ORIGINAL ARTICLE

# Relationship between Surpoint Tag Index, a Radiofrequency Ablation lesion quality indicator, and Atrial wall thickness in Cavotricuspid isthmus Ablations exhibiting bidirectional block

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## Abstract

**Background:** An RFA lesion quality indicator, Surpoint Tag Index® (TI) incorporates key factors: power, time, and contact force, impacting lesion quality. TI accurately estimates lesion depth in animal studies. However, the relationship between TI and *in-vivo* atrial wall thickness in patients exhibiting bidirectional block remains unknown.

**Objective:** To describe the relationship between atrial wall thickness and TI in CTI exhibiting bidirectional block.

**Methods:** Data from 492 RFA lesions from 25 patients undergoing PVI and CTI ablations in SR with point-by-point RF lesions (<45 W) utilizing a Thermocool Smarttouch® SF ablation catheter and CARTO-3 mapping were retrospectively analyzed. Operators were blinded to TI data and CTI thickness. CTI thickness was obtained using ICE images on Cartosound pre-ablation. Durable lesions were defined as part of a lesion set exhibiting bidirectional block of >30 min.

**Results:** In lesions exhibiting bidirectional block, the thinnest (1–2 mm; 5% lesions) and thickest (8–10 mm; 6% lesions) portions of the CTI correlated with the lowest ($429 \pm 75$) and highest ($516 \pm 64$) TI. The bulk of thickness (2–6 mm; 80%) correlated with a TI of $455 \pm 72$ ($p = 0.001$). There was a weak but positive correlation between TI and CTI thickness ($r = 0.2$; $p \leq 0.01$). Examined in sectors, the anterior $1/3^{rd}$ CTI was the thickest ($4.8 \pm 1.9$ mm) but correlated with a similar TI value ($479 \pm 75$ vs. $471 \pm 70$; $p = 0.34$) as the thinner middle $1/3^{rd}$ ($3.8 \pm 1.7$ mm; $p \leq 0.0001$).

**Conclusion:** A mean TI value of 455 correlates with bidirectional block across the bulk of CTI with lower and higher values needed for the thinner and thicker portions, respectively. Tissue composition, aside from wall thickness, influences TI values for the creation of the bidirectional block.

**KEYWORDS**
ablation, atrium, cavotricuspid isthmus, flutter, lesion, radiofrequency, transmural

# 1 | INTRODUCTION

Treatment of cardiac arrhythmias, such as atrial fibrillation (AF) and typical atrial flutter, requires targeted destruction of atrial tissue using catheter ablation. Transmural and durable ablation results in electrical disconnection of atrial tissue, which is critical for the treatment of atrial fibrillation or flutter. Ineffective lesion creation causes conduction recovery contributing to arrhythmia recurrence.[1] Radiofrequency (RF) current is a common source of energy for catheter ablation procedures. Creation of transmural RF ablation lesions is highly desirable to prevent recurrence of atrial arrhythmias; however, lesions must not be excessively deep due to the risk of collateral tissue injury. The use of an objective ablation parameter tool to estimate lesion quality remains an important way to effectively treat patients with cardiac arrhythmias.

Previously, the Force-Time Integral (FTI) index was used to predict ablation quality; but this index lacked the consideration of catheter power. An RF ablation lesion quality indicator, Visitag Surpoint Tag Index® (TI) incorporates key factors impacting lesion quality, including delivered power, catheter contact force, and contact time (and hence catheter stability) into a weighted logarithmic formula. TI can accurately estimate ablation lesion depth in preclinical canine studies[2] and is a better predictor of RF ablation lesion durability than FTI in AF ablation procedures.[3]

Clinically, the relationship between TI and atrial wall thickness has been inferred, with Das et al. reporting that a lower minimum value of TI was required for effective ablation within the posterior wall/floor of the left atrium, as compared to the anterior wall/roof.[3] This difference in TI value, they suggested, may be at least in part due to differences in atrial wall thickness between these sites,[3] however, the relationship between atrial wall thickness and TI value to create transmural durable RF lesions has not been previously studied.

Understanding the relationship between objective ablation parameter tools like TI and atrial wall thickness is critical in order to create transmural and durable RF ablation lesion. To further elucidate this relationship, we studied patients receiving AF ablation procedure, who also underwent cavotricuspid isthmus (CTI) ablation to treat CTI-dependent atrial flutter during the procedure. We hypothesized that thicker CTI atrial tissue as measured with intracardiac echocardiography (ICE) would require a higher TI to create a durable bidirectional CTI block and, *vice versa*.

# 2 | METHODS

We performed a retrospective, single-center chart review of 25 consecutive patients who underwent AF and CTI ablation for treatment of atrial fibrillation and typical atrial flutter during the study enrollment period at a tertiary care medical center, OhioHealth Riverside Methodist Hospital, Columbus, Ohio, USA between February 1, 2019, and July 1, 2020. The study was approved by the OhioHealth Institutional Review Board.

Inclusion criteria included:

1. Patients undergoing concurrent atrial fibrillation ablation, and a CTI ablation to treat CTI-dependent atrial flutter which was noted to spontaneously occur previously or was easily inducible during the ablation procedure as clinically indicated.
2. The AF ablation procedure utilized the CARTO 3® mapping system with ICE using Soundstar® catheter.
3. The CTI ablation procedure utilized the irrigated RF Biosense-Webster™ contact force-sensing ablation catheter, Thermocool Smarttouch SF® where calculation of TI was possible.

Exclusion Criteria included:

1. CTI ablation performed with "drag" RF ablation lesions
2. CTI thickness on ICE images could not be affirmatively established
3. CTI ablation was not clinically indicated or had been previously performed
4. CTI ablation was performed during ongoing atrial fibrillation or flutter

Eligible patients underwent CTI ablation for treatment of CTI-dependent atrial flutter commonly performed during an AF ablation. For ICE imaging we used 8 or 10F Soundstar catheter (Biosense Webster Inc) with 4–10 MHz imaging frequencies to display images on an Acuson SC2000 system (Siemens Medical Solutions USA, Inc.) in a standard echocardiographic format utilizing 64-element Parallel Drive Phased Array imaging technology. Imaging technological features, Tissue equalization (TEQ™), and Dynamic tissue contrast enhancement (DTCE™) were optimized and used consistently in the same fashion for reproducible image quality to minimize imaging artifact when measuring CTI thickness. CTI images for thickness measurement were only acquired in atrial diastole.

Prior to CTI ablation, ICE was used to image the CTI contours which were acquired on a Cartosound™ map. These contours were then extended on Cartosound™ maps, when analyzing the data retrospectively offline, to determine CTI thickness as previously described (Figure 1).[4] The ICE probe was kept in home view in the right atrium and slowly rotated in a counterclockwise fashion from the medial/septal to more lateral aspect of the CTI. Multiple ICE images from the para-septal region to the inferolateral isthmus were acquired in succession adjacent to each other to create a virtual "bed" of CTI ICE contours on which ablations were performed (Figure S1).

The ablations were performed in the central isthmus region between the TA and IVC on the CTI Cartosound™ map contours.[5] Point-by-point RF ablations (<45 W) were performed on the CTI using the Thermocool Smarttouch SF® ablation catheter (Biosense Webster, Inc.) during sinus rhythm using previously described conventional technique utilizing impedance drop of ≥5–7 ohms, diminution of local bipolar electrograms (EGMs) of >80% and emergence of wide split EMGs as endpoints.[6,7] Bidirectional block across the ablation line was confirmed as previously described.[8] If bidirectional block was not established then CTI mapping with Pentaray catheter was performed to identify the RFA lesions demonstrating trans-CTI

**Acquisition of CTI thickness using intra-cardiac echocardiography and Cartosound®**
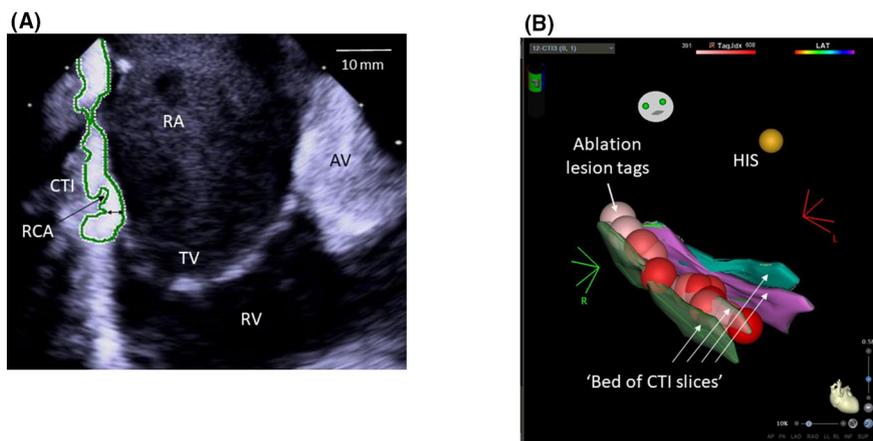


**FIGURE 1** Acquisition of CTI thickness using intracardiac echocardiography and Cartosound®: Panel A depicts the technique of CTI thickness acquisition using the ICE probe. The image is taken in the home view with the ICE probe in the right atrium. The contour of the CTI was traced using the Cartosound® software algorithm (green lining) in multiple adjacent planes cutting the CTI in a longitudinal fashion from the medial to the lateral fashion. The black line with double arrows is an example of CTI thickness measurement. Panel B depicts this "bed of CTI slices" in a modified RAO projection created using the protocol described in Panel A, on which RFA lesions were performed. AV, aortic valve; CTI, cavotricuspid isthmus; RA, right atrium; RCA, right coronary artery; RV, right ventricle; TV, tricuspid value

conduction; these areas received additional RF overlap ablation lesions. After the CTI ablation was completed and bidirectional block was confirmed (>30 min after CTI ablation is completed[9]), the ablation procedure was concluded. The operators were blinded to TI values and CTI thickness when performing CTI ablation.

Retrospectively, the CTI Cartosound™ map ICE contours were extended to complete full thickness CTI slices, which were then merged with the 3D anatomical maps incorporating the RFA lesions. Thereafter, all the study variables as noted in Table 1 for each of the CTI RFA lesions were acquired and analyzed. Local CTI thickness using ICE images was measured at a perpendicular angle from the center of the endocardial CTI surface where the ablation lesion was performed as previously described (Figure 1).[4]

Four distinct CTI anatomic variants were identified for the purpose of data analysis that are defined as follows:

1. Flat surface: A part of CTI with a plane and even surface
2. Ridge: The most proximal portion of CTI as it joins the inferior vena cava
3. Pouch: A broad depression or a concavity within the CTI
4. Recess: A focal or localized depression within the CTI

## 2.1 | Statistical analysis

For continuous variables, mean and standard error of mean were computed and for categorical variables, proportion and frequency count were calculated. Group comparisons of categorical variables were made using Fisher's exact or Chi-square test and of

**TABLE 1** Study variable

| Category | Data points |
|---|---|
| Demographics | 1. Date of Birth<br>2. Date of Ablation procedure<br>3. Gender (male, female) |
| Medical history | 1. Left ventricle ejection fraction %<br>2. CHADS Vasc 2 score |
| Medications | 1. Antiarrhythmic medication<br>2. Oral anticoagulant medication |
| Ablation parameters | 1. CTI length (mm)<br>2. RFA sequence number<br>3. CTI location (anterior 3$^{rd}$, middle 3$^{rd}$, posterior 3$^{rd}$)<br>4. Duration of RFA lesion (seconds)<br>5. Power (Watts)<br>6. Impedance drop (Initial impedance – Final Impedance; Ohms)<br>7. Initial impedance (Ohms)<br>8. Final impedance (Ohms)<br>9. Average Force (Grams)<br>10. Minimum Force (Grams)<br>11. Maximum Force (Grams)<br>12. Force-Time Integral (FTI) (Grams Seconds)<br>13. Initial Bipolar Voltage (mV)<br>14. Final Bipolar Voltage (mV)<br>15. Local CTI thickness as measured on Cartosound® (mm)<br>16. Local CTI anatomy (flat surface, ridge, pouch, recesses)<br>17. Tag Index®<br>18. Bidirectional trans-CTI block >30 min (yes/no) |

Abbreviations: CTI, cavotricuspid isthmus; RFA, radiofrequency ablation.

continuous variables using Student's _t_-test (for normally distributed variables) and non-parametric t-test or Mann-Whitney U test (for variables not distributed normally). Multiple continuous independent variables were compared using ANOVA or Kruskal Wallis test for normally and not normally distributed variables, respectively. Multiple categorical independent variables were compared using Chi-square test. Paired continuous variables pre and post-intervention were compared with either paired _t_-test or Wilcoxon signed-rank test for normally or not normally distributed data, respectively.

The Pearson correlation coefficient was used for normally distributed continuous variables to measure the strength of a linear association between two variables. Spearman rho test was used for correlation between data not normally distributed. A statistical test was considered significant if the _p_ value was <0.05.

We used SAS statistical software v9.4 for statistical analysis of the data.

## 3 | RESULTS

A total of 492 RFA lesions (20 ± 8/patient) from 25 patients (28% females) with a mean age of 61 ± 9 years, $CHA_2DS_2$ VAScscore of 2.4 ± 1.4, and LVEF of 56% ± 8% who met the study criteria were included in the analyses. Eighty percent (20/25) of the study patients were being treated with antiarrhythmic medication (14 amiodarone, 3 propafenone, and 3 flecainide) when they presented for their ablations. All the study patients were on therapeutic doses of anticoagulants for at least 4 weeks (15 apixaban and 10 rivaroxban) prior to their ablation.

The mean CTI length from the tricuspid annulus to the inferior vena cava junction as measured on ICE images was 36 ± 6 mm. A median power of 35 W (30–35), for a duration of 25 ± 9 s with a contact force of 14 ± 7 g was used to create bidirectional CTI block. Average impedance drop was 10.3 ± 6.5 with a mean FTI of 342 ± 182 per RFA lesion. On an average, a 65% reduction of local bipolar voltage was noted for each RFA lesion. The median inter-lesion distance measured from the center of the lesion was 1.8 (1.4–2.4) mm. No intra- or post-procedural complications were observed.

All of the study patients exhibited bidirectional block across the CTI after "first pass" ablation and did not require any additional touch-up RFA lesions when the block was rechecked at a time period of 119 ± 23 min after demonstrating initial bidirectional block.

Over a median follow-up period of 643 (446–732) days, no patients demonstrated spontaneous recurrence of typical atrial flutter on repeated 7-day cardiac monitors performed every 90–180 days over 1 year period and 12-lead ECGs performed either in the hospital or in the outpatient clinic during hospital admission and clinic follow-up thereafter, respectively. However, 32% (8/25) patients did have recurrence of AF over a median period of 86 (43–207) days. One patient underwent redo AF ablation 220 days after the first procedure and was noted to have bidirectional CTI block without needing any additional CTI ablation.

### 3.1 | Relationship between TI and CTI thickness across the entire CTI length

The pre-ablation CTI thickness across its length was measured from the ICE images and was noted to range from 1 to 10 mm with a mean of 4.3 ± 2 mm. The thinnest part of CTI (1–2 mm) correlated with the lowest TI value of 429 ± 75 (comprising 5% of RFA lesions; 25/492) and the thickest part of CTI (9–10 mm) correlated with the highest TI value of 520 ± 78.

Although, in general the TI values increased as the CTI thickness increased, there was only a weak albeit positive relationship between TI and pre-ablation CTI thickness in our study patients exhibiting bidirectional block ($r = 0.2$; $p < 0.01$; Figures 2 and 3).

The majority of the CTI thickness ranged between ≥2 mm but <6 mm (80%; 392/492) which correlated with a TI value of 455 ± 72. A TI value of 499 ± 66 correlated with a CTI thickness of ≥6 mm but <8 mm comprising 9% (44/492) of RFA lesions, and for a CTI thickness of ≥8 mm but <10 mm comprising 6% (31/492) of RFA lesions, a TI value of 516 ± 64 correlated with bidirectional block ($p < 0.0001$).

### 3.2 | TI and CTI thickness in relation to the anterior, middle, and posterior CTI sectors

The length of CTI was then divided into three sectors as previously described[5] to analyze the regional differences in CTI thickness and the TI associated with bidirectional block (Figure 4).



**Relationship between pre-ablation CTI thickness and Tag Index®**

r = 0.2
P<0.01

Cavo-tricuspid isthmus thickness (mm)
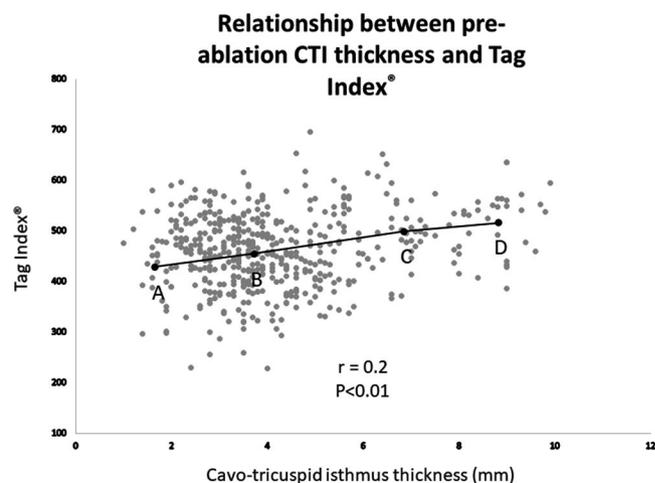
**FIGURE 2** Relationship between pre-ablation CTI thickness and Tag Index®: Scatter plot of 492 RFA lesions (gray dots) from 25 patients depicting the relationship between pre-ablation CTI thickness (mm; _x_ axis) and Tag Index® (_y_ axis). The black solid line connecting the points A, B, C, and D represents the mean TI values of 429 ± 75, 455 ± 72, 499 ± 66, and 516 ± 64 for CTI thickness ranges: ≥1 to <2 mm; ≥2 to <6 mm; ≥6 to <8 mm and ≥8 to <10 mm, respectively ($p < 0.0001$). Note the positive albeit weak relationship between CTI thickness and Tag Index® and a "ceiling effect" of Tag Index® at higher CTI thickness, causing the flattening of this relationship between C and D

| CTI thickness Range (mm) | CTI thickness mean (mm) | CTI thickness SD (mm) | TI mean | TI SD |
|---|---|---|---|---|
| 1 to 1.9 | 1.6 | 0.2 | 429 | 76 |
| 2 to 3.9 | 3.1 | 0.5 | 458 | 70 |
| 4 to 5.9 | 4.8 | 0.5 | 450 | 76 |
| 6 to 7.9 | 6.8 | 0.5 | 499 | 66 |
| 8 to 9.9 | 8.8 | 0.5 | 516 | 64 |

**FIGURE 3** Correlation of the means of CTI thickness and associated Tag Index[®]: The table depicts the correlation of mean CTI thickness and mean TI values for every 2 mm increment (except for the first category of 1–1.9 mm thickness) in CTI thickness. Note that the TI values of 2–4- and 4–6-mm thickness were statistically not different from each other ($p = 0.32$) and therefore were lumped together in the final analysis. Furthermore, the TI values of 1–2, 2–6, 6–8 and 8–10 mm were significantly different from each other and therefore were reported in separate bins ($p < 0.001$). CTI, cavotricuspid isthmus; SD, standard deviation



**FIGURE 4** Relationship between pre-ablation thickness and Tag Index[®] across anterior, middle, and posterior CTI sectors: Panel A and Panel B depicts the mean thickness and associated Tag Index[®] of the 3 CTI sectors, respectively. Note that despite being significantly thinner the middle sector correlates with a similar Tag Index[®] value when compared to the anterior sector, suggesting tissue composition aside from thickness as a likely modulator of RF energy required to achieve bidirectional block across CTI

We found that the middle third and posterior third of the CTI toward the inferior vena cava to be the thinnest ($3.8 \pm 1.7$ mm vs. $4 \pm 1.7$ mm; $p = 0.1$), with the thickest sector being the anterior third ($4.8 \pm 1.9$ mm; $p \leq 0.0001$ compared to middle third, and $p = 0.0001$ compared to the posterior third) toward the tricuspid annulus. However, the TI value correlating with bidirectional block was similar between anterior and middle third of CTI ($479 \pm 75$ vs. $471 \pm 70$; $p = 0.34$) and lowest for the posterior third ($438 \pm 71$; $p \leq 0.0001$ when compared to both anterior and middle third).

### 3.3 | Regional variation in ablation parameters across the CTI sectors

The pre-ablation impedance was highest in the anterior followed by the middle and lowest for the posterior sectors (132 [124–141] vs. 127 [120–133] vs. 125 [118–132]; $p \leq 0.0001$). The average contact force was similar in the anterior and the middle sectors ($14.4 \pm 5.2$ vs. $15.4 \pm 6.2$; p=ns) but was significantly lower in the posterior sector ($12.3 \pm 7.7$; $p \leq 0.001$ when compared to both anterior and middle sectors). Furthermore, the impedance drop with RF ablation lesions was similar for the anterior and middle sectors ($11.9 \pm 7$ vs. $11.2 \pm 5.8$; $p = $ ns) and significantly higher than the posterior sector

($8.1 \pm 5.9$; $p \leq 0.0001$ when compared to both anterior and middle sectors).

Higher energy was needed in certain parts of the CTI to create bidirectional block. Specifically, TI values of >550 were observed in 12% (60/492) of the lesions in our study. The sites that required TI >550 were most commonly encountered in the anterior 1/3rd of the CTI comprising 17% of all the lesions given in that sector. Likewise in the middle and the posterior CTI sectors, 13% and 7% of the total lesions had TI values >550, respectively. A total of 78% (47/60) of the lesions with TI >550 were given on flat surface, followed 13% (8/60) in pouches, ~7% (4/60) in recesses, and ~2% (1/60) on ridges.

### 3.4 | TI and CTI thickness in relation to the anatomic variants of CTI

We also analyzed the anatomic variants of the CTI as previously defined on ICE imaging,[4] their associated thickness and relationship with TI in order to create bidirectional block (Figure 5).

The most commonly encountered anatomy was the flat surface (73%; 361/492) with a thickness of $4.1 \pm 1.6$ mm which could be seen in the entirety of the CTI across the cohort of patients, followed by

## Relationship between pre-ablation thickness and Tag Index® across CTI anatomic variants

**(A)**



**(B)**



**(C)**
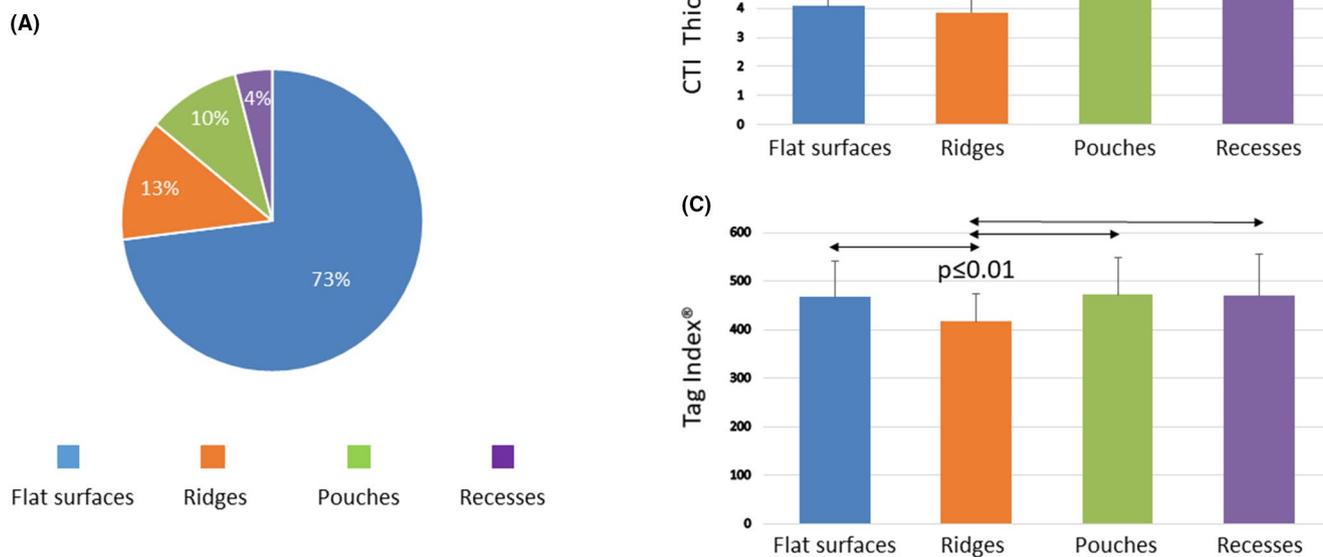


**FIGURE 5** Relationship between pre-ablation thickness and Tag Index® across CTI anatomic variants: Panel A depicts a pie chart showing percentages of different CTI anatomic variants across the study patients. Panels B and C depicts the mean thickness and associated Tag Index® of different CTI anatomic variants: flat surfaces, ridges, pouches, and recesses, respectively. Note similar CTI thicknesses of the flat surfaces and ridges (which were primarily located at the CTI/IVC junction) but significantly lower Tag Index® for ridges when compared to flat surfaces, again suggesting tissue composition aside from thickness as a likely modulator of RF energy required to achieve bidirectional block across CTI

ridges (13%; 63/492) with a thickness of $3.9 \pm 1.4$ mm most commonly (94%) encountered toward the IVC junction (Eustachian ridge), and then pouches (10%; 48/492) with a thickness of $4.9 \pm 2.5$ mm and recesses (4%; 18/492) with a thickness of $6.7 \pm 2.5$ mm noted sporadically across the length of the CTI.

The TI values for the flat surface and pouches forming 83% of the CTI were similar ($467 \pm 73$ mm vs. $472 \pm 77$ mm; $p = 0.7$) and significantly higher than for the ridges ($417 \pm 56$ mm; $p \leq 0.0001$ against both). There were very few recesses encountered, however, they correlated with a TI of $470 \pm 85$.

## 4 | DISCUSSION

The salient findings of our study are as follows: (1) The thinnest (1–2 mm) and the thickest (9–10 mm) portions of the CTI correlate with the lowest ($429 \pm 75$) and highest ($520 \pm 78$) TI in patients exhibiting bidirectional block from contiguous transmural ablation lesions; (2) TI value correlating with bidirectional CTI block increases with CTI thickness but the correlation is weak, with the bulk of CTI thickness (80%) ranging $\geq 2$ mm but $<6$ mm correlating with a TI value of $455 \pm 72$; (3) Heterogeneous atrial wall tissue composition aside from its thickness seems to influence the TI values associated with full thickness lesions.

Das et al. previously reported, in a retrospective fashion, TI values of $\geq 370$ for the posterior/inferior segments and $\geq 480$ for the anterior/roof segments around the pulmonary veins correlating with sustained entrance and exit block across wide antral contiguous ablation lines.[3] They postulated the difference in TI values likely related to a different atrial wall thickness of these segments.[3] Based on this observation, Hussein et al. prospectively performed pulmonary vein isolation procedures using TI targets of 400 for the posterior/inferior segments and 550 for the anterior/roof segments around the pulmonary veins and found significant improvements in the incidence of acute PV reconnection and atrial tachyarrhythmia recurrence when compared to only contact force guided ablations.[10] TI values from our study range from $429 \pm 75$ to $520 \pm 78$ across CTI and are in line with what has been previously reported for the atrial wall, albeit in the left atrium.[3,10]

TI guided CTI ablation has been previously performed and was found to be superior to contact force guided ablation.[11] In that study the operators used a predetermined TI value of 500 for the anterior 2/3rd and 400 for the posterior 1/3rd of the CTI to achieve a 93% first pass bidirectional block.[11] Similarly, in our study we also observe a higher TI value for the anterior 2/3rd ($479 \pm 75$ for anterior 3rd sector and $471 \pm 70$ for the middle 3rd sector; $p = $ ns) and a lower TI value of $438 \pm 71$ for the posterior 1/3rd of CTI correlating with a 100% first pass bidirectional block. This further confirms the validity of the TI

values from our study required to obtain first pass bidirectional block across the CTI.

We found the middle sector of the CTI to be the thinnest at $3.8 \pm 1.7$ mm closely followed by the posterior sector with a thickness of $4 \pm 1.7$ mm ($p$ = ns). The anterior sector was the thickest at $4.8 \pm 1.9$ mm. Baring the considerable anatomic variability of the posterior $3^{rd}$ CTI, these findings are in line with the anatomical and ICE studies of Cabrera et al.[5] and Morton et al.,[4] respectively. Nonetheless, the TI values correlating with bidirectional block were similar between anterior and middle third of CTI ($479 \pm 75$ vs. $471 \pm 70$; $p$ = 0.34) and significantly higher when compared to the posterior third ($438 \pm 71$; $p \leq 0.0001$ when compared to both anterior and middle third). This is an important observation, since it suggests that not all atrial walls are created equal and simply measuring atrial wall thickness to predetermine a TI value to create full thickness lesion may not be the correct approach. Since there is considerable variability in the makeup (connective tissue vs. muscle mass) of the atrial wall at the CTI,[5] the atrial wall composition besides tissue thickness seems to be an important modulator and will at least partly determine the RF energy needed to create full thickness lesions leading to bidirectional block. Variable atrial tissue composition can also explain the positive but only weak relationship between CTI thickness and TI as revealed by our data. Furthermore, difficulty in achieving consistent catheter stability, that is, more variable catheter-tissue contact, in the posterior $1/3^{rd}$ incorporating the Eustacian ridge/valve can also partly explain the above observation.

Our data also suggests that contact force and therefore the initial impedance is highest in the anterior sector of the CTI and progressively decrease as ablations are performed in the middle and then the posterior sector where we encounter Eustachian ridge and valve, leading to difficulty in increasing contact force due to catheter instability. Furthermore, despite significant anatomic variability between patients, the anterior $3^{rd}$ sector consistently is thicker and has the highest muscle content.[5] Consequently the amount of RF energy required in the anterior $3^{rd}$ sector is also the highest giving rise to the highest impedance drop when compared to middle and posterior sectors in that order, as noted in our data.

Clinically, there seems to be a "ceiling effect" of TI values at higher CTI thickness (Figure 2). This is most likely due to operator's decision to limit total energy delivery during a single lesion application in areas where it is tough to achieve ablation endpoints (in retrospect thicker areas of CTI) to prevent complications like "steam pop," especially when steep impedance drop is observed, and substituting it with multiple such lesions to achieve bidirectional block.

In our study, we found that the median inter-lesion distance measured from the center of the lesion was 1.8 (1.4–2.4) mm. Therefore, we would recommend an inter-lesion distance of <2.5 mm when performing a CTI ablation using a 3.5 mm Thermocool Smarttouch SF ablation catheter with CARTO mapping system to create a Contiguous line of RF lesion for creating CTI bidirectional block.

## 4.1 | Study limitations

Being a retrospective study, our study has inherent limitations including selection bias, and potentially inadequate number of subjects which may make its results less generalizable to a wider population.

Every effort was made to limit the point-by-point RF ablations in our study to the amount just needed to create bidirectional block based on conventional parameters utilized to monitor the adequacy of focal ablation including contact force of >10 g, impedance drop of ≥5–7 ohms, visual >80% bipolar electro-gram reduction, and appearance of widely split electrograms when apparent. However, over-ablation cannot be completely ruled out, primarily because of the retrospective nature of the study, and the fact that our study was not designed to evaluate the _lowest_ TI value for a given CTI thickness needed to establish bidirectional CTI block. Therefore, the inability to recognize the minimum TI value for a given CTI thickness at which reconnection will occur is a limitation of our study. This could potentially increase the TI values in our study, especially in the thinner portion of the CTI (a statistically insignificant increase in mean TI value of 8 was observed with 2–3.9 mm thickness when compared with 4–5.9 mm thickness). However, since the TI values from our study are generally in line with previously published data, we suspect the impact of this bias should also be minimal.

Overlap lesions were performed if needed during the ablation procedure. We used the original CTI thickness measured from the center of these overlap lesions to correlate with the TI values. This can potentially skew the relationship between the two and is therefore a limitation of the study.

It has been argued that it may be sufficient to create conduction delay (non-transmural lesion) and not necessarily conduction block (transmural lesion) across the CTI to prevent induction of typical atrial flutter. Even conventional differential pacing across the CTI ablation line cannot affirmatively differentiate between delay and block. Histological examination of the ablated CTI in a future animal study is needed to address this question. We acknowledge this to be an additional limitation of our study.

In our study, durable lesion was defined as part of a CTI lesion set exhibiting bidirectional block of >30 min without reconnection at the end of the procedure and does not include long term re-evaluation to confirm bidirectional block at a follow-up study. We acknowledge this to be a limitation of our study.

## 5 | CONCLUSION

An RF ablation lesion quality indicator Tag Index® incorporating power, contact force and duration of ablation, positively, albeit weakly correlates with atrial wall thickness in creating bidirectional block across the CTI. Significantly different thicknesses correlate with similar TI, suggesting in-vivo heterogeneous tissue composition aside from its thickness to be an important factor influencing creation of full thickness lesions.

Nonetheless, our data shows that a mean Tag Index® value of 455 correlates with bidirectional block across the bulk of CTI with lower and higher values needed for the thinner and thicker portions, respectively.

## CONFLICT OF INTEREST
None.

## ETHICS APPROVAL
This retrospective study was approved by OhioHealth IRB.

## DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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