High-power short-duration radiofrequency ablation of typical atrial flutter

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BACKGROUND High-power short-duration (HPSD) ablation has been explored for pulmonary vein isolation. Early data suggest similar efficacy with shorter procedure times and perhaps greater safety. Data are lacking on the use of this ablation strategy for other arrhythmias.

OBJECTIVE The purpose of this study was to evaluate the safety, efficacy, and clinical outcomes of HPSD ablation in patients with typical atrial flutter compared to those undergoing ablation with conventional settings.

METHODS Consecutive patients undergoing cavotricuspid isthmus (CTI) ablation using standard power settings were compared to those performed after transitioning to HPSD ablation. Demographics, procedural details, and ablation outcomes were prospectively collected. The primary endpoint was duration of radiofrequency energy delivery. Secondary endpoints were radiation duration and analgesia requirements.

RESULTS A total of 114 consecutive subjects undergoing CTI ablation (57 standard power, 57 HPSD) were included. HPSD ablation and electroanatomic mapping/contact force (EAM/CF) use were associated with 66% (95% confidence interval [CI] 58%–73%) and 50% (95% CI 37%–60%) shorter ablation times compared to standard power and not using EAM/CF, respectively. Patients in the HPSD group required 50 mcg less fentanyl relative to the standard ablation arm after adjusting for sex, age, and comorbidities (P = .048). At a median follow-up of 6 months, 4 patients (7%) in the standard arm had recurrence of atrial flutter, compared to none in HPSD group (P = .057).

CONCLUSION HPSD is a safe and effective approach to CTI ablation. This strategy may reduce ablation time and analgesia requirements. Larger studies and longer follow-up are needed to further evaluate this strategy.

KEYWORDS Ablation; Atrial fibrillation; Atrial flutter; Fluoroscopy; High-power short-duration ablation

Introduction

Ablation of typical atrial flutter involves interruption of the right atrial macroreentrant circuit via the application of energy along the critical isthmus between the tricuspid valve and the inferior vena cava (IVC). Ablation of the cavotricuspid isthmus (CTI) can be accomplished via cryoablation, nonirrigated radiofrequency (RF) ablation, and irrigated RF ablation. These strategies result in >95% acute success in achieving bidirectional block.[1]

Procedure time and radiation exposure can vary significantly between patients owing to variable CTI anatomy. With current strategies, average RF delivery time to achieve bidirectional block can range from 10 to 23 minutes, and the

risk of tissue vaporization ("steam pop") is reported as high as 2%.[2–5] Additionally, more than 75% of RF lesions during CTI ablation are perceived as painful by patients.[6,7]

High-power short-duration (HPSD) RF delivery has been evaluated in patients undergoing pulmonary vein isolation (PVI) and found to be associated with shorter procedure times and low complication rates.[8,9] There is no available data on the efficacy and safety of HPSD ablation for CTI-dependent atrial flutter. We performed HPSD RF ablation of the CTI using a 3.5 mm open-irrigated catheter with the hypothesis that it would reduce ablation time, radiation exposure, and patient discomfort.

Methods
Patients
Consecutive patients undergoing CTI ablation at the University of Ottawa Heart Institute between September

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KEY FINDINGS

- High-power short-duration (HPSD) ablation is a safe and effective alternative to standard "low-power" settings for atrial flutter ablation.

- HPSD ablation is associated with a substantial reduction in total ablation time, which was further reduced with the use of electroanatomic mapping and contact force–sensing catheters.

- HPSD ablation requires lower doses of analgesia, a surrogate marker of patient discomfort.

2017 and March 2019 were included in the study. Cases prior to January 1, 2018, were performed using standard ablation settings, while those performed after that date were performed using HPSD settings. All procedures were performed by 2 operators (M.G. and M.S.). This population included standalone CTI ablation or combined PVI and CTI ablation. Patients with prior CTI ablation, congenital heart disease, and heart transplant were excluded. All patients had CTI-dependent atrial flutter confirmed on a 12-lead electrocardiogram.[10]

Patients were enrolled prospectively in a longitudinal registry approved by the Ottawa Health Science Network Research Ethics Board (OHSN-REB). Baseline demographic and clinical patient characteristics, presence of atrial fibrillation (AF), total RF duration, fluoroscopy time, and sedation and analgesic doses (in cases done without general anesthesia (GA)) were collected and prospectively entered into a database. Clinical characteristics, procedural data, and clinical outcomes were analyzed.

Ablation procedure

Continuous monitoring of the surface electrocardiogram and intracardiac bipolar electrograms was done with a Pruka recording system (CardioLab Electrophysiology Recording System, GE Healthcare Systems, Chicago, IL). Endocardial bipolar electrograms were evaluated at 100 mm/s sweep speed and filtered at 30 to 5000 Hz.

All RF lesions were delivered point by point in power control mode using SmartAblate generator (Biosense Webster, Irvine, CA). In the standard ablation arm, energy was delivered at 30 W for a duration of 30–40 seconds. In the HPSD ablation arm, energy was delivered at 50 W for 8–10 seconds targeting electrogram attenuation and a 10–15 ohm impedance drop. Following observations of steam pops occurring at 10 seconds of ablation, the maximal duration of HPSD ablation was changed to 9 seconds (following patient #14 in the HPSD group). In the HPSD group, ablation catheter irrigation was set to 30 mL/min. In the group with low power setting ablation irrigation was set to 17 mL/min.

Patients with a history of only atrial flutter underwent standalone CTI ablation, which was completed under conscious sedation using midazolam and fentanyl. Under fluoroscopic guidance, a Halo catheter was placed in the right atrium and a deflectable decapolar catheter was placed in the coronary sinus (CS). Patients presenting in atrial flutter had the circuit confirmed by entrainment from the CTI using the ablation catheter for pacing. Entrainment was done at a cycle length (CL) 20–30 ms shorter than the tachycardia CL. A postpacing interval minus the tachycardia CL of <30 ms was used to confirm CTI-dependent atrial flutter. RF lesions were delivered using a 3.5 mm irrigated non-Nav ThermoCool SF catheter (Biosense Webster, Diamond Bar, CA). For patients in sinus rhythm, ablation was performed during atrial pacing at 600 ms from the CS proximal pole. Ablation lesions were placed starting at the tricuspid valve side by targeting the first sharp atrial signals. The catheter was then slowly dragged towards the IVC while ablating in a point-by-point manner. The IVC was marked by a loss of atrial signals on the ablation catheter. Signal attenuation and impedance changes were monitored closely during ablation. Intermittent fluoroscopy was used during catheter manipulation and energy delivery.

Patients with a history of atrial flutter and AF underwent combined PVI and CTI, which was completed under GA. Tidal volumes were reduced to <300 mL to reduce catheter motion. Right atrial anatomy and catheter manipulation was guided by a 3D electroanatomic mapping (EAM) system (CARTO; Biosense Webster). Lesion location and CTI lines were also annotated using the 3D EAM; therefore, no fluoroscopy was used during this portion of the procedures. Patients presenting in atrial flutter had the circuit confirmed as described above. RF lesions were delivered using a 3.5 mm irrigated NaviStar ThermoCool SmartTouch catheter (Biosense Webster). Contact force (CF) was targeted at 8–20 grams. VisiTag lesions were set to a catheter stability of 2 mm, average force of 8 grams, and minimum duration of 5 seconds. For patients in sinus rhythm, ablation was performed during atrial pacing at 600 ms CL from the CS proximal pole. Ablation times for the CTI portion of the procedure was collected and reported.

Acute procedural success was defined by achievement of bidirectional block across the CTI line. Bidirectional block was assessed using differential pacing maneuvers. Briefly, the ablation catheter is placed lateral to the CTI line and pacing from the CS is performed at a CL of 500–600 ms, and the stim-to-ablation interval is recorded (interval 1). The ablation catheter is then moved more laterally (away from the CTI line) while pacing from the CS at the same CL, and the stim-to-ablation interval is recorded again (interval 2). Unidirectional block across the line is noted if interval 1 is greater than interval 2. The same maneuver is repeated while pacing from the ablation catheter to ensure that bidirectional block across the line is present. In patients with standalone CTI ablation, the maneuvers were repeated at 30 minutes after ablation to ensure persistent bidirectional block. In patients with combined PVI and CTI, the CTI ablation was completed prior to transseptal puncture and PVI, and bidirectional block was rechecked at procedure end to ensure persistent bidirectional block.

Follow-up

Patients who underwent CTI ablation only had a 48-hour Holter done at 3 months and clinical follow-up to assess for arrhythmia or symptom recurrence. Patients who underwent PVI and CTI ablation had a 14-day Holter done at 3, 6, and 12 months and clinical follow-up at 4, 7, and 13 months to assess for arrhythmia or symptom recurrence.

Endpoints

The primary endpoint was the ablation time in minutes, defined as the duration of RF energy delivery. Secondary endpoints were fluoroscopic duration and dose, as well as procedural sedation and analgesic requirements. As EAM/CF cases required no fluoroscopy and were done under GA, secondary endpoints were analyzed using only CTI standalone procedures.

Statistical analysis

Categorical variables are reported as n (%) and were compared using χ^2 or Fisher exact tests. Continuous variables are reported as mean ± standard deviation or median (interquartile range) and were compared using t tests or Mann-Whitney U tests. Crude and adjusted differences in ablation times by power and use of EAM/CF were determined using univariate and multivariable linear regression adjusting for prespecified covariates of interest based on group consensus (age, sex, and hypertension) and any significantly different characteristic between groups at baseline. Given the non-normal distribution of ablation times, this variable was log transformed in regression analyses. Percent differences in ablation times are reported with 95% confidence intervals (CI) based on calculated geometric means. The associations of power with fluoroscopy time, fluoroscopy dose, and doses of fentanyl and midazolam used were also examined in cases not using GA. All analyses were performed using SAS 9.4 (SAS Institute, Cary, NC) using a 2-tailed α level of 0.05 to define statistical significance.

Ethics

The institutional review board (OHSN-REB) waived the need for review and informed patient consent owing to the context of the study as a quality assurance project, the retrospective nature of this study, and the use of de-identified patient information.

Results
Patients

One hundred and fourteen (114) consecutive patients undergoing first-time CTI ablation for symptomatic atrial flutter were enrolled between September 1, 2017, and March 31, 2019. Eighty-seven patients (76%) were male, the mean age was 65 ± 10 years, 57 (50%) underwent HPSD ablation, and 56 (49%) used EAM/CF during ablation. The HPSD ablation group had a higher portion of male patients (84% vs 68%, $P = .047$) but was otherwise similar to the standard ablation group (Table 1).

Table 1 Patient characteristics

	Standard ablation	HPSD ablation	P
Full cohort	n = 57	n = 57	
Male sex	48 (84%)	39 (68%)	.047
Age, y	65 ± 11	64 ± 10	.715
Congestive heart failure	6 (11%)	12 (21%)	.123
Hypertension	28 (49%)	20 (35%)	.129
Diabetes mellitus	8 (14%)	8 (14%)	1.000
Stroke/TIA	5 (9%)	3 (5%)	.717

HPSD = high-power short-duration; TIA = transient ischemic attack.

Primary endpoint: Ablation time

In univariate analyses, HPSD ablation and EAM/CF were associated with 71% (95% CI 63%–77%) and 60% (95% CI 47%–70%) shorter ablation times relative to standard power and to not using EAM/CF, respectively (Figure 1, Table 2). Multivariable regression indicated that HPSD ablation and use of EAM/CF were independently associated with reductions in ablation times of 66% (95% CI 58%–73%) and 50% (95% CI 37%–60%), respectively (Table 3). Hypertension was additionally suggested as a predictor of ablation time.

To further assess the impact of HPSD ablation in the absence of EAM/CF use, we analyzed patients who had CTI ablation without EAM/CF (n = 58). In the non-EAM/CF cohort, ablation time was significantly shorter in the HPSD ablation group (8.3 vs 21.6 minutes, $P < .001$).

Secondary endpoints

Including only cases of CTI standalone ablation (non-PVI cases), HPSD ablation was associated with lower fentanyl use (mean difference: 53 mcg, 95% CI 7–98 mcg; $P = .032$) (Figure 2). This difference persisted after adjusting for patient sex and comorbidities (adjusted difference: 50 mcg, 95% CI 41–99 mcg; $P = .048$). HPSD ablation was not associated with differences in fluoroscopy time, fluoroscopy dose, or midazolam dose (Figure 2).

Adverse events

Two steam pops occurred in patients undergoing HPSD ablation with no clinical sequelae (defined as an audible "pop" with an associated change in impedance). Both steam pops occurred at 10 seconds of ablation. Following this, the ablation limit was set to 9 seconds for subsequent cases. One patient in the HPSD ablation group sustained a subarachnoid hemorrhage 2 weeks post ablation, believed to be unrelated to the procedure. Otherwise, there were no procedural complications in either high- or standard-power ablation groups.

Follow-up

Median follow-up post ablation was 6 months (interquartile range 4–12 months) in both groups, with all patients completing 3 months follow-up. Four patients in the standard-power group (7%) had recurrent atrial flutter (all
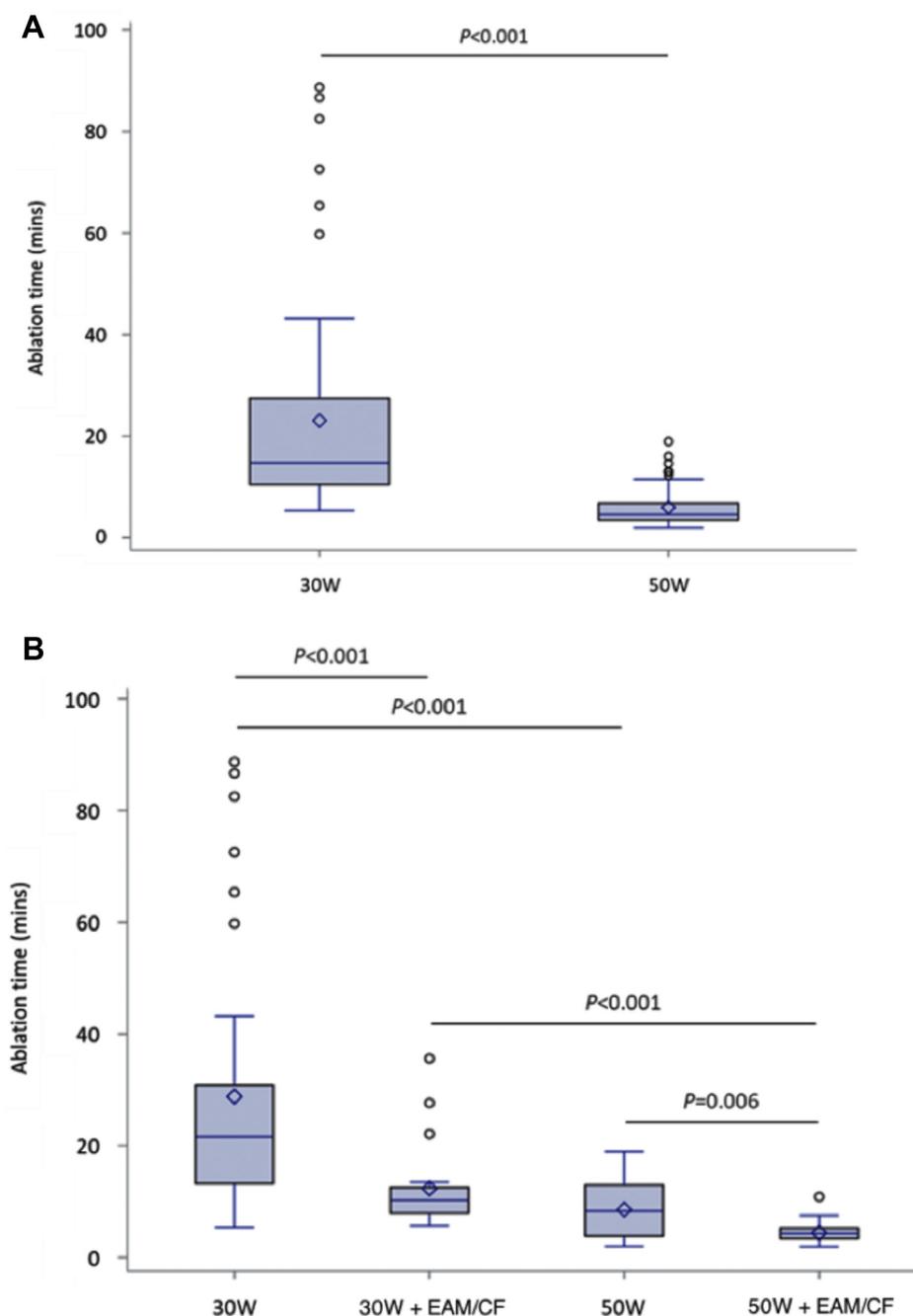
Figure 1   Box-and-whisker plot of ablation time. **A:** Ablation time by power. **B:** Ablation time by use of electroanatomic mapping (EAM) and contact force sensing (CF). Diamond symbol plotted at mean. Outliers defined as beyond 1.5 interquartile range.

had CTI-only ablation) during follow-up vs no patients in the high-power group ($P = .057$).

Five patients (9%) in the standard-power ablation group (3 with PVI+CTI and 2 with CTI-only ablation) and 4 patients (7%) in the high-power group (2 with PVI+CTI and 2 with CTI-only ablation) had documented AF during follow-up ($P = .742$).

Discussion
This study supports the efficacy and safety of HPSD RF ablation for typical atrial flutter. When compared to traditional settings, HPSD ablation was associated with a substantial reduction in total RF time, which was further reduced with the use of EAM/CF. Bidirectional block across the CTI line was achieved in all cases with no clinically relevant procedural complications and comparable atrial flutter recurrence risk to standard ablation techniques at 6 months. HPSD ablation was also associated with lower administered doses of fentanyl (a surrogate measure of patient discomfort).

RF energy leads to tissue ablation by 2 methods: immediate local resistive heating from high-frequency current passing from the catheter tip, and conductive heating, in which heat dissipation leads to deeper tissue injury. In theory, HPSD lesions prioritize application of rapid resistive heating,

Table 2   Procedural characteristics

	Standard ablation	HPSD ablation	P
Full cohort	n = 57	n = 57	
EAM/CF use	20 (35%)	36 (63%)	.003
Ablation time, mins	14.7 (10.4–27.4)[†]	4.6 (3.5–6.8)[†]	<.001
Non-EAM/CF cohort	n = 37	n = 21	
Ablation time, mins	21.6 (13.2–30.8)[‡]	8.3 (3.9–13.0)[‡]	<.001
Fluoroscopy, mins	36 ± 21	34 ± 18	.622
Fluoroscopy dose, mGy	816 ± 1011	728 ± 1240	.467
Fentanyl use, mcg	168 ± 85	116 ± 68	.032
Midazolam use, mg	4.6 ± 2.3	3.6 ± 1.7	.097

CF = contact force sensing; EAM = electroanatomic mapping; HPSD = high-power short-duration.
[†]Geometric means of 17.3 ± 2.1 and 5.0 ± 1.8 minutes for standard and HPSD ablation, respectively.
[‡]Geometric means of 22.3 ± 2.0 and 7.0 ± 2.0 minutes for standard and HPSD ablation, respectively.

avoiding deeper passive heating seen with longer lesions.[11] This renders HPSD ablation attractive for the purpose of ablating thinner structures such as the left atrial posterior wall, allowing for more rapid superficial tissue ablation while avoiding complications associated with deeper lesions (eg, phrenic nerve or esophageal injury). Indeed, recent data support the safety of HPSD ablation in the left atrium[9]; however, there are no data regarding its use for CTI ablation.

There are important considerations with ablating the CTI compared to the left atrium, which can pose additional challenges to adequate lesion formation. These include the presence of ridges and recesses, anatomic pouches, variable tissue thickness, and challenging catheter stability on the CTI. Saremi and colleagues[12] evaluated 201 patient hearts using a 64-section multidetector-row computed tomography. They found an average length of 24 mm for the central isthmus with tissue thickness of 4.3 mm as measured in atrial diastole.

In vitro models assessing lesion dimensions suggest that HPSD strategies (50–90 W delivered at 4–13 seconds) produce more contiguous lesions with fewer gaps in the left atrium. This is likely owing to formation of wider lesions (5–6 mm vs 4–5 mm) with similar tissue depth when compared to standard settings (25–40 W delivered at 30 seconds).[11,13,14]

Prior studies have suggested that cryoablation for CTI reduces pain but at the cost of increased procedural time and prolonged radiation.[6] We found less analgesic medication use (fentanyl) with the HPSD ablation strategy compared

to the standard power RF ablation, suggesting less patient discomfort with this technique.

Popular methods to reduce procedure time include the use of new catheter technology such as CF sensing or gold-tip catheters. However, CF sensing has shown variable results in improving procedural outcomes[2,15,16] and is associated with higher costs. In a study of 70 patients prospectively enrolled in 1:1 fashion to CF vs no-CF use at 25–35 W, CF use was associated with a 6-minute reduction in RF delivery time (10 min vs 15.9 min, P = .002) and a nonsignificant 2-minute reduction in fluoroscopic time.[2] Gül and colleagues[4] reported reduced RF delivery and fluoroscopy times with gold-tip catheters relative to CF sensing catheters in a study of 40 patients. Their study reported a time to achieve block of 36 minutes in the CF group vs 20 minutes in the gold-tip group (P = .048). Relative to the above results with CF and gold-tip catheters, in our present study the combined use of HPSD and EAM/CF was associated with much shorter RF delivery time. This may in part be due to the anatomical challenges posed by CTI ablation, as noted above. Larger studies are warranted to confirm these findings.

Of note, even though HPSD ablation was associated with shorter ablation time, it did not aid in the reduction of fluoroscopy time or dose. This is possibly owing to the fact that fluoroscopy is used to guide catheter placement and movement within the heart, and is not usually used during ablation when the catheter is in a stable position. Hence, although HPSD ablation may lead to shorter ablation times and thus shorter procedural times, it may not reduce the amount of fluoroscopy used. Other tools, such as EAM systems, can be used to reduce or completely eliminate the use of fluoroscopy during catheter ablation procedures.[17]

Limitations
This is not a randomized controlled trial and hence we cannot exclude that observed associations are owing to confounding. Our study included all cases with at least 3 months of follow-up. Recurrence of atrial flutter may occur over longer terms. However, the median follow-up period in our study was 6 months and is consistent with typical clinical practice. In addition, longer follow-up may uncover

Table 3   Predictors of ablation time

Predictor variable	Adjusted difference	95% CI	P
Age (per year)	-1%	(-2%, 0%)	.104
Male sex	-5%	(-26%, +22%)	.695
Hypertension	-20%	(-36%, -1%)	.043
High-power ablation	-66%	(-73%, -58%)	<.001
Electroanatomic mapping / contact force sensing	-50%	(-60%, -37%)	<.001
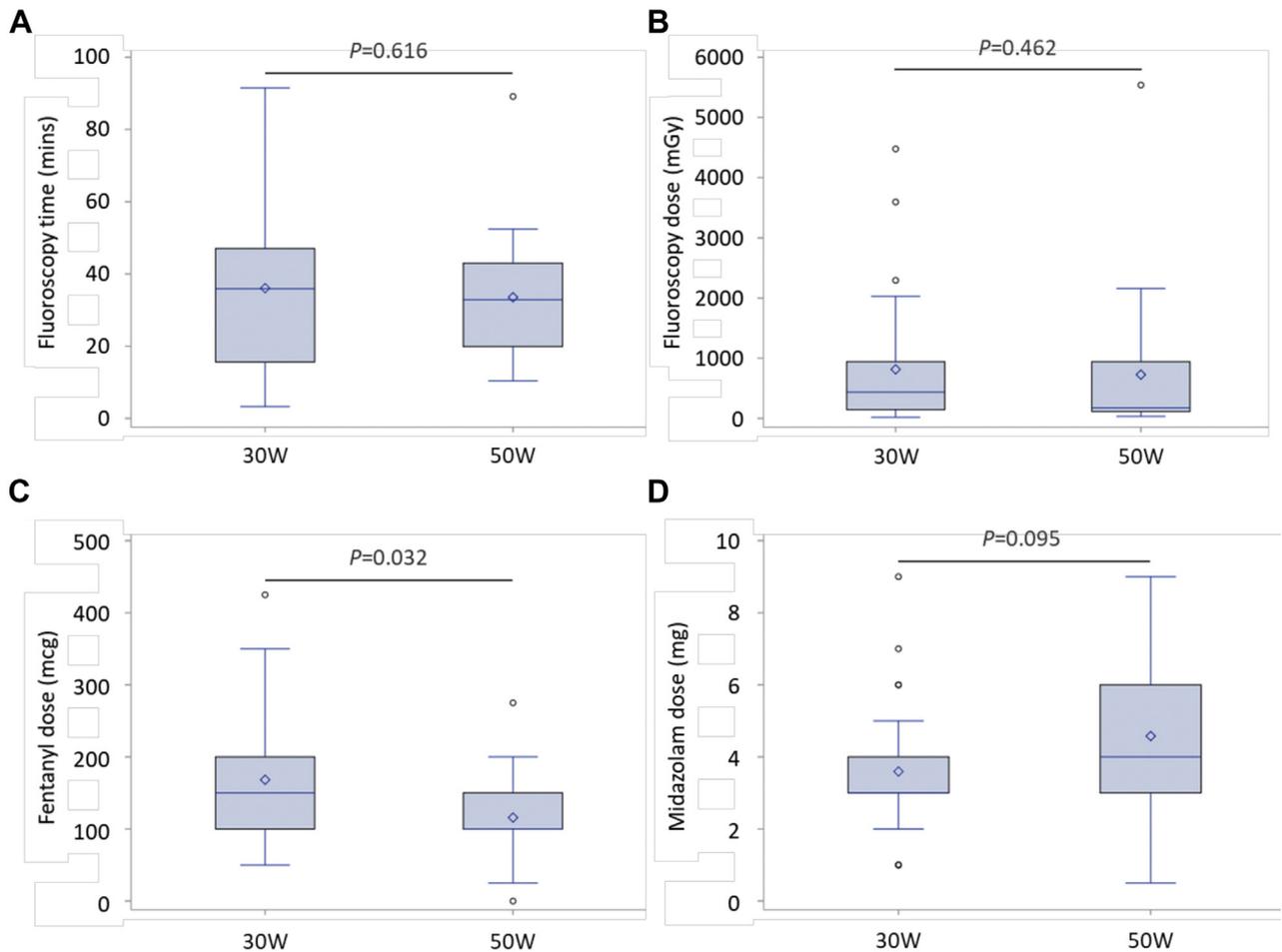
Figure 2   Box-and-whisker plot of **A:** fluoroscopy time, **B:** fluoroscopy dose, **C:** fentanyl use, and **D:** midazolam use, by power, in cases without general anesthesia or electroanatomic mapping (n = 56). Diamond symbol plotted at mean. Outliers defined as beyond 1.5 interquartile range.

higher rates of AF occurrence rather than atrial flutter recurrence.[18]

We used analgesic requirements as a surrogate for pain, which may be less accurate than individualized patient assessments via methods such as visual analogue scales. Lastly, since procedures using EAM also used CF sensing catheters and GA, we are unable to discern if reduced ablation time is due to EAM, CF, GA, or some combination of the 3. More patients in the HPSD group had EAM use and this could further contribute to overall reduced ablation time in that group.

Conclusion
Our data suggest that HPSD ablation for atrial flutter is a clinically feasible option to reduce RF ablation time and improve patient comfort, with a comparable safety profile and procedural success to standard ablation strategies. The use of EAM/CF may further reduce RF ablation time, arguing for its value when not cost prohibitive.

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Disclosures
Conflict of Interest: The authors have no conflict of interest to declare.

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