ATRIAL FIBRILLATION

CLINICAL DECISION MAKING

A New “Hands-Free” Non-Fluoroscopic Method for Monitoring Phrenic Nerve Function During Catheter Ablation

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ABSTRACT. Introduction: Diaphragm motion (DM) is usually assessed by fluoroscopy and manual palpation (F/MP) to avoid phrenic nerve (PN) palsy during catheter ablation. We tested a “hands-free” non-fluoroscopic method for monitoring PN function in 10 consecutive patients with atrial fibrillation undergoing cryoballoon pulmonary vein isolation. Methods and results: A neonatal blood pressure cuff filled with water was attached to the right costal margin using a Velcro® band around the thorax. Pressure signals from this cuff processed by a pressure transducer were displayed in mmHg as deflections from baseline. A multipolar electrode catheter in the superior vena cava was used to pace the right PN prior to and during isolation of the right-sided pulmonary veins. Pacing amplitude was varied randomly in 1–2 mA steps from 0 to 20 mA. An operator blinded to pacing amplitude and the pressure signals was asked to grade DM by F/MP from 0 to 4+. The strength of DM graded by F/MP varied as a direct function of PN pacing amplitude (Spearman correlation 0.738, p<0.001). Similarly, the amplitude of the pressure signals varied as a direct function of pacing amplitude and correlated well with the strength of DM as assessed by F/MP (Spearman correlation 0.811, p<0.001). One patient developed transient PN palsy during isolation of the right superior pulmonary vein. The pressure signal amplitude decreased with the onset of PN palsy and recovered within 1 min after cryoapplication was halted. Conclusion: This “hands-free” non-fluoroscopic method is an alternative way to assess PN function during catheter ablation.

KEYWORDS. ablation, atrial fibrillation, cryoballoon, phrenic nerve palsy, pulmonary vein isolation.

Introduction

Phrenic nerve palsy (PNP) is a recognized complication of various catheter ablation procedures. Palsy of the right phrenic nerve (PN) is most commonly encountered during isolation of the right superior pulmonary vein using the cryoballoon balloon (Arctic Front™, Medtronic CryoCath, Kirkland, Quebec, Canada.), occurring with an estimated incidence of 3–11%.1–6 If one uses the second-generation cryoablation balloon (ArcticFront Advance™, Medtronic CryoCath), which permits more uniform and efficient freezing, the incidence of this complication may approach 20%.7,8 In order to avoid permanent PNP during such procedures, diaphragmatic function is monitored continuously during ablation and energy delivery halted as soon as diminution of diaphragmatic contraction is detected. Several methods for monitoring diaphragmatic function during ablation have been described. The usual technique employed is to pace the right PN with an electrode catheter placed in the superior vena cava, while...
monitoring diaphragmatic function by palpating the abdomen and observing diaphragmatic excursion under continuous fluoroscopy. Another method is to record compound motor action potentials of the right hemidiaphragm using modified surface electrocardiogram (ECG) electrodes on the chest wall surface, while pacing the PN. Motion of the diaphragm can also be monitored using intracardiac echocardiography. The present study describes a new method of monitoring diaphragmatic function during ablation that does not require palpation of the abdomen or use of fluoroscopy.

Methods

Study population

Ten consecutive patients (8 male, 2 female) with atrial fibrillation (AF) undergoing pulmonary vein isolation were included in the present study. Five of the patients had paroxysmal AF and five had persistent AF. Ages ranged from 36 to 81 years (average 60 years). All patients had failed treatment with at least one antiarrhythmic drug, and all patients had given written informed consent before undergoing their ablation procedure. The study was approved by the institutional review board of Cape Cod Hospital.

Recording of diaphragmatic pressure signals

A pediatric blood pressure cuff (Classic Cuf™, Critikon/GE Healthcare, Milwaukee, WI) was modified to enable recording of pressure signals from the body surface generated by diaphragmatic contraction. Water was injected into the cuff using the port usually attached to the insufflation bulb (Figure 1). This port was then closed with a stopcock (Figure 1). The port usually connected to a sphygmomanometer (Figure 1) was, instead, connected to a standard pressure transducer (Figure 1), which, in turn, was connected to a physiologic recording system that allowed one to display and analyze the pressure signals. The cuff was then applied.
to the right costal margin and secured in place using a Velcro® band placed circumferentially around the thorax (Figure 2).

**Ablation procedure**

All patients underwent cardiac computed tomography (CT) scanning prior to ablation to define their pulmonary vein anatomy. Patients with persistent AF also underwent transesophageal echocardiography to exclude atrial thrombus before ablation. All patients were taking warfarin and had a therapeutic international normalized ratio at the time of ablation. Ablation was performed under general anesthesia, but without use of paralytic agents that might obscure diaphragmatic function. Bilateral femoral venous access was obtained. Under intracardiac echo guidance a transseptal catheterization was performed using either an SL1 sheath or an Agilis sheath and a BRK1 needle (St. Jude Medical, St. Paul, MN). Heparin was then administered and supplemental doses were given throughout the procedure to maintain an activated clotting time between 350 and 400 s. A duodecapolar catheter (DX20, Boston Scientific, San Jose, CA) looped in the right atrium and advanced into the coronary sinus was used as a position reference during mapping and to pace the left atrium. A steerable multipolar catheter (PentAray™, Biosense-Webster, Diamond Bar, CA) was introduced into the left atrium and was used to construct a three-dimensional (3D) electroanatomic map of the left atrium and pulmonary veins. This map was then registered with the preoperative CT scan using a 3D electroanatomic mapping system (EnSite NavX, St. Jude Medical). After completion of the map, the left atrial sheath was exchanged over a guidewire for a 14F transseptal sheath (FlexCath™, Medtronic CryoCath, Kirkland, Quebec, Canada). A circular mapping catheter (Achieve™, Medtronic Ablation Frontiers, Carlsbad, CA) was used to cannulate each pulmonary vein and to confirm isolation of the veins after ablation. The Arctic Front Advance™ cryoballoon (Medtronic CryoCath) was used for ablation in
all patients. In all patients the left superior pulmonary vein was isolated first, followed by the left inferior pulmonary vein, and, lastly, the right superior pulmonary vein. At least two cryoablations, each lasting 4 min, were performed in each vein. Following isolation of the veins, if AF persisted, sinus rhythm was restored by cardioversion. None of the 10 patients underwent linear ablation in the left atrium or ablation of complex fractionated electrogram sites.

**Assessment of diaphragmatic function**

After isolation of the left-sided veins and before isolation of the right-sided veins the PentAray™ catheter was advanced to the right atrial/superior vena caval junction and positioned to pace the right PN. Pacing was performed initially at 20 mA amplitude and 2.0 ms pulse width. Once stable PN capture was achieved the catheter position was recorded on the 3D electroanatomic map and monitored periodically to ensure that the catheter position did not change. The pacing amplitude was then varied randomly in 1–2 mA steps from 0 to 20 mA. At each pacing amplitude the operator who was scrubbed and manipulating catheters was asked to judge the motion of the right hemidiaphragm on a scale of 0 to 4+ based upon palpation of the abdomen and observation of diaphragmatic excursion by fluoroscopy. This operator was blinded to pacing amplitude. At each pacing amplitude the diaphragmatic pressure signal was also recorded but not displayed on the monitor. Thus, the operator who was assessing diaphragmatic function by palpation and fluoroscopy was blinded to the diaphragm pressure signal in addition to pacing amplitude. The size of the diaphragm pressure signal at each pacing amplitude was measured subsequently off line at the end of the procedure. At each pacing amplitude, six to eight of the diaphragm pressure signals were measured and used to calculate a mean value for the pressure signal at each pacing amplitude.

**Statistical analysis**

In each scatter plot (see Figures 4 and 6), a positive Spearman correlation value is reported. This non-parametric measure of statistical dependence was utilized as
it is appropriate for both continuous (PN pacing output and diaphragm pressure signal) and discrete (palpation/fluoroscopy motion score) variables without requiring the knowledge of the joint probability distribution of each measure. Significance testing was conducted against the null hypothesis of no association. p-Values <0.05 were considered as statistically significant associations.

Results

The strength of diaphragmatic contraction, as assessed by abdominal palpation and fluoroscopy, varied directly as a function of PN pacing stimulus amplitude. This was readily apparent in each individual patient (Figure 3) and was also seen when the group was analyzed in aggregate (Spearman correlation 0.738, p<0.001, Figure 4). During PN pacing, the blood pressure cuff attached to the right costal margin registered a positive pressure wave with each diaphragmatic contraction (Figure 5). The amplitude of the diaphragm pressure signal during PN pacing also varied with changes in the pacing stimulus amplitude. The pressure signal amplitude was greatest at the maximal PN pacing stimulus amplitude and decreased progressively with reductions in pacing stimulus amplitude (Figure 5). When the group was analyzed in aggregate there was a high degree of correlation between diaphragmatic contraction strength as assessed by fluoroscopy and abdominal palpation and diaphragmatic contraction strength as assessed by the diaphragm pressure signal (Spearman correlation 0.811, p<0.001, Figure 6). One patient in our series developed transient PNP during cryoballoon isolation of the right superior pulmonary vein. This was detected by abdominal palpation and fluoroscopy, but was noticed even earlier by monitoring the diaphragm pressure signal (Figure 7). With prompt cessation of freezing the diaphragm pressure signal and diaphragmatic function as assessed by palpation and fluoroscopy returned quickly to baseline (Figure 7).
Discussion

Early detection of PNP during catheter ablation is essential in order to prevent permanent paralysis of the hemidiaphragm. This complication is most commonly seen during isolation of the right superior pulmonary vein using cryoablation balloon technology. The usual method for monitoring diaphragmatic function is to pace the PN with an electrode catheter in the superior vena cava and to monitor the strength and amplitude of diaphragmatic contraction by manual palpation of the abdomen and observation of diaphragmatic motion with fluoroscopy. This method, though simple and reliable, exposes the patient and laboratory staff to excess radiation and often requires the assistance of a second operator. Like skeletal muscle over which one can exert voluntary control, the depth of inspiration, which is partly mediated by diaphragmatic contraction, is not an all or none phenomenon. Thus, it is logical to expect that, as the stimulus strength during PN pacing is increased, more axons will be recruited which, in turn, should increase the strength and amplitude of contraction of the hemidiaphragm. This was, indeed, observed in the present study. It was demonstrated that the strength of diaphragmatic contraction, as assessed by fluoroscopy and abdominal palpation, was a direct function of the amplitude of the PN pacing stimulus. The second and principal finding of the present study was that contraction of the hemidiaphragm during PN pacing could also be detected and measured by recording the pressure signal generated by diaphragmatic contraction using a modified pediatric blood pressure cuff placed on the surface of the abdomen. The size of this pressure signal was also a direct function of PN pacing amplitude and correlated well with the vigor of diaphragmatic contraction as assessed by palpation and fluoroscopy. An obvious advantage of abdominal pressure signal monitoring during PN pacing is that it does not require use of fluoroscopy or the assistance of another operator. Another method for monitoring right hemidiaphragmatic function during catheter ablation is to record the compound motor action potential generated by the diaphragm while pacing the PN. This method was originally described in a canine model of ablation, using a multipolar electrode placed in the esophagus to record the compound motor action potential. More recently, a modified recording technique using surface ECG electrodes placed along the right costal margin was described in a single patient during isolation of the right superior pulmonary vein. This method also has the advantage of not requiring additional fluoroscopy or the aid of a second operator. However, it can be difficult in some cases to delineate clearly the signal generated by the diaphragm from the pacing stimulus. This difficulty may be one reason why widespread adoption of this method for monitoring diaphragmatic function has been slow.

Limitations

The present study, conducted in a relatively small number of patients, was purely observation. It does not
Conclusions

Contraction of the right hemidiaphragm can be detected and measured by recording a pressure signal from the surface of the abdomen using a modified pediatric blood pressure cuff. During pacing of the PN the size of the abdominal pressure signal is a direct function of PN pacing stimulus amplitude and correlates well with diaphragmatic function as assessed by abdominal palpation/fluoroscopy. Although we did encounter one patient in whom diminution of the diaphragm pressure signal seemed to be an early warning of impending PNP, the present study does not allow one to conclude that this method is superior to or even equal to other methods for early detection of impending PNP.
palpation and fluoroscopy. This is a novel “hands-free” non-fluoroscopic method for monitoring PN function during catheter ablation.

References


