left ventricular (6 transseptal and 6 retroaortic approach), and 12 right ventricular endocardial maps. VO was defined as adequate when the vector was directed toward the myocardium. During epicardial mapping, 46% of the points showed an adequate VO and a median CF of 8 (4–13) g, however, with significant differences among the 8 regions. When VO was inadequate, median CF was higher at 16 (10–24) g (P<0.0001). During left ventricular and right ventricular endocardial mapping, 94% of VO were adequate. Median CF of adequate VO was higher in the left ventricular and right ventricular endocardium than in the epicardium (15 [8–25] and 13 [7–22] g versus 8 [4–13] g, respectively; both P<0.001). Global median left ventricular CF with transseptal approach was not statistically different from retroaortic approach, but CF in the apicoinferior and apicoseptal regions was higher with transseptal approach (P<0.001).

Conclusions—Ventricular mapping demonstrates important regional variations in CF, but in general, CF is higher endocardially than epicardially where poor catheter orientation is associated with higher CF. A transseptal approach may lead to improved contact particularly in the apicoseptal and inferior regions.

Key Words: catheter ablation ■ contact force ■ endocardium ■ epicardium ■ ventricular tachycardia

Ablation of scar-related ventricular tachycardia (VT) often relies on a substrate-based approach. Electroanatomic mapping is commonly performed to identify low-voltage regions and local abnormal ventricular activities.1-3 During substrate mapping, poor tissue contact may lead to gaps in the electroanatomic shell or may mislabel a normal region as a low-voltage scar area. Substrate detection may be affected, and local abnormal ventricular activities may be more difficult to identify. Unfortunately, several indicators of contact during mapping and ablation, including observation of catheter movement during fluoroscopy, catheter impedance, and ST changes in the unipolar signal during ablation, have limited efficacy.4,5

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The contact force (CF) catheter allows assessment of realtime CF at the tip of the catheter. The CF observed during endocardial and epicardial ventricular mapping and ablation has not been reported yet.

This study aimed to assess the CF in different endocardial and epicardial regions during VT substrate mapping using a CF catheter (Smartouch; Biosense-Webster) and to compare transseptal and retroaortic approaches.

Methods

Study Population
CF was assessed in a total of 37 ventricular chambers in 21 patients (18 men; age, 53±15 years) referred to our center for VT ablation, using a 3-dimensional electroanatomic mapping system and CF catheter. Seven patients presented with ischemic cardiomyopathy, 9 with arrhythmogenic right ventricular (RV) cardiomyopathy, 1 with myocarditis, and 1 with Brugada syndrome. Three patients had no structural heart disease. The study was approved by our local institutional review committee. Written informed consent was obtained for all patients.

Left Ventricle and RV and Pericardial Accesses
Substrate mapping and ablation were performed under conscious sedation and supplementary analgesia (sufentanil or remifentanil) under supervision of an anesthesiologist for the pericardial approach. Vascular sheaths were inserted into the right femoral vein, right femoral artery, and subxyphoid area under local anesthesia (bupivacaine). A 6-French steerable quadripolar or decapolar catheter (2.5-2 mm; Xtreem; ELA Medical, Montrouge, France) was positioned in the RV apex or coronary sinus.

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Retrograde access to the left ventricle (LV) was obtained through the right femoral artery in 6 patients. The LV endocardium was accessed by transeptal puncture using a long curve steerable sheath (Agilis; St. Jude Medical) and BRK Needle (St. Jude Medical) in 6 patients. The transeptal sheath was advanced to the level of the mitral annulus. The access to RV was obtained through the right femoral vein using a medium curve sheath (Agilis; St. Jude Medical).

Pericardial access was obtained in patients in whom an epicardial substrate was suspected based on the clinical VT morphology on surface ECG, the nature of the underlying heart disease, or the preprocedural MRI, suggesting subepicardial substrate. Pericardial access, as described by Sosa et al6,7 was modified so as to access the pericardial space through an anterior puncture to prevent intra-abdominal route, as previously described.8 The pericardial puncture was guided by a 90° left lateral fluoroscopic projection. A steerable sheath (Agilis; St. Jude Medical) was then introduced in the pericardial space to provide catheter stability and maneuverability.

**CF Catheter**

All procedures were performed with an irrigated CF catheter (Thermocool SmartTouch; Biosense-Webster, Inc, Diamond Bar, CA) and the CARTO 3 mapping system (Biosense-Webster). The catheter uses a 3.5-mm irrigated tip electrode with location sensors at the tip that are connected by a precision spring to the shaft, housing microsensors to detect small movements of the catheter.

Before mapping, the catheter was calibrated while floating free in the right atrium to set the baseline value. The force was measured in real-time in grams. The direction of the force was displayed as an arrow vector on the tip of the catheter image on the CARTO 3 system. CF for each acquired point was recorded along with the voltage and local activation time.

**Mapping**

Two experienced operators performed endocardial and epicardial ventricular mapping blinded to CF information. During radiofrequency delivery, CF and force vector orientation (VO) were carefully monitored. Electroanatomical maps were constructed by manually tracing the wall surface with the roving catheter. When the operator judged the position and contact as stable (≥2.5 s), the point was acquired on the CARTO system. Low voltage and scar were defined by bipolar voltage of 0.5 to 1.5 mV and <0.5 mV, respectively (Figure 1).

Thirteen epicardial, 12 LV endocardial maps (6 with transseptal and 6 with retroaortic), and 12 RV endocardial maps were constructed in the 21 patients. A total of 4155 epicardial, 2629 LV, and 2195 RV endocardial mapping points were recorded in sinus rhythm. The CF and VO were assessed among the following regions: anterior, LV, inferior, RV for the epicardium and anterior, lateral, inferior, and septal for LV endocardium. Each region was divided into basal and apical segments. RV endocardial regions were apical, septal, inferior, free wall, and RV outflow tract (Figures 2, 4 and 7). VO was defined as adequate epicardially when the vector was pointing inward the myocardium and adequate endocardially when pointing outward from the myocardium with an angle strictly higher than 0° (Figure 1). Each point was assigned to one of the different regions, the CF was registered, and the vector was assessed as adequate or not. In normal healthy regions, the voltage of each point was recorded.

**Statistical Analysis**

Continuous variables are expressed as mean±SD or median and interquartile range (25th–75th percentile), depending on the normality of the distribution. Categorical variables are represented as percentages. Comparison of quantitative CF was performed using general linear mixed models with $\gamma$ distribution. The correlation between patient values was handled through the unstructured covariance matrix of random effects. Categorical variables were compared using a general linear mixed model. The relationship between a bipolar signal amplitude >1.5 mV, and quantitative CF was evaluated by fitting a logistic mixed regression. The response variable was a bipolar signal >1.5 mV and the covariate was CF with subjects and regions defined as random effects. The estimated probabilities were used to determine the threshold allowing us to minimize the total misclassification rate. A value $P<0.05$ was considered statistically significant.

Statistical analysis testing was performed with the Language and Environment for Statistical Computing: R software version 3.1.0 (R Core Team; R Foundation for Statistical Computing, Vienna, Austria).

**Results**

**Patient Characteristics**

Twenty-one patients aged 53±15 years were included. Eighteen (82%) were men and 17 (81%) had a previously implanted implantable cardiac defibrillator. An underlying structural heart disease was present in 18 patients, ischemic in 7 (39%), arrhythmogenic right ventricular cardiomyopathy in 9 (50%), Brugada syndrome in 1 (5.5%), and myocarditis in 1 (5.5%). Patient characteristics are summarized in the Table.

A total of 8979 points were analyzed corresponding to 13 epicardial maps (4.155 points), 12 LV endocardial maps (2.629 points), and 12 RV endocardial maps (2.195 points). Six LV endocardial maps were performed with a transseptal approach and 6 with a retroaortic.

**Epicardial CF**

Of 4,155 analyzed points, 46% showed adequate VO (ie, pointing inward the myocardium). The median CF observed epicardially in case of adequate VO was 8 (4–13) g. CF was significantly greater (16 (10–24) g; $P<0.0001$) when the VO was adequate.
not adequate. There was a significant difference in CF between different regions in the epicardium ($P<0.0001$). It was lower in the 4 apical regions. There was also a significant regional difference in the percentage of adequate VO ($P<0.0001$). In the 4 apical regions, more than half of the vectors were not pointing inward the myocardium. In apical and basal LV region, only 20% and 31% of VO were adequate (Figure 2).

**Left Endocardial CF**

During endocardial LV mapping, 92% of VO were adequate. Median CF was greater than in the epicardium (15 [8–25] versus 8 [4–13] g; $P<0.001$). The overall median CF using a transseptal approach was not significantly different from a retroaortic approach (16 [8–27] versus 14 [8–22] g; $P=NS$). High CF (>40 g) was recorded in 7% of transseptal points and in 4% of retroaortic points. With transseptal, CF>20 g was recorded in 41% of the points and in 30% with retroaortic approach ($P<0.01$; Figure 3).

There was a significant difference in CF within the 8 segments of the LV using a transseptal approach ($P<0.0001$). CF was lower in the basal septum and basal anterior regions when compared with that in other regions (Figure 4). There was also a significant difference in CF within the 8 segments of the LV using a retroaortic approach ($P<0.0001$). CF was lower in the septum and basal anterior regions (Figure 4). Highest contact was observed in basal-lateral and basal-inferior regions.

When comparing the effect of approach on CF by region, a significant difference was observed in apicoinferior and apico-septal region in favor of a transseptal approach ($P<0.001$ and $P=0.02$, respectively; Figure 5).

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ARVC indicates arrhythmogenic right ventricular cardiomyopathy; BS, Brugada syndrome; CAD, coronary artery disease; EF, ejection fraction; EPI, epicardium; ICD, implantable cardiac defibrillator; LV, left ventricle; RAo, retroaortic; RV, right ventricle; and TS, transseptal.
Right Endocardial CF
During endocardial RV mapping, 95% of VO were adequate. Median CF was lower than in the LV endocardium and greater than in the epicardium (13 [7–22] versus 15 [8–25] g; \( P < 0.0001 \) versus 8 [4–13] g; \( P < 0.0001 \), respectively).

There was a significant difference in CF within the 5 regions of the RV endocardium (\( P < 0.0001 \)). CF was lower in the septal and apical regions and the highest CF was observed on the free wall (Figure 6).

Potential Amplitude According to the Contact in the Endocardium and in the Epicardium
In the endocardium, the bipolar signal amplitude in healthy regions of the ventricles increased with CF. No further significant increase was observed after 10 g (Figure 7).

Based on a general linear mixed model analysis, the best cutoff value for CF to obtain a signal amplitude >1.5 mV in the LV endocardium was 7 g (sensitivity 80% and specificity 75%) and 9 g (sensitivity 65% and specificity 83%) in the RV endocardium.

In the epicardium, the bipolar signal amplitude of healthy regions increased progressively with CF. No further significant increase was noted after 10 g (Figure 7). The best cutoff value to obtain a normal potential in the epicardium was 4 g (sensitivity 83% and specificity 64%).

Discussion
This study provides new insights into the characterization of CF during endocardial and epicardial ventricular mapping:

1. Important regional differences exist in CF according to the mapped region of the ventricle but as a rule, endocardial contact is higher than epicardial.
2. During epicardial mapping, catheter orientation can be inadequately directed away from the myocardium in almost half of the mapping points, and this inadequate orientation is frequently associated with higher CF.
3. During LV endocardial mapping, transseptal approach is associated with higher CF than the retroaortic approach in the apicoinferior and apicocephalic regions.

Epicardial Contact
Inadequate VO in the epicardium may potentially decrease ablation efficacy and increase risks, by causing extracardiac lesions. The pericardial space is virtual, allowing to maintain the catheter in contact with the myocardium. Applying significant force to the catheter seems to direct the vector to the concavity of the pericardial space, potentially tenting the parietal pericardium. In an animal study, our group showed, (albeit with another contact catheter), that the total force was much higher when ablation was performed on the endocardium because of an increased axial force. On contrary, in the pericardial space, the lateral component of the force was more important. This could also explain the tendency of epicardial lesions to be shallower and wider than endocardial lesions. In that article, we also showed that a CF of <10 g in the epicardium was sufficient to create a lesion, and there was no clear difference in lesion depth or volume with increased CF. In addition, extracardiac lesions were also observed, particularly on lungs, when the force was not directed toward the myocardium. These data suggest that, in the pericardial space, the force orientation may be more important, for both safety and efficacy, than the amount of applied force.
Mapping healthy epicardium, bipolar signal amplitude increased significantly with CF but not after 10 g. The best cutoff value to have a normal bipolar signal amplitude (>1.5 mV) was 4 g. A small number of points of the curve may be altered because of the presence of fat, which led to a smaller potential amplitude. Mizuno et al. have calculated a best CF cutoff value to obtain systolodiastolic contact in the epicardium at 8 g. The difference could be explained by the fact that we only took into account points with adequate VO.

When analyzing regional differences of CF in the epicardium, apical segments and the whole lateral region (LV) showed lower contact when VO was adequate and fewer adequate VO. This could be explained by an anterior pericardial puncture. The steerable sheath is, therefore, important to stabilize VO. This could be explained by the careful attention of the operator in relation to contact, we did not find any improvement in bipolar signal amplitude with strong force when compared with the epicardium where lateral force was more predominant.

Mizuno et al. reported a mean CF during LV endocardium mapping of 10.5±9.2 g using a retroaortic approach alone, whereas, by combining it with transseptal approach, the CF significantly increased to 13.9±10.2 g. We also reported an overall force of 16 g with transseptal versus 14 g with retroaortic route, but the difference is not statistically significant. With a transseptal route, 41% of the mapping points displayed a CF>20 g versus 30% with a retroaortic approach.

When comparing regions with both approaches, basal anterior and basal septum LV seemed to have lower overall CF. As recently demonstrated in the left atrium, LV anatomy mapping can be more challenging in certain areas. No data are available yet on the relationship between CF and VT recurrence or local abnormal ventricular activities elimination.

Tilz (oral communication American Heart Association 2011) showed dividing the LV in 11 regions and using retroaortic approach, that the highest CF was in basal-inferior and basal-lateral areas, which is concordant with our findings.

When comparing the effect on CF of the 2 approaches by region, there is a significant difference in apical septum and apical inferior region in favor of a transseptal approach.

To reach the septum and the anterior region of the LV by a retroaortic route, the catheter needs 2 curves, which probably results in less contact. Tortuosity of the aorto-ileo-femoral arteries may also have an effect on CF. With a transseptal approach, a steerable sheath may stabilize the catheter and increase CF. Shah et al. showed on a porcine heart model that time to LV perforation was shorter when a sheath was used because of a greater contact. A large proportion of patients with VT have ischemic cardiomyopathy with cardiovascular risk factors. Manipulation of an ablation catheter in the aorta or peripheral arteries may be hazardous in this setting. A transseptal puncture is not without risk; however, and ultimately, the approach must be tailored to the patient.

Okumura et al. and more recently Mizuno et al. reported the relationship between the catheter contact and the electrogram amplitude. When analyzing electrograms according to contact, we did not find any improvement in bipolar signal amplitude after 10 g in the endocardium. We found 7 g as a cutoff contact value to expect a normal bipolar signal amplitude (>1.5 mV). Similarly, Mizuno et al. found no improvement of bipolar signal amplitude with strong force (>20 g), whereas a weak CF resulted in low-signal amplitude and a cutoff value for good systolodiastolic contact in the LV endocardium of 8 g was calculated.

**LV Endocardial Mapping**

During LV endocardial mapping, most VO were adequate. Here, the VO information seems to be less important because the catheter may move freely within the cavity. The median CF of 15 g was significantly greater than in the epicardium. Our group already showed a much higher CF (39±18 g) in a sheep model from the endocardium because of increased axial force when compared with the epicardium where lateral force was more predominant.

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**RV Endocardial Mapping**

RV endocardial mapping characteristics were similar to the LV with mostly adequate VO and a greater CF when compared with the epicardium. Overall, CF in the RV was lower than in the LV but the difference, although statistically significant, was modest.

There were significant differences in CF within the 5 RV regions. Surprisingly, in the apex, a lower CF of 9 g was observed. In clinical practice, the apex is usually easily accessible and a higher CF would be expected. This may be partially explained by the careful attention of the operator in relation with the risk of perforation, especially with the use of a steerable sheath. The highest CF was observed in the free wall. The greater proportion of arrhythmogenic right ventricular cardiomyopathy (9/12) in our cohort could explain this result with the use of a steerable sheath. The highest CF was observed in the free wall. The greater proportion of arrhythmogenic right ventricular cardiomyopathy (9/12) in our cohort could explain this result with the use of a steerable sheath.
be optimum to acquire a normal bipolar signal amplitude (>1.5 mV), which is similar to the 9 g reported by Mizuno et al.10

Limitations
This article describes CF and VO during ventricular endocardial and epicardial mapping only. Epicardial fat may decrease signal amplitude in spite of good contact, and this may have a modest effect on our cutoff value for CF required to identify a normal bipolar signal amplitude in the epicardium. As the operators were blind to CF data during mapping, the catheter stability was assessed on classical parameters. The fact that a sheath was used during transseptal access but not during retrograde access may have influenced the CF measurements; however, this could not be expounded in the study.

Conclusions
Ventricular mapping demonstrates important regional variations in CF, but in general, CF is higher endocardially than epicardially where poor catheter orientation is associated with higher CF. In the pericardium, the sole amount of applied force may be misleading and force orientation has to be carefully monitored. Endocardially lower CF is observed in the basal septum and basal anterior regions. However, a transseptal approach may lead to improved contact, particularly, in the apicoseptal and inferior regions.

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Disclosures
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References

CLINICAL PERSPECTIVE
During ventricular tachycardia substrate mapping, poor tissue contact may lead to gaps in the electroanatomic shell or may mislabel a normal region as a low-voltage scar area. Substrate detection may be affected. We characterized the contact force (CF) in the 3 ventricular chambers and within each chamber. Ventricular mapping demonstrates important regional variations in CF, but in general, CF is higher endocardially than epicardially. In the pericardium, even with experienced operators, catheter orientation can be inadequately directed away from the myocardium. In this chamber, the force orientation may be more important, for both safety and efficacy, than the amount of applied force. We also compared retroaortic and transseptal approaches for the left ventricle. With both, basal anterior and basal septum left ventricle seemed to have lower overall CF and basal-inferior and basal-lateral areas the highest CF. The transseptal approach is associated with higher CF than the retroaortic approach in the apicoseptal and apicoseptal regions. Left ventricular anatomy mapping can be more challenging in certain areas. The approach can also be chosen according to the scar location. The information about areas of poor, good, or excessive contact in ventricular chambers may help to optimize catheter manipulation, to improve substrate mapping, lesion formation efficacy, and to avoid complications. At the moment, no data are available on the relationship between CF and ventricular tachycardia recurrence. This could be the next step.
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