ARTYKUŁ ORYGINALNY / *ORIGINAL ARTICLE*

The influence of cavotricuspid isthmus length on total radiofrequency energy to cure right atrial flutter

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Abstract

Background and aim: The complexity and success rate of right atrial flutter ablation is highly dependent on anatomical structures.

Methods: The study comprised 35 consecutive patients (33–77 years old; 30 men) who underwent ablation of typical atrial flutter. The linear ablation line was measured offline as a surrogate for the cavotricuspid isthmus (CTI) length with the help of a three-dimensional mapping and navigation system (Ensite™). Biophysical parameters, such as total radiofrequency (RF) energy and time of the ablation procedure, were analysed to test the hypothesis that any of these variables show a correlation with the length of the ablation line.

Results: Bidirectional isthmus block was achieved in all cases. The isthmus length had a mean value of 32 ± 12 mm with a range of 14–57 mm. The linear regression between the CTI length and the total RF energy was not significant. There was no significant difference in energy (32.281 ± 25.587 vs. 37.136 ± 24.250 W-s, p = NS) or in the total ablation time (759 ± 646 vs. 802 ± 533 s, p = NS) between the group with short (< 29 mm; n = 17) vs. long CTI (≥ 29 mm, n = 18). When comparing different ablation technologies, total RF energy delivered with 8-mm catheter technology (group I) was significantly lower than in patients with cross over from 8-mm to cooled ablation technology (group III) (29.615 ± 12.331 vs. 62.674 ± 28.735 W-s, p = 0.01). The same was true for the comparison between cooled ablation technology (group II) and group III (19.879 ± 13.669 vs. 62.674 ± 28.735 W-s, p = 0.002).

Conclusions: The length of the CTI as measured with help of a three-dimensional mapping system may reflect only a weak indicator for the complexity of flutter ablation procedures. The thickness of musculature and specific anatomy of the CTI seem to be the main challenges in performing a linear ablation to achieve bidirectional block.

Key words: atrial flutter, cavotricuspid isthmus, radiofrequency catheter ablation

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INTRODUCTION

Radiofrequency (RF) catheter ablation of the cavotricuspid isthmus (CTI) is routinely used in patients with typical right atrial flutter (AFl), due to the curative effect and low complication rate of the procedure [1–3]. Recent studies and modern medical imaging techniques have provided important insights into the specific anatomy of the CTI, which is frequently dependent on the underlying cardiac disease [4–8]. Hence, these anatomical aspects affect the complexity and success rate of right AFl ablation. The duration of ablation and total amount of RF energy to obtain a predefined endpoint vary considerably from one patient to another. Beyond catheter technology this variation seems to be related in part to the anatomical length of the CTI [9]. The purpose of this study was to assess the influence of the CTI length on the ablation procedure and its success rate, which is defined by achieving a consistent bidirectional block as protection for recurrence of this arrhythmia.

METHODS

The retrospective study comprised a total of 35 consecutive patients who were referred to our institution for ablation of

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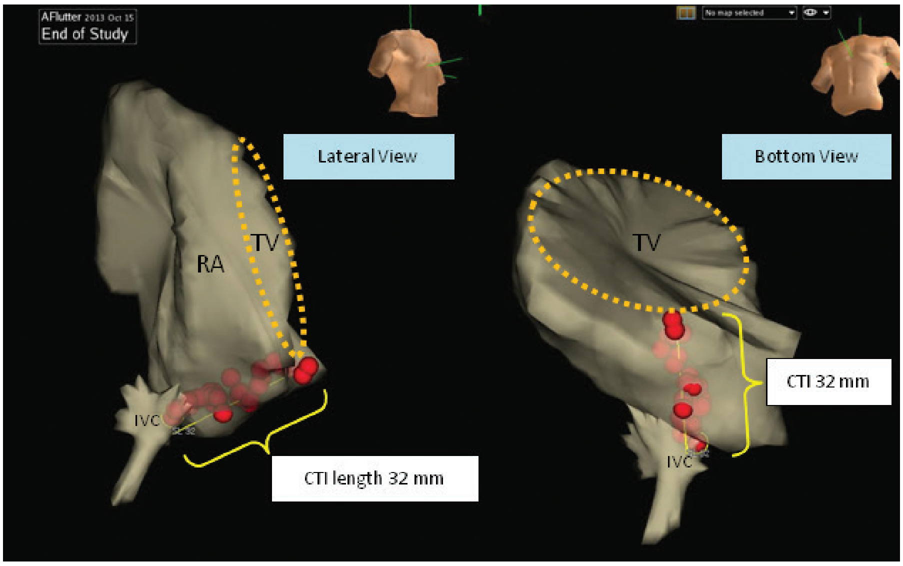

Figure 1. Measurement of the cavotricuspid isthmus (CTI) length using EnSite™. A three-dimensional model of the right atrial chamber is shown, in which the red dots represent the point-by-point ablation along the cavotricuspid isthmus region. The thin yellow line represents the calliper, which measures the length of the isthmus in millimetres from the first ablation point near the tricuspid valve to the proximal ablation point close to the inferior vena cava. These measurements were conducted offline in all 35 patients with help of the integrated software; IVC — inferior vena cava; RA — right atrium; TV — triscupid valve

typical right AFl. Previous documentation of the clinical arrhythmia presenting the electrocardiographic characteristics of typical right AFl was mandatory. All patients signed an informed consent prior to the electrophysiological study and RF ablation. The procedure was carried out in a standardised way with the following set of diagnostic catheters: two quadripolar electrode catheters were introduced from the femoral veins and positioned in the His-bundle area and right ventricle; a decapolar catheter was inserted from the right internal jugular vein and placed in the coronary sinus (CS); a steerable duo-decapolar Halo catheter was used to record the right atrial activation sequence around the tricuspid annulus. Entrainment pacing was used to confirm the diagnosis of CTI-dependent AFl.

In group I a temperature controlled-ablation technique with an 8-mm-tip catheter was used, and the generator was set to 70 W with a target temperature of 60–65°C. In group II the cooled catheter ablation technique was applied. The generator was set to 40 W in the power-controlled mode with a temperature cut-off at 43°C. The ablation catheter tip (3.5 or 4 mm tip) was irrigated with isotonic saline at a flow rate from 17 up to 30 mL/min. If the conventional ablation technology (8-mm tip) was not successful in achieving CTI block, due to temperature and/or impedance rise, the operator switched to the cooled-tip ablation technique (cross-over group III) to overcome the limitations of energy delivery. RF delivery was applied point-by-point starting from the ventricular aspect of the tricuspid annulus, where a stable electrocardiogram with a smaller atrial than ventricular amplitude was observed. The catheter was dragged back after each application, to create a linear and continuous lesion until the inferior vena cava was reached. The endpoint was the achievement of a complete bidirectional block across the CTI confirmed by standardised pacing techniques and wide split double potentials on the ablation catheter [3]. RF energy was delivered with a Stockert RF generator (Biosense Webster, Diamond Bar, CA, USA).

A three-dimensional (3D) mapping system (NavX/EnSite™, St. Jude Medical, St. Paul, MN, USA) was used in all cases [10, 11]. The geometry of the NAVX/Ensite mapping and navigation system was used to measure the length of the line between the tricuspid valve and the inferior cava vein along the single ablation points that were annotated within the right atrial chamber (Fig. 1). All measurements of the CTI were performed offline after the procedure was finished, with no impact on the routine examination and ablation procedure. The rhythm during the ablation procedure was either AFl or pacing from the CS. If AFl was present, the isthmus dependence was confirmed with entrainment pacing.

Biplane fluoroscopy (Philips Allura Xper FD10/10) was used for catheter placement and during RF ablation. The following parameters were measured and collected for each procedure: dose area product (DAP) in mGycm^2; fluoroscopy time, and total procedure time (in minutes). The total procedure time is the time from beginning (groin puncture) until withdrawal of all catheters, including a 30-min post-ablation waiting time. The total RF energy was calculated by multiplying the average power with the duration (seconds) of each ablation, adding up the total sum of all ablations counts. The derived value represents the total energy delivered in each case and is given in Watt-seconds (W-s) or Joules, the SI unit for energy.

Statistical analysis

Statistical analysis was performed using the SPSS and/or Minitab 17 Software system. Data for continuous variables were expressed as mean ± standard deviation (SD). For testing the correlation between the continuous variables of interest, simple linear regression (Pearson) was applied. Differences between groups were calculated using the Student's t-test or the non-parametric Mann-Whitney test. P values ≤ 0.05 were considered statistically significant.

RESULTS

The baseline, clinical, and electrophysiological characteristics are given in Table 1. All procedures were carried out without complications. Bidirectional isthmus block was achieved in all cases and proofed with differential pacing after a waiting time of 30 min. The radiological data are listed in Table 2. To test our hypothesis, we checked the relationship between the total RF energy delivered to achieve bidirectional block and the CTI length (mm). The linear regression between these two variables was not significant, and only a weak trend was noted between the length of the CTI and the total energy delivered (Fig. 2).

The mean isthmus length (n = 35) was 32 ± 12 mm with a range of 14–57 mm. For comparison of short vs. long isthmuses we divided the total study population by the median of the isthmus length into two groups. "Short" isthmus was defined as CTI length < 29 mm (n = 17), and "long" isthmus in the presence of a CTI length ≥ 29 mm (n = 18). The group with short CTI (n = 17) had a mean length of 23 ± 4 mm (median 24, range 14–28 mm) and required a mean RF energy of 32.281 ± 25.587 W-s for successful ablation. The group with long CTI (n = 18) had a mean length of 41 ± 10 mm (median 41, range 29–57 mm) and required a mean RF energy of 37.136 ± 24.250 W-s to create an isthmus block. There was no statistically significant difference between the two groups (Fig. 3).

The mean ablation time for all cases was 781 ± 582 s (median 603 s, range 114–2.682 s). As expected, the total time of ablation correlated significantly with the total RF energy (Pearson's correlation = 0.955; $p < 0.0001$). In line with our results regarding RF energy, there was no difference in the mean total time of ablation between the short (n = 17) and the long (n = 18) isthmus group (759 ± 646 s vs. 802 ± 533 s, p = NS).

Two different types of catheter technology were used routinely for flutter ablation, i.e. the temperature-controlled 8-mm catheter (group I, n = 14) and the power-controlled irrigated or cooled catheter technology (group II, n = 12). Group III (n = 9) comprised cases in whom switching from the non-irrigated to

Table 1. Baseline, clinical, and electrophysiological characteristics

Variables	Mean values ± SD or n (%)
Age [years]	62 ± 10
Gender (male)	30 (86%)
Height [cm]	175 ± 8
Weight [kg]	88 ± 13
Concomitant diseases:	
Hypertension	21 (60%)
Diabetes	7 (20%)
Coronary artery disease	6 (17%)
Coronary artery bypass graft	1 (3%)
Valve replacement	3 (9%)
Symptoms:	
Palpitations	28 (80%)
Dyspnoea	2 (6%)
Fatigue	3 (9%)
Angina pectoris	1 (3%)
Asymptomatic	1 (3%)
Clinical presentation:	
Paroxysmal atrial flutter	17 (49%)
Persistent/permanent atrial flutter	18 (51%)
History of atrial fibrillation	15 (43%)
History of cardioversion	12 (34%)
Functional status (NYHA-class):	
NYHA I	16 (46%)
NYHA II	14 (40%)
NYHA III	5 (14%)
Left ventricular ejection fraction:	
> 50%	23 (66%)
35–50%	9 (26%)
< 35%	3 (9%)
Antiarrhythmic drugs:	
Class I antiarrhythmics	6 (17%)
Beta-blocker	19 (54%)
Amiodarone	1 (3%)
Beta-blocker + amiodarone	2 (6%)
Class I antiarrhythmics + beta-blocker	1 (3%)
Oral anticoagulation	17 (49%)
Rhythm during ablation:	
Atrial flutter	13 (37%)
Coronary sinus pacing	22 (63%)

Table 2. Radiological and procedural data (mean values ± standard deviation)

Dose area product [mGycm²]	29.713 ± 21.996
Fluoroscopy time [min]	29 ± 19
Total procedure time [h]	1.9 ± 1.0

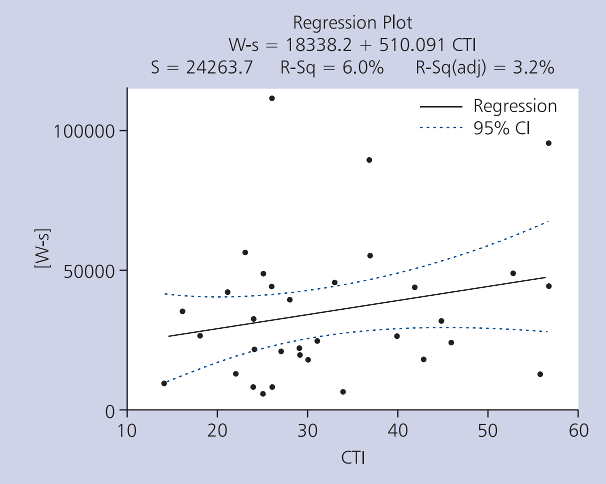

Figure 2. Correlation of the cavotricuspid isthmus (CTI) length and total ablation energy. The horizontal line displays the length of the CTI in millimetres and the vertical line the total energy in Watt-seconds (W-s) delivered to achieve bidirectional isthmus block; CI — confidence interval

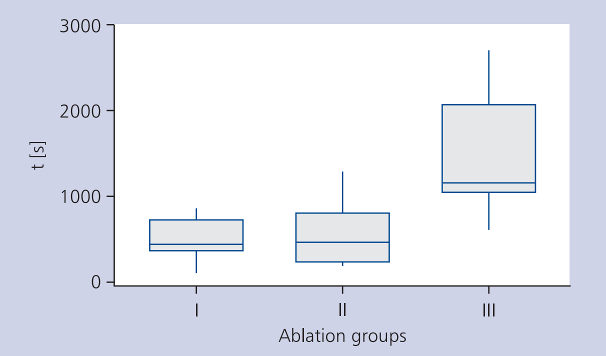

Figure 4. Boxplots showing the total time of ablation (t, second) in relation to the used catheter technology. No significant difference existed between group I (8-mm tip) and group II (irrigated tip); however, ablation time increased substantially when both technologies (non-irrigated and irrigated ablation) were necessary to achieve cavotricuspid isthmus ablation (cross-over group III). Group I vs. group III (518 ± 217 vs. 1.468 ± 665 s, p = 0.002) and group II vs. group III (571 ± 386 vs. 1.468 ± 665 s, p = 0.004)

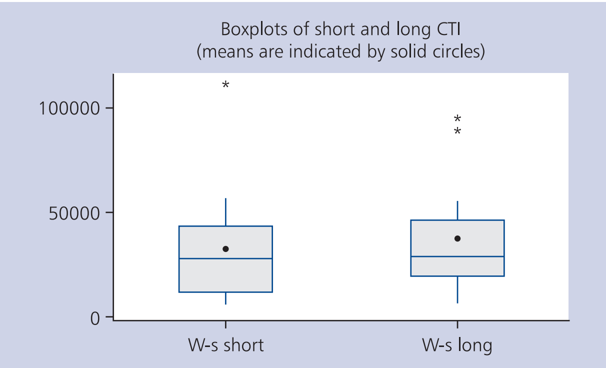

Figure 3. Boxplots showing the distribution of energy (Watt-seconds [W-s]) necessary to ablate the group with "short" (23 ± 4 mm) or a "long" cavotricuspid isthmus (CTI) (41 ± 10 mm). There was no statistically significant difference between the two groups

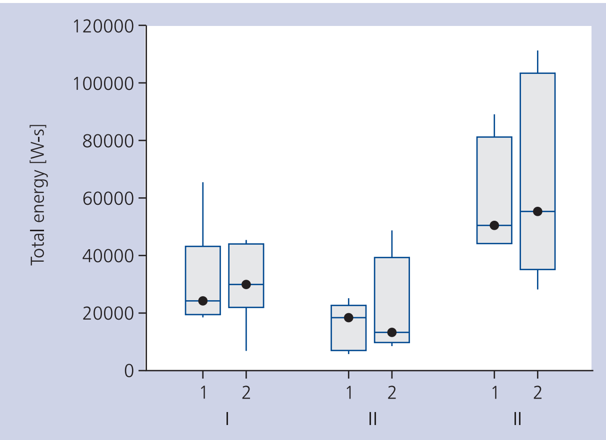

Figure 5. Boxplots with median values (black dots) of total energy (Watt-seconds, W-s) showing no difference with respect to the underlying rhythm (1 = atrial flutter, 2 = coronary sinus pacing) among the three ablation groups (group I = 8-mm tip, group II = colled; irrigated tip, group III = switch; both technologies, cross-over group)

the cooled catheter technology was necessary due to limitations in energy delivery. Total RF energy delivered in group I (8-mm catheter tip) was significantly lower than in group III (29.615 ± 12.331 vs. 62.674 ± 28.735 W-s, p = 0.01). The same was true for the comparison between group II (cooled ablation technology) and group III (crossover from 8-mm to cooled technique) (19.879 ± 13.669 vs. 62.674 ± 28.735 W-s, p = 0.002). Group II (cooled ablation technology) required the lowest total RF energy to achieve bidirectional block due to the power controlled ablation technique. However, the difference between group I and II was not significant (29.615 ± 12.331 vs. 19.879 ± 13.669 W-s, p = 0.071).

Similar results were found for the total time of ablation categorised by the different ablation techniques. In group I (n = 14, 8-mm tip catheter) the mean ablation time was 518 ± 217 s (median 440 s), in group II (n = 12, irrigated catheter) 571 ± 386 s (median 477 s), and in group III (n = 9, both catheter types) 1.468 ± 665 s (median 1.167 s) (Fig. 4). The mean CTI lengths showed a similar distribution among the three catheter groups (group I: 33 ± 11 mm, group II: 30 ± 11 mm, group III: 35 ± 15 mm).

In order to evaluate the influence of the underlying rhythm we compared data of patients ablated during AFl to patients ablated during stable CS pacing. At the beginning of the ablation 13 (37%) patients were in AFl and 22 (63%) cases were ablated with stable CS pacing only. No significant differences were found between the two rhythm groups (AFl vs. CS pacing) with respect to CTI length (34 ± 12 vs. 32 ± 12 mm), total RF energy (32.607 ± 23.147 vs. 36.060 ± 25.960 W-s), and total time of ablation (759 ± 573 vs. 794 ± 601 s) in the study population as well as among the three catheter-type subgroups (Fig. 5). In four patients of group III (n = 9) ablation was started during right AFl. Termination of AFl occurred in three cases using an 8-mm tip catheter; however, bidirectional block could not be achieved with the conventional technology requiring a conversion to an irrigated catheter. In one patient termination of AFl was not achieved with the 8-mm tip and electrical cardioversion was performed at the discretion of the operator. Thereafter, the isthmus line was completed with an irrigated catheter during stable CS pacing.

As far as radiological parameters were concerned, no relationship was found between DAP or fluoroscopy time and the CTI length due to multiple influential factors, such as the body mass index.

DISCUSSION

Angiographic visualisation of the right atrium on an X-ray image gives only a 2D view of the anatomy, whereas a 3D view may provide a more precise measurement of the true CTI length [6, 10–12]. The present study investigated the influence of the CTI length — as measured with help of a 3D mapping system — on the extent of ablation required to sever the CTI, such as total RF energy and ablation time. From a clinical point of view, it was conceivable that longer isthmuses would require more extensive ablation to achieve the endpoint of bidirectional isthmus block in comparison to shorter isthmuses. However, analysis of our data showed that there was only a weak correlation between total delivered RF energy or ablation time and the CTI length. Some of the CTI isthmuses were very difficult to ablate and required switching from the conventional 8-mm to the power-controlled irrigated ablation technique. These cases were associated with significantly higher energy delivery and ablation time compared to the cases treated with only one ablation technique. Deeper analysis demonstrated, however, that there was no significant dependency on the CTI length. In other words, the difficulties in ablation were not caused by the anatomical distance or length as measured with the 3D mapping system.

The most likely explanation for this finding is the fact that the thickness of the atrial musculature and the specific anatomy with possible pouches and ridges has a major influence on the feasibility of linear ablation. It has been published previously that both the atrial electrographic amplitude (P or F waves on surface ECG) as well as the local intracardiac atrial electrogram amplitude correlate significantly with the amount of RF energy required to ablate typical AFl [13, 14]. In addition there is convincing evidence of a so-called "muscle bundle" hypothesis for CTI conduction. Discrete muscle bundles seem to serve as preferential pathways of conduction for AFl, and focal ablation guided by the maximum voltage can block the CTI even without creating a continuous line [5, 15].

At the time of the AFl ablation procedure we did not acquire the local atrial amplitude in a systematic way to create detailed voltage maps of the CTI with use of NavX/Ensite. Due to the retrospective character of this analysis we focused on length measurements of the virtual 3D anatomy, similarly to measurements of anatomical structures with computed tomography imaging.

However, the lack of a significant correlation between the CTI length and RF energy does not imply that this information is not helpful in clinical practice. First the measurements may be important for selection of the appropriate catheter curve and guiding sheath to reach the distal end of the ablation line close to the tricuspid valve. As far as catheter technology is concerned, we observed that the irrigated ablation technique was most successful to overcome limitations in energy delivery. The conventional technique using a temperature-controlled 8-mm tip is dependent on sufficient blood cooling to prevent temperature or impedance rises associated with power drops. In a quarter of all cases it was necessary to change from the conventional to the power-controlled irrigated technique to finish isthmus ablation, resulting in excessive energy delivery and ablation times. In line with literature and most clinical electrophysiologists, the irrigated catheter technique is currently the method of choice for targeting right and left atrial flutter substrates [3, 16, 17].

Limitations of the study

A limitation of this study is the retrospective non-randomised design and the limited number of consecutive patients included. The relationship between the lengths of the CTI with the total energy delivered, mean ablation time, dose area product, fluoroscopy time, and total procedure time were calculated for the total cohort to address the primary purpose of the study. According to the clinical course, analysis was performed among the three subgroups representing the utilised catheter technology (8-mm tip/cooled or irrigated tip/cross-over group), but bearing in mind the small numbers and statistical limitations. Thus, it is possible that a higher number of cases might demonstrate a stronger correlation between the CTI lengths with the investigated ablational or radiological parameters.

Myocardial thickness of the CTI seems to have a significant impact on ablation time and energy. Due to methodological limitations this aspect was not taken into consideration in this project. Principally, the electroanatomical mapping system allows voltage mapping as an indirect measure of the local myocardial thickness, but voltage maps along the isthmus were not performed in a systematic way during routine electrophysiological procedures.

Most importantly, the specific anatomy of the CTI with ridges and pouches plays a crucial role when ablation in a linear manner is performed [4]. Previous studies demonstrated that complex forms and shapes of isthmus anatomy make it difficult to perform a linear ablation and therefore more energy is needed to achieve a complete isthmus block, even if the isthmus length is found to be short [9].

Pre-procedural computed tomography or magnetic resonance imaging, to better visualise CTI anatomy, was not used in this study because the planned procedure was confined to a right-sided ablation. Recently it has been shown that intracardiac echocardiography-guided ablation, which accurately shows the CTI anatomy, shortens the procedure and fluoroscopy time and is very helpful in challenging cases [8].

CONCLUSIONS

The results of the present study may help to understand the complexity of a highly standardised type of ablation procedure. Ablation of typical right atrial AFl is typically performed as anatomically driven ablation with the aim to create a continuous linear lesion. However, the present analysis demonstrated clearly that the length of the ablation line has only a limited effect on the total energy required to severe the CTI. In complex cases additional imaging techniques, such as intracardiac echocardiography, may be necessary to define the specific isthmus anatomy and myocardial thickness in order to prevent extensive procedure and ablation times.

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Conflict of interest: *none declared*

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Wpływ długości cieśni trójdzielno-żylnej na całkowitą energię prądu o wysokiej częstotliwości stosowanego w trzepotaniu prawego przedsionka

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Streszczenie

Wstęp i cel: Stopień trudności i odsetek pozytywnych wyników ablacji w trzepotaniu prawego przedsionka zależy od warunków anatomicznych.

Metody: Do badania włączono 35 kolejnych pacjentów (33–77 lat; 30 mężczyzn), których poddano ablacji z powodu typowego trzepotania przedsionków. Linię ablacji zmierzono w trybie *offline* jako wartość zastępczą długości ujścia trójdzielno-żylnego (CTI) za pomocą systemu do trójwymiarowego mapowania i nawigacji (Ensite™). Parametry biofizyczne, takie jak całkowita energia prądu o wysokiej częstotliwosci (RF) i czas ablacji analizowano w celu sprawdzenia, czy którakolwiek z tych zmiennych wykazuje korelację z długością linii ablacji.

Wyniki: We wszystkich przypadkach uzyskano dwukierunkowy blok cieśni. Średnia długość cieśni wynosiła 32 ± 12 mm, zakres — 14–57 mm. Analiza regresji liniowej wykazała, że zależność między długością CTI i całkowitą energią RF była nieistotna statystycznie. Nie stwierdzono znamiennej różnicy dotyczącej energii (32,281 ± 25,587 *vs*. 37,136 ± 24,250 W-s, p = NS) oraz czasu ablacji (759 ± 646 vs. 802 ± 533 s, p = NS) między grupami z krótką (< 29 mm; n = 17) i długą CTI (≥ 29 mm, n = 18). Porównując różne technologie stosowane do ablacji, wykazano, że całkowita energia RF dostarczona za pomocą 8-milimetrowego cewnika (grupa I) była istotnie niższa niż u pacjentów, u których stosowano najpierw technologię 8-milimetrowego cewnika, a następnie ablację chłodzonymi elektrodami (grupa III) (29,615 ± 12,331 *vs*. 62,674 ± 28,735 W-s, p = 0,01). Podobną zależność stwierdzono, porównując osoby poddane ablacji chłodzonymi elektrodami (grupa II) z grupą III (19,879 ± 13,669 *vs*. 62,674 ± 28,735 W-s, p = 0,002).

Wnioski: Długość CTI mierzona za pomocą systemu do trójwymiarowego mapowania jest słabym wskaźnikiem złożoności zabiegów ablacji w trzepotaniu przedsionków. Grubość tkanki mięśniowej i określone cechy anatomiczne CTI stanowią najważniejsze problemy w trakcie zabiegu liniowej ablacji w celu uzyskania dwukierunkowego bloku.

Słowa kluczowe: trzepotanie przedsionków, cieśń trójdzielno-żylna, ablacja cewnikowa prądem o wysokiej częstotliwości

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