

Evaluation of five algorithms in predicting the sublocalisation of right ventricular outflow tract arrhythmia (RVOTA) when compared to 3D electroanatomical mapping origin

Raluca Sirbu Prisecaru^a, Cristina Leatu^a, Leila Riahi^b, Victor Costache^c, Ioan Manitiu^c

^a Cardiology Department, European Polissano Medlife Hospital, Sibiu, Romania

^b Cardiology Department, Military Hospital Tunis, Tunis, Tunisia

^c Lucian Blaga University Sibiu, Sibiu, Romania

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SOUHRN

Cíl: Srovnat predikční přesnost pěti různých algoritmů, ověřených úspěšnou ablací s použitím 3D elektroanatomického bezkontaktního mapování, u pacientů se symptomatickými i asymptomatickými tachykardiemi výtokového traktu pravé komory (right ventricular outflow tract, RVOT) a vysoce zatížených těmito arytmiemi.

Metody: Do studie bylo zařazeno 28 po sobě následujících pacientů přijatých pro radiofrekvenční katetrizační ablací pro symptomatické, případně asymptomatické, idiopatické předčasné komorové stahy (premature ventricular contractions, PVC) znamenající vysokou zátěž pro srdeční komory. Všichni pacienti již dříve absolvovali neúspěšnou terapii beta-blokátory a/nebo alespoň jedním antiarytmikem třídy IC (případně takovou léčbu nesnášeli); měli normální ejekční frakci levé komory. U všech pacientů byly prokázány monomorfní PVC s morfologií blokady levého Tawarova raménka s průběhem výsledného vektoru směrem dolů inferior axis. Následně se hodnotila shoda mezi místem vzniku arytmiie podle EKG algoritmu a místa určeného pomocí 3D mapování. Z pěti algoritmů byly pro srovnání použity dva pro snadnost použití a zapamatovatelnost (Dixit, Joshi) a tři složitější a přesnější (Ito, Zhang, Pytkowski).

Výsledky: Posouzení diagnostické přesnosti prokázalo pouze středně kvalitní přesnost všech algoritmů, přičemž nej přesnější byl podle kardiologů algoritmus navržený Pytkowským a při hodnocení elektrofyzilogem algoritmy navržené Dixitem a Pytkowským. Při srovnání jejich přesnosti, specifity a senzitivity nicméně nebyly nalezeny žádné významné rozdíly ($p = 0,99$).

Závěry: Všechny pět publikovaných algoritmů pro určení místa RVOT pomocí 12svodového EKG záznamu bylo z hlediska diagnostické přesnosti, specifity a senzitivity podobných. V naší studii vykázal největší přesnost a specifitu v predikci místa algoritmus Pytkowského, pokud jej hodnotili elektrofyzilogové a/nebo kardiologové.

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ABSTRACT

Aim: To compare the predictive accuracy of five different algorithms as verified by successful ablation site using 3D electroanatomical non-contact mapping in patients with symptomatic and asymptomatic but high ventricular burden right ventricular outflow tract (RVOT) tachycardias.

Methods: 28 consecutive patients admitted for radiofrequency catheter ablation for symptomatic and asymptomatic, but high ventricular burden idiopathic premature ventricular contractions (PVC) were recruited for this study. All patients had previous failed or intolerant to beta-blocker and/or at least one class IC anti-arrhythmic agents, and they had normal left ventricular ejection fraction. All patients had documented monomorphic PVC with left bundle branch block morphology and an inferior axis. Concordance of the arrhythmia origin based on ECG algorithm and 3D mapping system site were further evaluated. Of the five algorithms, two algorithms with easy applicability and having a memorable design (Dixit and Joshi) and three algorithms with more complex and detailed design (Ito, Zhang, Pytkowski) were selected for comparisons.

Address: Raluca Sirbu Prisecaru, MD, Cardiology Department, European Polissano Medlife Hospital, Izvorului Street 1A, Sibiu 550172, Romania,

e-mail: raluvsirbu@gmail.com

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Results: Assessment of the diagnostic accuracy showed that each of the five algorithms had only moderate accuracy, and the greatest accuracy was observed in the algorithm proposed by Pytkowski algorithm when assessed by a general cardiologist and Dixit and Pytkowski algorithms when evaluated by the electrophysiologist. However, when the algorithms were compared for their accuracy, specificity, sensitivity, no significant differences were found ($p = 0.99$).

Conclusions: All the five published 12-lead ECG algorithms for RVOT location were similar in terms of the diagnostic accuracy, specificity, and sensitivity. In our study, Pytkowski algorithm exhibits the best accuracy and sensitivity among the algorithms, while predicting a precise location and when evaluation is performed by electrophysiologists and/or cardiologists.

Introduction

The majority of idiopathic ventricular arrhythmias arise from the right ventricular outflow tract (RVOT)¹ and they represent nearly 10% of all ventricular tachycardia (VT) admissions.^{2,3} Frequent premature ventricular complexes (PVC) or non-sustained and sustained ventricular tachycardias are among the most common presentation scenarios and they may cause heart failure and ventricular dysfunctions.⁴ The question of how many PVCs are required to cause PVC-induced cardiomyopathy is not yet completely answered. Though in one study from Carbellera et al., the PVC burden was not associated with the development of cardiomyopathy⁵ (a PVC burden higher than 10% being used as an inclusion criterion in this study), several other studies showed correlation between PVC frequency and cardiomyopathy.^{6,7} The results of Baman's et al. study revealed that a PVC burden higher than 24% best differentiated patients likely to develop impaired left ventricular (LV) function from those less likely to develop dysfunction. Also, patients with preserved left ventricular function but dilated LV were associated with an intermediate PVC burden of 22%, which was significantly lower compared to patients with LV systolic dysfunction but significantly higher compared to patients with normal LV dimensions and systolic function.⁷

PVCs originating from the RVOT are characterized by left bundle branch block (LBBB) morphology on 12-lead electrocardiograms (ECG) with an inferior frontal plan axis. Most frequently, the site of origin of those tachycardias is established to be in the anterior septal region

below the pulmonary valve (Fig. 1).⁸ However, less frequently the origin site is found in the right ventricular free wall, posterior septal area, and other rare areas.⁹⁻¹¹

In patients with symptomatic RVOT-VT/PVCs, primary catheter ablation is recommended.¹² In published reports, acute success rates of RVOT-VT/PVC catheter ablation are >95% in patients without structural heart disease.¹³⁻¹⁵ Therefore, it is paramount to precisely predict the origin of RVOT arrhythmias to define the appropriate approach before the ablation procedure. Conventional 12-lead electrocardiogram (ECG) is a useful tool for analysing cardiac arrhythmias, and numerous ECG algorithms for predicting the origin of RVOT arrhythmias have been reported.¹⁶⁻²⁵

The aim of this study was to compare the predictive accuracy of five different algorithms as verified by successful ablation site using 3D electroanatomical non-contact mapping in patients with symptomatic and asymptomatic but high ventricular burden RVOT tachycardias. Of the five algorithms, two algorithms having easy-applicability and a memorable design (Dixit²⁶ and Joshi³) and three more complex algorithms of a more detailed design (Ito¹², Zhang²⁴, Pytkowski²⁷) were selected for comparisons.

Algorithms

1. The Ito algorithm (2003) is based on evaluating the S wave amplitude in V_6 and the determination of transition zone in V_4 or S wave in lead I. Furthermore, the R/S amplitude index, the R duration index and

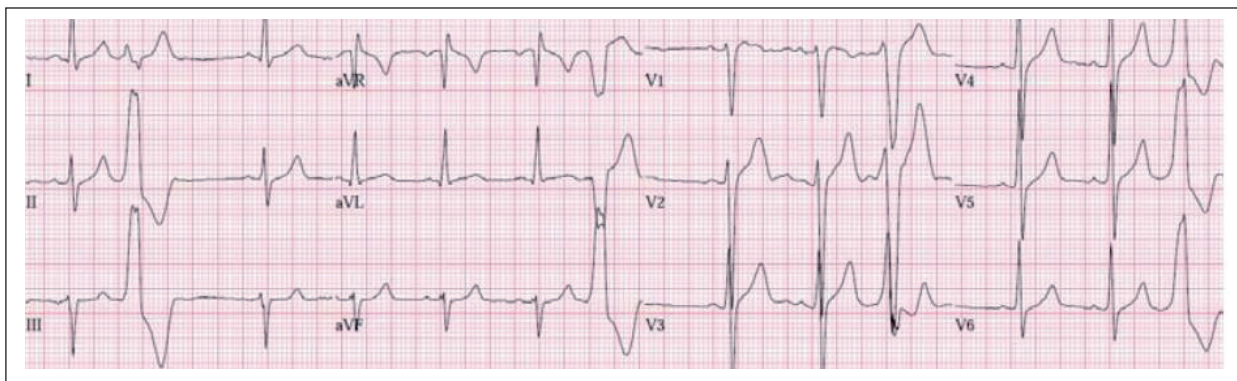


Fig. 1 – 12-lead electrocardiogram with paper speed 25 mm/s indicating premature ventricular complex (PVC) originating in the right ventricular outflow tract (septal wall). PVC exhibits left bundle branch morphology, inferior axis, QRS transition in V, a positive QRS vector in lead I and a negative QRS vector in aVL.

the QRS pattern in lead I are determined. Finally, the QRS morphology in aVL, aVR, lead I and inferior leads, and the S wave in V_2 are evaluated. Three arrhythmia areas in the RV (septal, free wall, near His, left ventricular endocard/epicard, and left coronary sinus) are defined.

2. The Dixit algorithm (2003) uses “notching” in leads II, III, and aVF, and late precordial transition ($R \geq S$ at or beyond lead V_4) to predict the arrhythmia origin. QRS polarity in lead aVL was assessed to determine the anterior or posterior arrhythmia locations.
3. The Joshi and Wilber scheme (2005) is based on three criteria for separating the septal from the free wall sites (QRS duration ≥ 140 ms, R-wave “notching” in inferior leads, lead V3 R/S ratio ≤ 1). Then, according to the QRS polarity in lead I, anterior or posterior location of arrhythmias is established. Finally, the QRS polarity in aVL lead determines caudal or cranial sites.
4. The Zhang algorithm (2009) starts with the determination of the QRS morphology and axis. Arrhythmia origin is in four different sites (near the His, left ventricular origin, RV septal or free wall origin). RV arrhythmias origins are defined as anterior, posterior and mid regions. LBBB morphology with inferior axis suggested RVOT origin. Then, transitional zone in V_4 is determined. Later on the R wave duration index, R/S amplitude index and RR'/RSR' pattern in lead aVL are evaluated. Afterwards, PVC-QRS duration/the preceding sinus beat QRS duration and QRS pattern in lead I are evaluated. R duration index and precordial leads transitional zone are determined.
5. The Pytkowski scheme (2013) uses “notching” in leads II, III, and aVF and lower R wave amplitude in these leads to predict free wall origin. Based on the lead I polarity, RVOT is divided in three vertical zones (posterior to anterior). Then, depending on the transitional zone in the precordial leads, 3 horizontal zones were defined, with horizontal intermediate zone ($R[r] = S[s]$ in V_4) occupying a small region of the median RVOT part and separating superior and inferior zones. 3 vertical and 3 horizontal zones divided RVOT into 9 sub-regions.

Methods

Study population

Twenty-eight consecutive patients admitted in our centre for radiofrequency catheter ablation of idiopathic PVC between November 2016 and February 2021 were included in this study. All patients had documented monomorphic PVC with left bundle branch block morphology and an inferior axis. Although symptomatic patients usually have a high PVC burden ($>10\,000$ PVCs/24 h), symptoms are not exclusive to these patients and those with a reduced PVC burden ($5000\text{--}10\,000/24$ h) may also be highly symptomatic and warrant ablation.²⁸ For asymptomatic patients with a high volume of PVCs, prophylactic catheter ablation may be proposed to prevent LV dysfunction and cardiomyopathy. The cut off is still not yet defined, but several studies have demonstrated that a cut off val-

ue of 20% to 24% PVCs per 24 hours is associated with an increased risk of developing reduced LV function and cardiomyopathy.^{6,7}

In our study, both symptomatic patients with PVCs refractory or intolerant to antiarrhythmic drug (beta-blocker and/or at least one class IC anti-arrhythmic agents) with a ventricular burden $>5\%$ and asymptomatic patients with ventricular burden $>20\%$ on a 24 h Holter monitoring were included. All patients had normal left ventricular ejection fraction.

All the ECG recordings were analysed at a paper speed of 25 mm/s and 50 mm/s. All ECG were reviewed by two cardiologists following each algorithm and next by two electrophysiologists to establish the origin of the arrhythmia. Concordance of the arrhythmia origin based on ECG algorithm and 3D mapping system site were further evaluated.

To determine the correct sublocalisation of RVOT arrhythmias origin, several criteria were established:

1. For Ito algorithm using two approximate locations in RVOT – septal or free wall, correct sublocalisation was identified if ECG based origin corresponded with the EPS origin.
2. For Dixit and Zhang algorithms using 4–6 RVOT zones – septal (anterior, mid, posterior) and free wall (anterior, mid, posterior), correct sub localisation was identified if ECG based origin either septal or free wall corresponded with the EPS origin and if on the horizontal plane was no significant mismatch as anterior/posterior. Mismatches as anterior – mid, posterior – mid were considered as non-significant mismatches.
3. For Joshi and Pytkowski algorithms which used 9 zones in RVOT based on 3 vertical lines and 3 horizontal lines, match between the ECG and EPS origin was confirmed if ECG based origin either septal or free wall corresponded with the EPS origin and if on the horizontal and vertical plane was no significant mismatch as anterior / posterior and inferior/ superior. Mismatches as anterior – mid, mid – posterior, superior – mid, mid – inferior were considered as non-significant mismatches.

The origin of RVOT arrhythmias was established either on septal vs free wall when using Ito algorithm. Based on Dixit and Zhang algorithm, a more precise sub localisation in the RVOT could be performed - septal vs free wall and on the horizontal plane (posterior, median and anterior zones). Using Zhang or Pytkowski algorithm, location was identified in one of the nine regions of the RVOT divided by 3 vertical and 3 horizontal lines. One of the objectives of our study was to evaluate the concordance between the arrhythmia origin based on each ECG algorithm and the 3D mapping system when evaluated by cardiologists and electrophysiologists. Next, we set out to establish any significant differences in terms of sensitivity and specificity when comparing RVOT ectopy localisation based on the 5 algorithms, performed by general cardiologists and electrophysiologists. It is known that ECG electrodes placement in both limb and precordial leads from standards 12-lead ECG may differ and lead to mistakes in correct localisation. So, evaluation was performed on the same ECG to avoid localisation discrepan-

cies between cardiologists and electrophysiologists. Our objective was to determine if the use of complex, time consuming analysis and difficult to memorise algorithms to predict a precise location (a region from one of the nine zones described by Pytkowski and Joshi) is feasible and preferable instead of determining a wider location of RVOT ectopies (septal or free wall location as in the Ito algorithm), when performed by a general cardiologist before the electrophysiologist evaluation.

Electrophysiological procedure

Procedures were performed in the fasting state and all anti-arrhythmic drug therapy was discontinued at least five half-lives before. One quadripolar electrode catheter was inserted into a femoral vein and positioned in the right ventricle apex. An eight-French quadripolar catheter with a 4 mm distal electrode, sensor enabled interelectrode spacing of 1–4–1 mm, and a flexible tip (*Abbott Laboratories, Abbott Park, IL, USA*) was also inserted through the femoral vein in the right ventricle for mapping and ablation.

Twelve electrocardiographic leads and the bipolar intracardiac electrograms were recorded by optical disk. The filter settings for the intracardiac electrograms were set at 30–500 Hz. Pacing was performed at twice the diastolic threshold with a programmable stimulator using stimuli with 2 ms duration. The 3D geometry of RVOT was constructed by navigating the mapping and ablation catheter within the RVOT using the non-contact electroanatomical mapping system (Ensite system, Abbott Laboratories). Areas of interest as the His bundle were annotated using the 4 mm sensor enabled tip catheter. Spontaneous PVC at baseline and during intravenous isoprenaline (1–4 µg/min) infusion was recorded.

For identification of earliest activation (EA) site, a broad colour setting with high pass filter set at 2 Hz was used. Then, the EA site was identified by stepping further back in time in which the red colour-zone shrinks down to the blue colour. Furthermore, unipolar virtual electrograms at this site were reconstructed. The presence of QS morphology was also used an additional criterion for EA site. Radiofrequency catheter ablation was targeted at the EA site. At each of the target sites, pace mapping was also performed to ensure at least 11 of 12 matching on the 12-lead ECG. Ablation was performed by delivering radiofrequency energy with the ablation catheter in temperature-control mode (Stockert, Biosense Webster, Diamond Bar, CA, USA). The power output was titrated to as high as 40 W to achieve a target temperature 45 °C for 60–120 s. A waiting period of 30 min was applied to all patients. If complete elimination of VAs was not achieved, surrounding sites were further investigated by activation and pace mapping to find alternative ablation sites and subsequent ablations were applied to those sites. The ablation procedure was considered successful, if clinical PVC disappeared during RF, didn't reoccur within 30 minutes after the last RF application and if PVCs were non-inducible after Isoproterenol infusion (1–10 µg/min).^{29,30}

Based on the 3D electroanatomical non-contact mapping (Ensite, Abbott Laboratories, IL, USA), we divided RVOT through 3 vertical and 3 horizontal imaginary lines

into nine distinct sites to facilitate the description of the origin of PVC based on the successful ablation site into 9 sub-regions.

Statistical analysis

Data analysis was performed using IBM SPSS Statistics for Windows (version 20.0; IBM Corp., Armonk, NY, USA). Continuous variables are presented as median and mean $\pm$ standard deviation (SD). Categorical variables are expressed as counts and percentages. Coefficients of Kappa were used for determining the levels of interobserver agreement. Kappa values over 0.75 were accepted as excellent, 0.40–0.75 and below 0.40 were accepted as fair to good and poor; respectively.

Results

Twenty-eight patients with RVOTAs were enrolled into this study. Patient clinical characteristics are summarized in Table 1. Acute procedural success was achieved for all the included patients. Ablation was delivered at 22 septum sites and 6 free wall sites. The 3D electroanatomic maps were reconstructed for all patients, which were then applied to localize the origin of RVOT ectopy recorded before the EPS and ablation procedure. The RVOT chamber was correctly identified by the evaluators in 28/28 (100%) patients. Algorithm's accuracy is presented in Table 2.

The five ECG algorithms were assessed for their diagnostic accuracy, specificity, sensitivity, and likelihood ratios (LRs) of differentiating between the septal and free wall origin. The results are summarized in Table 3. Assessment of the diagnostic accuracy showed that each of the five algorithms had only moderate accuracy, and the greatest accuracy was observed in the algorithm proposed by Pytkowski algorithm when assessed by the general cardiologists and, Dixit and Pytkowski algorithm when evaluated by the electrophysiologists. However, when the algorithms were compared for their accuracy ($p = 0.61$), specificity ($p = 0.07$), sensitivity ($p = 1$), no significant differences were found.

In addition, the receiver operating characteristic (ROC) curve analysis regarding the predictive value of 3D elec-

Table 1 – Clinical characteristics

Age (years; median)	53
Female/Male (n)	16/12
PVC burden (%; median)	17.5
LVEF (%; median)	61
Use of antiarrhythmic drugs (%)	39.28%
History of CHD (n)	1/28
History of hypertension (n)	3/28
History of diabetes (n)	2/28
Hypercholesterolemia (n)	6/28

CHD – coronary heart disease; LVEF – left ventricular ejection fraction; PVC – premature ventricular contraction; RVOT – right ventricular outflow tract; SD – standard deviation.

Table 2 – Accuracy of each algorithm when evaluated by the electrophysiologists and the cardiologists

Algorithms	Electrophysiologist 1 Number and percentage	Electrophysiologist 2 Number and percentage	Cardiologist 1 Number and percentage	Cardiologist 2 Number and percentage	p value
Ito	20/28 patients (71.42%) $p = 0.02$	21/28 patients (75%) $p = 0.59$	18/28 patients (64.28%) $p = 0.006$	16/28 patients (57.14%) $p = 0.09$	0.94
Dixit	26/28 patients (92.95%) $p = 0.35$	25/28 patients (89.29%) $p = 0.59$	18/28 patients (64.28%) $p = 0.08$	18/28 patients (64.28%) $p = 0.27$	0.79
Joshi	24/28 patients (85.71%) $p = 0.23$	23/28 patients (82.14%) $p = 0.83$	14/28 patients (50%) $p = 0.53$	16/28 patients (57.14%) $p = 0.09$	0.59
Zhang	20/28 patients (71.42%) $p = 0.4$	19/28 patients (67.85%) $p = 0.67$	14/28 patients (50%) $p = 0.0009$	18/28 patients (64.28%) $p = 0.27$	0.86
Pytkowski	24/28 patients (85.71%) $p = 0.23$	24/28 patients (85.71%) $p = 0.23$	23/28 patients (82.14%) $p = 0.14$	23/28 patients (82.14%) $p = 0.14$	0.99

Table 3 – Accuracy, sensitivity, specificity, positive and negative likelihood ratios (LLR+, LLR–) for each algorithm when evaluated by the electrophysiologists (E1 and E2) and the cardiologists (C1 and C2) compared to data reported in the literature

Algorithms	Parameters evaluated	E1	E2	C1	C2	Reported in literature	p value
Ito	Accuracy Sensitivity Specificity LLR+ LLR–	71.43% 93.75% 41.67 % 5.83 0.62	75% 94.12% 45.45% 5.45 0.58	64.29% 92.86% 35.71% 6.42 0.71	57.14% 91.67% 31.25 % 6.87 0.83	78.57% 93.33% 61.54% 2.42 0.1	0.94
Dixit	Accuracy Sensitivity Specificity LLR+ LLR–	92.86% 95.45% 83.33% 1.66 0.45	89.29% 95.24% 71.43% 2.85 0.47	64.29% 92.86% 35.71% 6.42 0.71	64.29% 92.86% 35.71% 6.42 0.71	78.57% 94.44% 50% 1.88 0.11	0.79
Joshi	Accuracy Sensitivity Specificity LLR+ LLR–	85.71% 95% 62.5% 3.75 0.5	82.14% 94.74% 55.5% 4.44 0.52	50% 90% 27.78% 7.22 1	57.14% 91.67% 31.25% 6.87 0.83	– 93.75% 58.33% 2.25 0.1	0.59
Zhang	Accuracy Sensitivity Specificity LLR+ LLR–	71.43% 93.75% 41.67% 5.83 0.62	67.08% 93.33% 38.46% 6.15 0.66	50% 90% 27.78% 7.22 1	64.29% 92.86% 35.71% 6.42 0.71		0.86
Pytkowski	Accuracy Sensitivity Specificity LLR+ LLR–	85.71% 95% 62.5% 3.75 0.5	85.71% 95% 62.5% 3.75 0.5	82.14% 94.74% 55.56% 4.44 0.52	82.14% 94.74% 55.56% 4.44 0.52		0.99

troanatomical origin and the five ECG algorithms for differentiating the septal and free wall arrhythmias was conducted. The results showed a similar diagnostic accuracy among the five ECG algorithms, with areas under the curve (AUCs) ranging from 0.62–0.81 when assessed by an electrophysiologist and 0.54–0.69 when evaluated by a general cardiologist ($p > 0.5$) (Fig. 2).

The interobserver agreement between the evaluators in localizing the septal versus the free wall was evaluated

for each algorithm. The algorithm published by Pytkowski had the highest kappa value of 0.77. Excellent kappa value was also noticed for Ito algorithm – 0.75. Acceptable kappa values were obtained for the algorithms proposed by Dixit and Joshi – 0.69 and for Zhang algorithm 0.66. When the interobserver agreement was evaluated between both cardiologists and between both electrophysiologists, excellent kappa values ranging between 0.82–0.92 were observed.

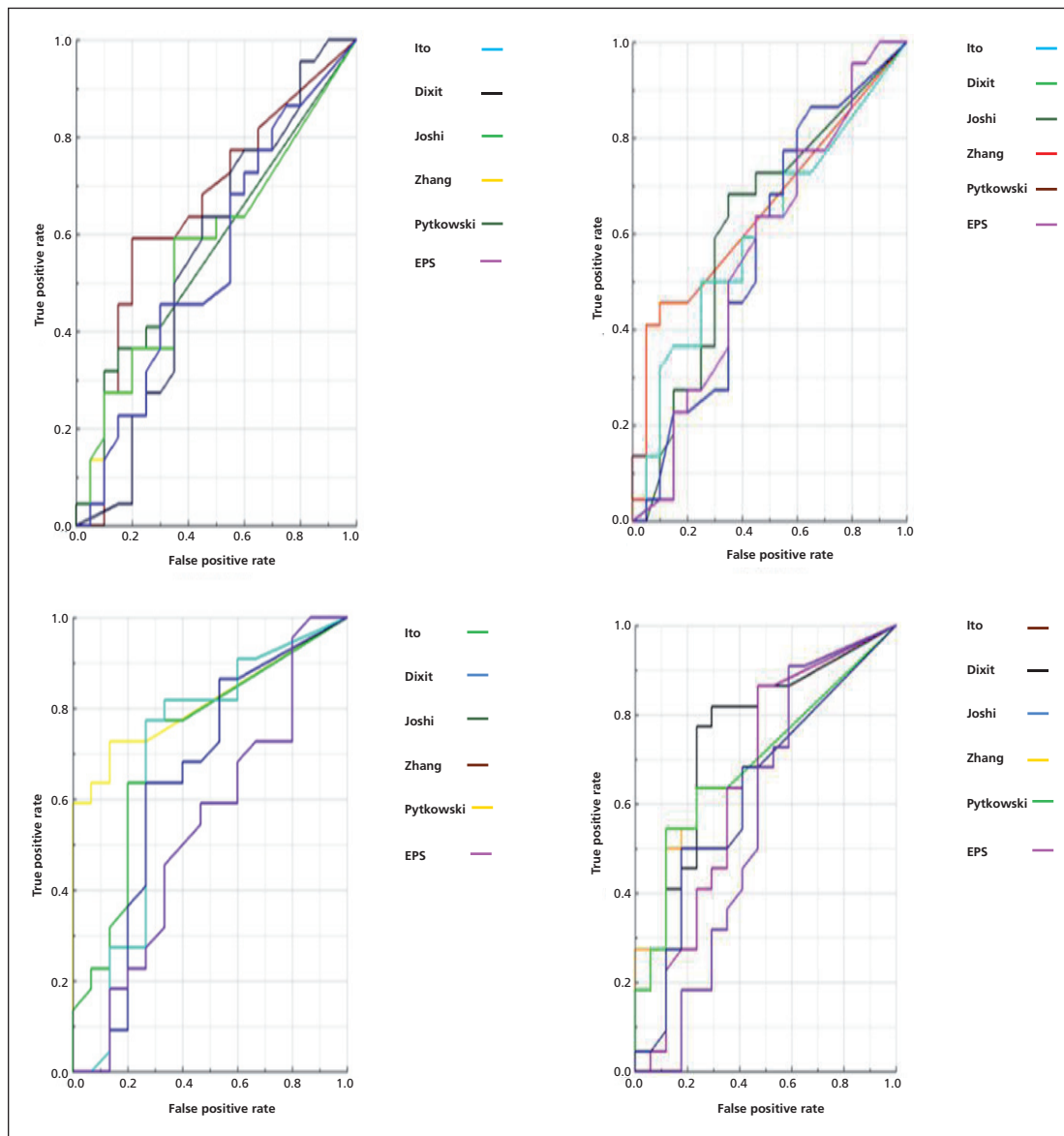


Fig. 2 – Receiver operating characteristic (ROC) curve analysis regarding the predictive value of 3D electroanatomical origin and the five ECG algorithms for differentiating the septal and free wall arrhythmias origin when performed by cardiologists (left panels) and electrophysiologists (right panels).

Discussion

All the five published 12-lead ECG algorithms for RVOT arrhythmia differentiation were similar in terms of the diagnostic accuracy, specificity, sensitivity and LRs. The predicted accuracy of the ECG algorithms in our study ranged from 50% to 92.86%, with a median value of 67.5% for Ito algorithm, 76.5% for Dixit algorithm, 69.5% for Joshi scheme, 65.6% for Zhang algorithm and 83.5% for Pytkowski scheme, all of which were lower compared with results that were previously reported.^{9–18} Possible explanations for the lack of reproducibility may be the differences in the population and the heterogeneity between the assessors in the present study and the developers of algorithms because one of the five ECG algorithms exhibited lower interobserver agreement – Zhang.

The best interobserver agreement was observed with the algorithm published by Pytkowski ($k=0.77$) and Ito ($k=0.75$). Though the algorithms with complex stepwise analysis and/or predicting a precise location are more prone to deliver inaccurate results and thus interobserver discrepancies, Pytkowski scheme exhibits excellent interobserver agreement and accuracy.

When the general cardiologists assessed the ECGs, the Joshi algorithm revealed the lowest accuracy level, 50 and 57%, respectively. Values are lower than reported in other studies. This could be explained partially by a more detailed design of the algorithm and a more refined sublocalisation of the RVOT arrhythmias compared with algorithms differentiating only septal from free wall. The highest accuracy was achieved with the Pytkowski algorithm – 82.14%, with more precise sublocalisation

of RVOT arrhythmias, but with an elementary algorithm design.

When ECGs were evaluated by the electrophysiologists, the lowest accuracy was observed for Ito and Zhang algorithms – 71.43%, respectively 67.08% ($p = 0.6$). The results are similar to those reported in other studies. The highest accuracy was achieved with the Dixit criteria's – 92.86% and 89.29%, followed by the Pytkowski algorithm – 85.71%, like those reported by the authors. Compared to Dixit algorithm, Pytkowski scheme leads to a more precise location of the RVOT arrhythmias, not only in predicting septal vs free wall location, but also in the horizontal and in the vertical plane.

When sublocalisation in one of the nine zones of the RVOT was intended, there was no significant difference in terms of accuracy and sensitivity between Pytkowski and Joshi scheme ($p = 0.09$). Based on these findings and the excellent kappa value of the Pytkowski algorithm (0.77), we can conclude that the use of a more detailed and difficult to memorise algorithm as Pytkowski, can be routinely used to precisely localise the RVOT arrhythmia origin instead of other algorithms with a less precise sublocalisation of arrhythmia origin not only by general cardiologists but also for electrophysiologists.

The ECG based algorithms for precise localising in the RVOT may simplify the mapping process, reduce the procedural and fluoroscopic time, and improve clinical outcomes, resulting in greater clinical utility.

Meanwhile, it is paramount to understand that the algorithms with a discriminating stepwise analysis may lessen the inaccurate results. Remembering detailed algorithms is not easy and orientation of the subsequent steps may be challenging. Time consuming and complex analyses of such algorithms may be more helpful while predicting the arrhythmia location and may lead to a better preparation before the procedure, but at the same time, the missed time in analysing the algorithm may be gained during the procedure. All the erroneous predictions of the ROTV arrhythmia origin that used a 12-lead algorithm may result in inappropriate ablation approaches and negatively affect its effectiveness.

Limitations

The number of recruited patients is relatively small, and this may affect the results of the comparison among the ECG algorithms. Several limitations associated with using the 12-lead ECG algorithms were found in our study and have been reported in previous studies. Some algorithms require an accurate measurement of many ECG parameters, and thus, inconsistencies and heterogeneities between assessors are inevitable, due to lack of electronic callipers, wandering baselines.^{20–22} Inaccuracies in ECG algorithms might also be caused by variable precordial lead placements or by the spatial relationship between the heart and torso.^{13,31,32} As we did not perform magnetic resonance imaging (MRI) to all patients, right ventricular dysplasia cannot be ruled out. Therefore, the accuracy of algorithms cannot be correctly evaluated. The patients' age range was 15 to 67 years for this study, and we did

not include more pediatric and older patient populations, thus the age-related changes in PVC morphology were not discussed.

Conclusions

All the five published 12-lead ECG algorithms for RVOT arrhythmia differentiation were similar in terms of the diagnostic accuracy, specificity, sensitivity and LR_s. In our study, the Pytkowski algorithm, has the best accuracy and sensitivity among the evaluated algorithms, in predicting an even more precise location of the RVOT arrhythmias origin, not only septal vs free wall, but also in the horizontal and in the vertical plane and an excellent interobserver agreement.

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