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Full Length Research Paper

Near-zero exposure radiofrequency ablation of paroxysmal supraventricular tachycardia guided by EnSite NavX mapping

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This study explores the feasibility and safety of radiofrequency ablation of paroxysmal supraventricular tachycardia (PSVT) under EnSite NavX mapping guidance. Radiofrequency ablation was performed on 46 young patients (age range of 14 to 32 years; mean age of 22±3.5 years) with PSVT, including atrioventricular nodal re-entrant tachycardia, atrioventricular re-entrant tachycardia, atrial flutter, and atrial tachycardia. Subjects were randomly divided into an EnSite NavX mapping guidance group (n = 23) and a conventional X-ray fluoroscopy group (n = 23). There was no significant difference in age between the two groups (mean ages of 19.0±3.7 and 19.4±4.1 years; P = 0.605). All procedures yielded immediate success without severe complications. No significant difference between surgical time of both groups were found (mean time of 76.5±22.4 and 74.8±21.3 minutes, P = 0.776). Compared with the conventional X-ray fluoroscopy group, the X-ray exposure time of the EnSite NavX group was less (mean exposure of 20.7±43.4 and 339.3±187.8 s, P = 0.000). Among those in the EnSite NavX group, 78.3% (18/23) were not irradiated by X-ray. Radiofrequency ablation of PSVT under the guidance of EnSite NavX and conventional X-ray fluoroscopy are equally effective and safe. The utilization of EnSite NavX notably reduces surgical X-ray exposure time.

Key word: Radiofrequency ablation, supraventricular tachycardia, EnSite NavX mapping system, near-zero fluoroscopy.

INTRODUCTION

Medical X-ray is the most common man-made radiation source, providing the largest quantity of radiation that people may come in contact with. Radiation can damage cells and their Deoxyribonucleic acid (DNA) (Sigurdson et al., 2008), and can even induce some cancers (Elizabeth et al., 1985; Boice et al., 1991; Kovoor et al., 1988). The quantity of X-ray radiation in radio frequency ablation is remarkably higher than that of common radiography and CT, and is considered to increase the occurrence of malignant tumors (Kovoor et al., 1988). Consequently, there is a need to reduce the quantity of X-ray exposure in radiofrequency ablation.Paroxysmal supraventricular tachycardia (PSVT) is the most common tachyarrhythmia. It can be completely cured by radiofrequency ablation, with continuous X-ray fluoroscopy during placement of the mapping catheter and the ablation catheter, as well as during the process of radiofrequency ablation. Exposure time for completing the procedure is usually not less than two (2) minutes.

The EnSite NavX mapping system is capable of three-dimensional location of mapping and ablation catheters in cardiac chambers, and has thus been widely applied in radiofrequency ablation procedures in recent years. At present, Ensite NavX is largely used in the treatment of

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Abbreviations: **WPW,** Wolff-Parkinson-White; **AVNRT,** atrioventricular nodal reentrant tachycardia; **AF,** atrial fibrillation; **PSVT,** paroxysmal supraventricular tachycardia; **DNA,** deoxyribonucleic acid.

special arrhythmias, such as atrial fibrillation (AF), problematic ventricular tachycardia, and atrial tachycardia. Few studies have applied this technique in common radiofrequency ablation of supraventricular tachycardia.

This prospective randomized study compared the safety, feasibility, and effectiveness of radiofrequency ablation of PSVT under the guidance of EnSite NavX and conventional X-ray fluoroscopy.

MATERIALS AND METHODS

Patients

From July, 2010 to March, 2011, we conducted radiofrequency ablation of SVT in 46 young patients in our center, with an age range of 14–32 years and a mean age of 22±3.5 years. They all had history of PSVT out of the hospital and did not have other chronic organic heart diseases after examination. They were randomly divided into two groups: 23 cases (11 males and 12 females) in the non-X-ray EnSite NavX version 8.0 (St. Jude Medical, St Paul, MN, USA) mapping guidance group and 23 cases (11 males and 12 females) in the conventional X-ray fluoroscopy group.

NavX system-guided radiofrequency ablation

Preoperative preparation

Local anesthesia was used for all patients in the waking state. One reference electrode was pressed on abdominal skin and three other pairs of NavX electrode slices in orthogonal direction (X Y Z axis) were placed on the left and right armpits, forebreast and back, and nape and medial left thigh, respectively. The Seldinger's technique was adopted to separately puncture the right femoral vein, right internal jugular vein, and /or right femoral artery.

Construction of right atrium/left ventricle model

EnSite NavX system was used in unipolar navigation. A long wire was inserted into the vascular sheath and sequentially into the vena femoralis, inferior vena cava, atrium dextrum, and superior vena cava. After determination of the approximate positions of the vessels, the long wire was withdrawn and replaced with a 4-pole electrode for construction of the atrium dextrum model and the key position.
Specific procedures are described in the next subsections.

Establishment of atrium dextrum/left ventricle model: A tetrapolar electrode was inserted into the femoral vein and passed through the inferior vena cava into the atrium dextrum. X-ray fluoroscopy was not necessary in this process. Endocardial electrocardiogram could clearly display the A wave of the atrium. In left bypass, the 4-pole catheter was retrograded into the aorta, thus successfully establishing the model simultaneously. Based on the electric potential (V wave), entrance into the left ventricle was detected, leading to establishment of the left ventricle model (Figure 1).

Location of the orifices of the superior and inferior vena cavae: The operator was assisted by the catheter-recorded electric potential, in locating the orifices of the superior and inferior vena cavae. If electric potential from distal to proximal electrode was found when the catheter entered the atrium dextrum from the inferior vena cava, the orifice of inferior vena cava is determined as the point where non-potential develops into distal electrode. Similarly, if electric potential disappeared from distal to proximal electrode when entering the superior vena cava from the atrium dextrum, the point where the potential disappears is determined to be the orifice of the superior vena cava.

Location of the tricuspid annulus: With the electrode, the potential of the atrium and ventricle can be simultaneously recorded. The amplitude between the two potentials is the locus of the tricuspid annulus, thus providing an estimate of the location of the tricuspid valve collar.

Location of the His bundle: The points where the His potential can be detected and recorded are demarcated in the model.

Placement of the coronary sinus catheter and other electrophysiology catheters: After successful puncture of the subclavian or internal jugular vein, the wire monopole was connected and the wire inserted up to the marked position of the inferior vena cava according to the superior vena cava model. Then, the wire was withdrawn and replaced with a coronary vein 10-pole electrode, which was sent into the coronary sinus based on NavX anatomical model, potential, and three-dimensional structure constructed previously. Placement of other catheters, such as the right atrium, right ventricle, and His bundle electrodes, was performed under NavX guidance model in turn or one by one. The current model was functionally similar to X-ray, since the operator could clearly see the movements of the catheter's head end. In addition, this model can offer a real-time three dimensional image that can aid in the precise placement of catheters.

Ablation

A 4-mm temperature-controlled ablation catheter or a 4-mm cold saline infusion catheter was used for radiofrequency. Ablation mode was present at 55℃ and 40 W for the temperature-controlled ablation catheter, with 60 s for each ablation; or 43℃ and 35 W for the cold saline infusion catheter, with a saline flow rate of 2000/hr and 200 s for each ablation.

Surgical time, exposure time, and complication

Surgical time was from the start of catheter placement up to catheter removal at the end of operation. Exposure time was automatically recorded by the X-ray imaging system. Severe complications include pericardial tamponade, atrioventricular block, pulmonary embolism, and hemopneumothorax.

Success of operation

Determination of the success of operation varied for the different mechanisms of tachycardia. For atrioventricular nodal reentrant tachycardia (AVNRT) and concealed atrioventricular reentrant tachycardia, success was indicated by failure of induction of tachycardia even with intravenous infusion of isoproterenol after the last discharge and 30-min observation. For Wolff-Parkinson-White (WPW) syndrome, the dominant WPW should have disappeared and tachycardia cannot be induced. For typical AF, AF should be terminated and the isthmus of tricuspid valve should have a two-way power block, with conduction time of more than 120 ms. For right atrial tachycardia, there should be failure of induction of atrial tachycardia even after intravenous infusion of isoproterenol for more than 30 min.

Panel (a)

Panel (b)

Figure 1. Panel (a) Non-fluoroscopic three-dimension reconstruction of the venous system (olive green) up to the right atrium (red) and SVC (violet). Collateral branches (pale yellow) are clearly visualized. Catheter advancement was continuously monitored through two simultaneous aspects. If the catheter tip diverged from the femoral caval axis, a collateral branch would be identified, facilitating retraction of the tip branch point and advancement into the correct trajectory. Panel (b) Reconstruction of the aortic arch. The mapping catheter was gently advanced up to the aortic valves (red), then pulled back and bent to a J-shaped loop. The looped catheter was pushed forward while being visualized on the mapping system in both AP and LAO. Two modified aspects were better illustrated ablation pulses (white) at the mitral annulus, which were necessary for AP ablation. Where SVC=superior vena cava ; AP=accessory pathway; LAO=left anterior oblique.

Postoperative follow-up

Routine physical examination and 12-lead ECG were performed at the first, third, and sixth month after the patient's discharge from hospital.

Data analysis

All data were expressed as mean ± standard deviation. Differences between the two groups were analyzed by t-test. A $P<0.05$ was considered statistically significant.

RESULTS

The EnSite mapping guidance group consisted of 11 males and 12 females, with an age range of 14 to 31 years

Table 1. EnSite NavX mapping guidance group.

S/N	Gender	Age	Type of supraventricular tachycardia	Surgical time (min)	Exposure time (s)	Complication
1	Male	21	AVNRT	65	65	None
2	Female	17	AVNT	96	96	None
3	Female	18	AVNRT	67	67	None
4	Female	15	LL AP	172	172	None
5	Male	16	Bight-sided AP	104	104	None
6	Male	15	right atrial flutter	110	110	None
7	Female	14	AVNRT	78	78	None
8	Male	18	AVNRT	70	70	None
9	Male	17	AVRT	70	70	None
10	Female	18	right atrial flutter	112	112	None
11	Male	23	right atrial flutter	125	125	None
12	Male	18	AVNRT	100	100	None
13	Male	25	right atrial tachycardia	130	130	None
14	Female	17	AVNRT	67	67	None
15	Female	14	right atrial flutter	68	68	None
16	Female	16	AVNRT	59	59	None
17	Male	20	AVRT	56	56	None
18	Female	15	AVRT	82	82	None
19	Female	14	AVNRT	54	54	None
20	Male	16	AVRT	58	58	None
21	Male	15	AVRT	56	56	None
22	Female	31	LLAP Af	80	80	None
23	Female	14	AVNRT	79	79	None

and a mean age of 21.4±2.8 years. There were 10 cases of AVNRT, 8 cases of AVRT, 4 cases of right AF, and 1 case of right atrial tachycardia (Table 1). The conventional X-ray fluoroscopy group was composed of 11 cases of males and 12 females, with an age range of 14–32 years and a mean age of 22.3±3.1 years. There were 13 cases of AVNRT, 7 cases of AVRT, 1 case of right AF, and 2 cases of right atrial tachycardia (Table 2).

Surgical time ranged from 54 to 130 min, with a mean of 79.0±17.8 min in the EnSite mapping group, while the range was 54–132 min and mean was 74.8±14.6 min in the conventional X-ray fluoroscopy group. Although, the average surgical time of the latter group is slightly shorter than that of the former, they do not differ statistically (*P>0.05*).

In the EnSite mapping group, 18 cases (78.3%) did not receive X-ray fluoroscopy and 5 cases were assisted by X-ray during surgery. Among them, exposure time ranged from 28 to 190 s with a mean exposure time of 28.39±43.1 s. The five cases consist of one case with AVNRT and vascular malformation of femoral vein; one case with AVRT was actually epicardial left posterior septal bypass; one had right AF combined with atrial septal defect; one had a left anterior AVRT with auricular fibrillation; and the last case was characterized by difficulty in locating the ablation target point because of transposition of the coronary sinus reference electrode during operation. Pacing mapping examination was performed in six cases (4 cases of AF, 1 case of atrial tachycardia, and 1 case of left anterior bypass combined with auricular fibrillation) (Figure 2). X-ray exposure time in conventional X-ray fluoroscopy group ranged from 113 to 671 s with a mean of 339.3±162.6 s. Exposure time of the EnSite NavX group was significantly less than that of the conventional X-ray fluoroscopy group (*P<0.01*).

All patients exhibited immediate success and there was no onset of tachycardia at follow-up. There were no significant complications in either group.

DISCUSSION

In this study, radiofrequency ablation of PSVT (including AVRT, AVNRT, right AF, and right atrial tachycardia) with EnSite NavX guidance under non-ray conditions is equally effective and safe compared with that using conventional X-ray fluoroscopy.

Most PSVT patients are young and largely have atrioventricular reentrant and atrioventricular nodal reentrant tachycardia. Catheter ablation is a relatively safe method with high success rate and is currently advised as the first choice of treatment in most PSVT cases. The traditional ablation technique consists of catheter placement with the help of screen, which

Table 2. Conventional X-ray fluoroscopy group.

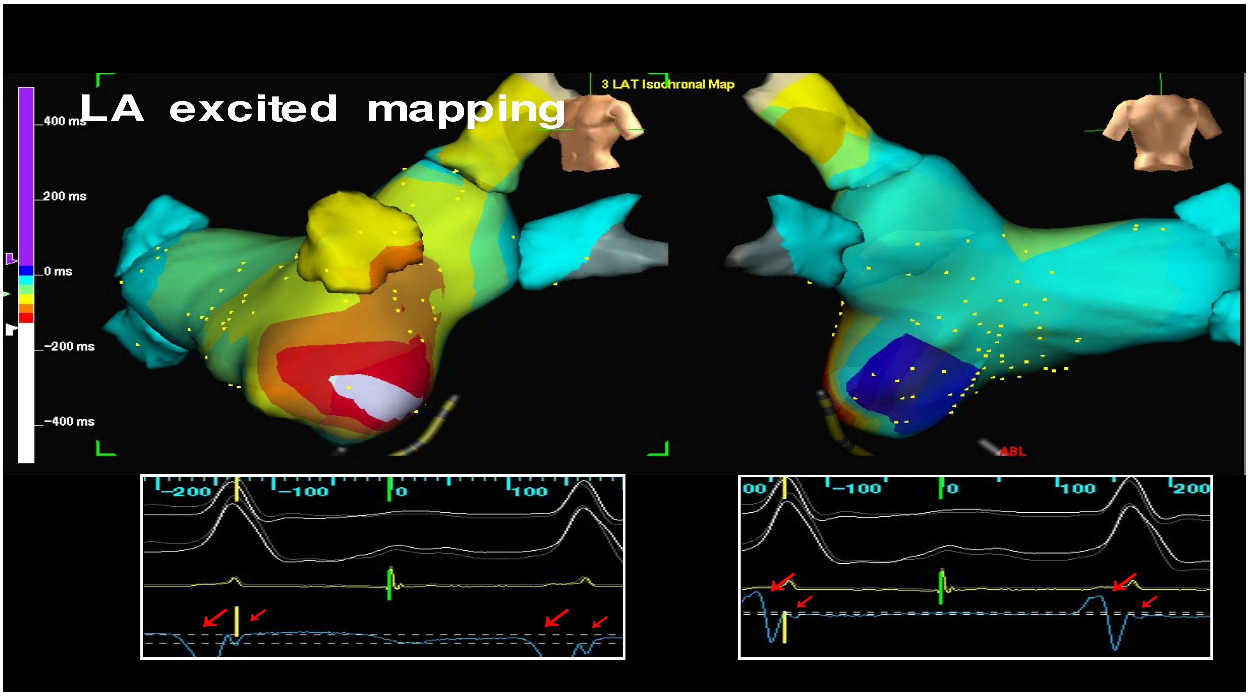
S/N	Gender	Age	Type of supraventricular tachycardia	Surgical time (min)	Exposure time (s)	Complication
1	Male	20	AVNRT	56	218	None
2	Female	16	right atrial tachycardia	117	612	None
3	Female	15	AVNRT	77	113	None
4	Female	18	LAP	67	413	None
5	Male	19	AVNRT	62	146	None
6	Male	18	AVRT	78	478	None
7	Female	32	AVNRT	68	161	None
8	Female	20	Bight-sided AP	76	615	None
9	Male	17	AVNRT	80	198	None
10	Male	14	AVNRT	71	132	None
11	Female	22	AVNRT	65	256	None
12	Female	24	L AP	56	475	None
13	Female	22	AVNRT	60	315	None
14	Male	19	AVRT	83	671	None
15	Male	19	AVNRT	73	246	None
16	Female	19	AVNRT	64	316	None
17	Female	20	right atrial tachycardia	132	639	None
18	Male	16	LLAP	74	456	None
19	Male	25	right atrial flutter	124	564	None
20	Female	21	AVNRT	62	168	None
21	Female	22	AVRT	65	316	None
22	Male	15	AVNRT	54	163	None
23	Male	14	AVNRT	57	132	None

inevitably leads to some X-ray exposure.

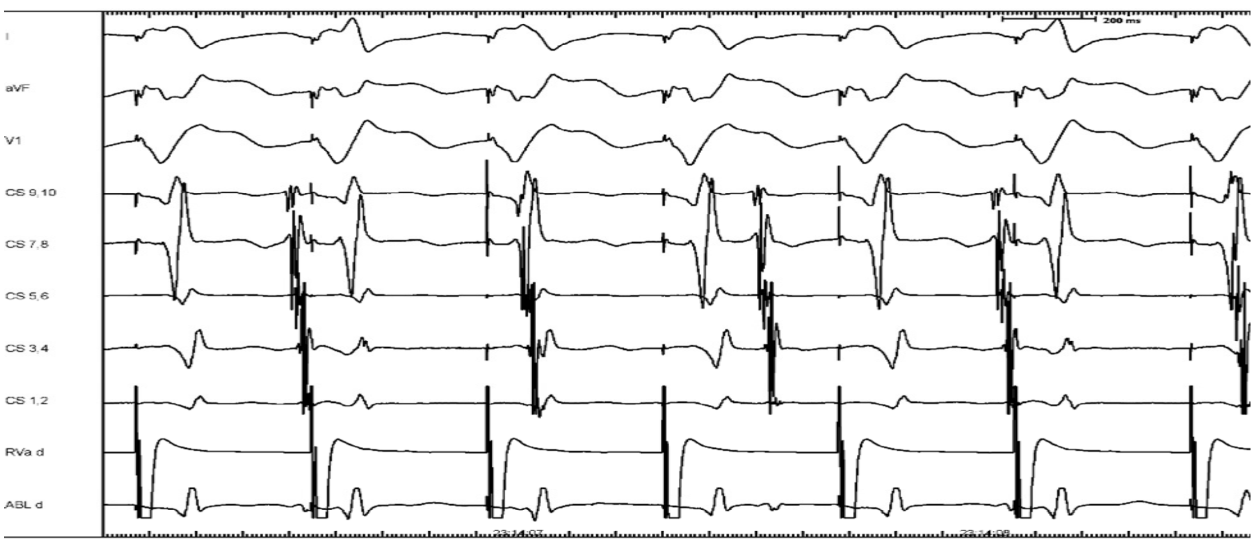
Due to statistical limitations, it is difficult to evaluate the correlation between small quantities of radiation with long-term cancer risk. Nevertheless, the “linear-no-threshold” model from BEIR VII of the U.S. National Institute indicates that present evidence support the simple linear relation between cancer risk and radiation quantity. Based on this model, there is no starting point of radiation risk. Recent studies have shown that even small quantities of radiation may have harmful effects. For instance, in children who have received cardiac catheterization, lymphocyte DNA damage in circulating blood can be observed at acute and chronic stages (Ait-Ali et al., 2010; Andreassi et al., 2006; Bedetti et al., 2008). Kovoor et al. (1988) found that extension of exposure time in radiofrequency ablation may increase the incidence of fatal cancers, especially lung cancer. This indicates that minimization of radiation use can benefit both patients and operators.

The Ensite NavXTM electric anatomical mapping system can guide ablation and reduce radiation. Reducing radiation enables it to be more extensively applied in simple ablation surgeries like AF, AVRT, and AVNRT. Compared with the conventional X-ray ablation, X-ray exposure time in Ensite NavXTM electric anatomical mapping is markedly less (P = 0.000).

Several studies have applied the electric mapping anatomical system for maximally reducing SVT ablation procedures in children at most, with 3 studies utilizing EnSite NavX mapping system for guidance (Beels et al., 2009; Fazel et al., 2009; Papagiaannis et al., 2006; Drago et al., 2002; Papez et al., 2007). Papagiannis and his team demonstrated that total ablation time of AVNRT, AVRT and left APs could be decreased, although they still used X-ray ablation and the reduction in exposure time in AVNRT patients was not statistically significant (Einstein et al., 2007). Studies by Smith and Clack (2007) and Tuzcu (2007) indicated that 80–86% of patients did not receive fluoroscopy, while it was remarkably reduced in the remaining 14%–20% of patients. There are also some reports on the use of Ensite NavXTM mapping system to guide non-X-ray ablation in adult patients with SVT (Pachon et al., 2009; Venneri et al., 2009). In a random experiment (Pachon et al., 2009), Ensite NavXTM mapping system was utilized in 27% of patients to completely avoid fluoroscopy. Alvarez and his team recently demonstrated that non-fluoroscopy ablation is feasible in 98% of AVNRT patients (Alvarez et al., 2009). Pachon et al. (2009) applied EnSite NavX to guide non-ray radiofrequency ablation to treat typical AF. In March, 2011, Casela et al. (2011) reported complete realization of non-ray radiofrequency ablation in 38 among 50 adult patients (76%), including 4 cases of left bypass. In the present study, the EnSite NavX group included 8 cases



Panel (a)



Panel (b)

Figure 2. This is a 31-year old female included in the Ensite Navx group (number 22). Panel (a) Exited mapping showed that the AVRT was caused by left-side concealed accessory pathway. Picture on the left was from LAO view, while that on the right picture was from PA view. White point in the exited mapping indicates the earliest exited point—the fusion of V and A waves, which corresponds to the red arrows in the electric pictures. Panel (b) Intra-cavity electrogram when the endpoint of ablation was acquired by cooled-saline irrigation showing isolation of V and A waves. RF settings are as follows: temperature of 43℃, power of 35 W, first application of 6 s that resulted in termination of tachycardia, and consolidated application of 60 s. LAO = left anterior oblique; PA = posteroanterior.

of AVNRT, 7 cases of left AVRT, 2 cases of right AF, and 1 case of right atrial tachycardia. They account for 78.3% (18/23), all of whom did not receive any exposure. 21.7% (5/23) of patients had X-ray fluoroscopy with Ensite NavX mapping guidance, with an average exposure time that was significantly less than that of the conventional group (mean exposure time of 30.6±11.8 and 339.26±187.83, respectively; P=0.001). The main reasons for additional

X-ray use in the NavX group are:

1. Malformation of heart and vessels.
2. Combination of atrial fibrillation.
3. Bypass of epicardial origin.
4. Transposition of reference electrode, which reduced guidance of bulk ablation electrode and made localization of ablation target points difficult.

Adult patients who were able to totally avoid fluoroscopy accounted for 78.3%, including left and right supraventricular arrhythmias, indicating that the results of our study are similar to the findings of Casella et al. (2011).

We found that precise geometric reconstruction is significant, and the time spent on it is justified by the acceleration of the latter part of the procedure. Ablation of 3D model based on precise heart anatomy provides exact and notable technical advantage, facilitating time conservation and easing the procedure. Electric anatomical mapping can provide perspective on the patient's cardiac anatomical structure. Geometric reconstruction urges the operator to connect the endocardiac part in contact with the movable electrode with the different parts related to subsequent ablation. 3D model enables operators to simultaneously and continuously observe two images (for example, right anterior oblique and left anterior oblique positions), which can possibly accelerate ablation. This advantage is more pronounced for specific types of arrhythmia. For instance, traditional ablation is performed after radio-frequency pulse. It is sometimes complicated by the minimization and temporary disappearance of the stimulus after precise identification of AP, thus leading to wastage of operation time. The adoption of 3D mapping system can avoid this problem, since it allows for marking of the AP position once it is reached. In addition, one radio-frequency pulse can be used as guide when pre-excitation is reduced or paused. When AVNRT anatomical ablation is accurately located in the Koch triangle, the procedure becomes very easy, especially when it is located before the CS opening. In addition, the His bundle can be located as an area but not as a point. Observation of these areas under three-dimension through a movable electrode from atrium dextrum to CS opening is essential in understanding the anatomy. Incomplete linear ablation of AF leads to decreased heart rate but persistent tachycardia. Pacing mapping can more easily determine the position of online vacancy.

The limitations of this study are as follows:

1. Mono-centricity with small quantity of samples.
2. Large scale of forward-looking randomized controlled studies is still needed.
3. Surgical expense is relatively high compared with conventional X-ray radiofrequency ablation.

Conclusion

Radiofrequency ablation of PSVT under the guidance of EnSite NavX and conventional X-ray fluoroscopy are equally effective and safe. The utilization of EnSite NavX mapping system notably reduces surgical exposure time.

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