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Endocardial radiofrequency ablation of septal hypertrophy in the interventional treatment of the hypertrophic obstructive cardiomyopathy; comparison with the alcohol septal ablation, pilot data of the randomized trial

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Zlepšení funkční třídy NYHA

SOUHRN

Úvod: Hypertrofická obstrukční kardiomyopatie (HOCM) je charakterizována dynamickou obstrukcí výtokového traktu levé komory (LVOT) způsobenou asymetrickou hypertrofií septa a systolickým anteriorním pohybem (SAM) předního cípu mitrální chlopně. U pacientů s přetrvávajícími symptomy navzdory optimalizované farmakoterapii je indikována intervenční metoda redukce septální hypertrofie. Zatímco alkoholová septální ablace (ASA) je dlouhodobě zavedenou metodou, endokardiální radiofrekvenční ablace septální hypertrofie (ERASH) se v poslední době jeví jako slibná alternativní strategie. Cílem naší práce je ukázat pilotní výsledky randomizované studie srovnávající účinnost a bezpečnost ERASH a ASA.

Metodika: Cílem této prospektivní, randomizované pilotní studie bylo srovnat účinnost a bezpečnost ERASH a ASA u symptomatických pacientů s obstrukční HOCM refrakterní na medikamentózní terapii. ERASH byla provedena pomocí katétrové radiofrekvenční ablace septální hypertrofie za použití 3D elektroanatomického mapování, přítlakových katétrů a intrakardiální echokardiografie (ICE). ASA spočívala v aplikaci 96% alkoholu do septální větve levé koronární arterie a v následném kontrolovaném infarktu této tepny, který vedl k fibróze septa a jeho ztenčení s následnou redukcí obstrukce výtokového traktu. Gradienty v LVOT byly invazivně měřeny před výkonem a bezprostředně po výkonu. Sledování pacientů probíhalo v 3., 6. a 12. měsíci a zahrnovalo kontrolu echokardiografických parametrů a klinického stavu pacientů.

Výsledky: Celkem bylo randomizováno 19 pacientů k výkonu ERASH (n = 10) nebo ASA (n = 9) od května 2021 do prosince 2023. Doba výkonu byla signifikantně delší ve skupině ERASH (medián 180 vs. 30 minut, $p < 0{,}001$), zatímco čas a dávka rtg záření byly srovnatelné (6,24 min/11 000 mGy/cm^2 ERASH vs. 7,18 min/11 151 mGy/cm^2 ASA, $p = 0{,}391/0{,}967$). Obě skupiny dosáhly výrazného bezprostředního poklesu gradientu ve výtokovém traktu levé komory (LVOTG). Ve skupině ERASH se klidový gradient snížil z mediánu 103 mm Hg na 22,5 mm Hg a provokovaný gradient z 205 mm Hg na 67 mm Hg. Ve skupině ASA došlo ke snížení klidového gradientu ze 72 mm Hg na 20 mm Hg a provokovaného ze 155 mm Hg na 54,5 mm Hg. Při 12měsíčním sledování zůstávaly klidové gradienty nízké (17,5 mm Hg ve skupině ERASH vs. 15,5 mm Hg ve skupině ASA) a došlo ke zlepšení funkční třídy NYHA na 2,25 a 1,75. Také došlo k zlepšení testu šestiminutovou chůzí (395,9 m vs. 311,9 m, $p = 0.264$).

Periprocedurální komplikace byly četnější ve skupině ERASH, včetně dvou případů perikardiálního výpotku a jedné trvalé atrioventrikulární (AV) blokády, převážně u pacientů s předchozími poruchami převodního systému.

Závěr: V této randomizované pilotní studii prokázala metoda ERASH srovnatelnou účinnost jako ASA při redukci LVOTG a zlepšení symptomů pacientů. Vyšší výskyt komplikací ve skupině ERASH může souviset s učební křivkou a rizikovým profilem pacientů. ERASH může do budoucna představovat alternativní metodu septální redukce u pacientů s nevhodnou anatomií koronárních tepen nebo jinými kontraindikacemi k ASA. K potvrzení těchto výsledků a upřesnění indikačních kritérií jsou zapotřebí rozsáhlejší multicentrické studie.

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ABSTRACT

Introduction: Hypertrophic obstructive cardiomyopathy (HOCM) is characterized by dynamic left ventricular outflow tract (LVOT) obstruction due to asymmetric septal hypertrophy and systolic anterior motion (SAM) of the mitral valve. In patients with persistent symptoms despite optimized medical therapy, septal reduction therapy is indicated. While alcohol septal ablation (ASA) is a well-established catheter-based treatment, endocardial radiofrequency ablation of septal hypertrophy (ERASH) has recently emerged as a promising alternative. Aim of our study is to report the pilot data of the randomized study comparing efficacy and safety of ERASH versus ASA.

Methods: This single-center, prospective, randomized pilot study compared the efficacy and safety of ERASH versus ASA in symptomatic patients with obstructive HOCM refractory to medical therapy. ERASH procedure is catheter radiofrequency ablation of septal hypertrophy using contact force-sensing irrigated ablation catheters guided by 3D electroanatomical mapping with use of intracardiac echocardiography. ASA is based on injection of 96% alcohol into the septal branch of the left coronary artery to induce a small, controlled infarction of the hypertrophic septum and consequently abolishes the dynamic outflow obstruction. LVOT gradients were measured invasively at baseline and immediately post-procedure, and patients were followed at 3, 6, and 12 months for clinical and echocardiographic reassessment.

Results: Nineteen patients were randomized to undergo ERASH (n = 10) or ASA (n = 9) from May 2021 to February 2023. Procedural duration was significantly longer in the ERASH group (median 180 vs. 30 minutes, p <0.001), while fluoroscopy time and dose (6,24 min/11000 mGy/cm^2 ERASH group vs 7,18 min/11151 mGy/cm^2 ASA group, p = 0.391/0,967) were comparable. Both groups achieved substantial immediate reductions in LVOT gradients. In the ERASH group, resting LVOT gradient decreased from a median of 103 mmHg to 22.5 mmHg, and provocable gradient from 205 mmHg to 67 mmHg. In the ASA group, resting gradient decreased from 72 mmHg to 20 mmHg, and provocable gradient from 155 mmHg to 54.5 mmHg. At 12-month follow-up, resting gradients remained low (17.5 mmHg in ERASH vs. 15.5 mmHg in ASA), and NYHA functional class improved to 2.25 and 1.75, respectively. ERASH patients showed a greater improvement in 6-minute walk distance (395.9 m vs. 311.9 m, p = 0.264). Periprocedural complications were more frequent in the ERASH group, including two pericardial effusions and one permanent arioventricular (AV) block, mostly occurring in patients with pre-existing conduction disorders.

Conclusion: In this randomized pilot study, ERASH demonstrated comparable clinical and hemodynamic efficacy to ASA in reducing LVOT gradients and improving symptoms. While the complication rate was higher with ERASH, it may reflect procedural learning curve and baseline patient risk. ERASH may offer an alternative in patients with unsuitable coronary anatomy or different contraindications to ASA. Larger studies are needed to confirm these results and optimize patient selection.

Keywords:
Alcohol septal ablation
Endocardial radiofrequency ablation of septal hypertrophy
Functional NYHA class improvement
Hypertrophic obstructive cardiomyopathy
Left ventricle outflow tract gradient

Introduction

Hypertrophic obstructive cardiomyopathy (HOCMP) is characterized by abnormal thickening of the left ventricular myocardium not explained by abnormal hemodynamic conditions.[1] HOCMP is a common inherited cardiomyopathy, typically autosomal dominant, caused by >1,500 mutations across ≥15 sarcomeric genes,[2] with a prevalence of approximately 1 : 500 in adults.[3]

In adults, hypertrophic cardiomyopathy (HCM) is defined by a maximal wall thickness ≥15 mm in one or more left ventricle (LV) segments, as measured by any imaging modality, in the absence of other causes.[1] The obstructive form is characterized by left ventricular outflow tract (LVOT) obstruction with a maximal LVOT gradient (LVOTG) ≥30 mmHg at rest and/or after provocation.[4] Hemodynamically significant obstruction occurs in up to ~25% of patients with HCM[5] and is frequently associated with systolic anterior motion (SAM) of the anterior mitral leaflet.

Symptomatic pharmacological treatment is the basis of HOCMP therapy. Treatment choice is guided by symptoms and the severity of LVOT obstruction.[6] Agents with negative inotropic effects (e.g. betablockers and verapamil) reduce myocardial oxygen demand, prolong diastolic filling and decrease LVOT gradient and symptoms. Mavacamten, the first representative of a new drug group of selective allosteric myosin inhibitors that reduce myocardial oxygen demand and prolong diastolic filling, reduces actin-myosin cross-bridge formation and lowers LVOT gradients with functional improvement (EXPLORER-HCM; VALOR-HCM).[7,8] However, pharmacological treatment has limited efficacy with risk of adverse effects.[9,10] Contemporary guidelines recommend invasive septal reduction therapy for persistently symptomatic patients, typically New York Heart Association III–IV (NYHA III–IV) with resting or provoked LVOTG ≥50 mmHg despite guideline-directed medical therapy.[6,11] Some centers consider earlier intervention in highly symptomatic NYHA II with marked provocable gradients and SAM-related mitral regurgitation.[11] Reducing LVOTG is strongly associated with improved survival compared to healthy population.[12]

The oldest method to reduce LVOTG is surgical septal myectomy (Morrow procedure), introduced in the 1960s and still considered the gold standard in many centers, especially in the United States. The principle is resection of the hypertrophic basal interventricular septum (IVS) to the papillary muscle bases with selective mobilization.[13] Concomitant mitral valve surgery is required in ~11–20% of patients.[14] In experienced centers, operative mortality is ~<1–2%, and permanent pacemaker (PPM) dependency is ~4% after septal myectomy.[15]

Less invasive strategies such as dual-chamber pacing were explored in the 1970s,[16] aiming to alter activation and lessen dynamic obstruction. The principal is the api-

cal preexcitation effect, which is the shortening of the atrioventricular conduction interval. First, contraction of the apex and apical part of the IVS is present, while the basal parts of the IVS participate in LVOT narrowing and contract at the end of systole, which leads to improved ejection fraction of the left ventricle, however, it is not longer recommended for LVOTG reduction.

Alcohol septal ablation (ASA) was first reported by Sigwart in 1994.[17] This catheter-based intervention relies on the injection of 96% alcohol into the septal branch of the left coronary artery to induce a small, controlled infarction of the hypertrophic septum and consequently abolishes the dynamic outflow obstruction (in the case of a suitable coronary artery anatomy). LVOTG decrease was correlated with a significant clinical improvement in the patient's symptomatology and left ventricular remodeling. Periprocedural mortality is <1% in tertiary centers, and survival approaches that of the general population.[18] Atrioventricular (AV) block is the principal complication (temporary or permanent ~20–50%) with a need of pacemaker implant rates 7–20%, especially with pre-existing LBBB or larger alcohol volumes.[19] A total volume of 2 ml is generally safe. Higher doses of alcohol are slightly more effective in reducing LV obstruction and result in a higher incidence of peri-procedural complete heart block,[20] and other severe risks are potential developing defects of the interventricular septum. Therefore, ASA should be indicated in cases of IVS thickness >15 mm as recommended by American guidelines in 2011[21] and >16 mm as recommended by European guidelines in 2014.[1] After the procedure, reduction of LVOTG significantly decreased total mortality, which is likely comparable to the healthy population.[22] However, in 10–15% of patients, ASA could not be performed because of unsuitable coronary artery anatomy.[6]

Endocardial radiofrequency ablation of septal hypertrophy (ERASH) seems to be a new method to reduce septal hypertrophy. Principally, this is catheter-based ablation procedure that targets the hypertrophied basal interventricular septum to reduce LVOT obstruction.[23] Using retrograde transaortic or transseptal access, an irrigated RF catheter delivers focal lesions at the mitral-septal contact zone under fluoroscopy plus electroanatomic mapping with intracardiac echocardiography guidance. The aim is to create localized hypokinesis and lessen SAM-mediated obstruction, lowering resting and provocable gradients. ERASH is repeatable, avoids coronary injury, and – when guided by 3 D mapping/ICE – can be performed with low risk of complications; the principal safety concerns are conduction block (occasionally requiring pacing) and, less commonly, pericardial effusion.

ERASH first emerged in the early 2000s as a catheter-based alternative to surgical myectomy and alcohol septal ablation for obstructive HCM. The first clinical experience, reported by Lawrenz and colleagues in 2004, demonstrated technical feasibility: after two inconclusive transseptal attempts, a stable retrograde approach with an irrigated catheter achieved a substantial decrease in resting and provocable LVOT gradients.[24] Larger retrospective series from the same group six years later were made on 19 patients using electroanatomic mapping and irrigated RF energy via right- or left-ventricular approaches, showing consistent reductions in resting and provocable gradients and improvement in NYHA class, while also revealing the main deal – conduction injury (complete AV block in ~21% requiring pacing) and a small risk of pericardial effusion.[25]

Parallel pediatric work from Emmel et al. described two children with meaningful gradient reduction,[26] and Sreeram et al. subsequently reported a 32-patient pediatric cohort with sustained hemodynamic improvement over long follow-up, tempered by rare serious events including one death from paradoxical obstruction and occasional pacemaker implantation for AV block.[27]

By 2016, a transseptal series from Crossen et al. (n = 11) demonstrated a decrease in the gradient and symptomatic benefits, again with a measurable risk of permanent pacing.[28] Beaser et al. explored ERASH against pharmacologic comparators such as disopyramide, showing substantial early gradient reduction.[29]

Taken together, these studies trace ERASH's evolution to focused, image-guided therapy: a repeatable option that consistently reduces LVOT gradients and improves symptoms. However, conduction system injury stays as the principal periprocedural risk to be avoided.[29]

Despite of these studies, there still remains a lack of randomized studies directly comparing the two approaches. Our study reports pilot data from a prospective randomized trial designed to evaluate and compare the efficacy and safety of ERASH versus ASA in patients with symptomatic hypertrophic obstructive cardiomyopathy who remained refractory to optimal medical therapy.

Methods

Study design

The primary aim of our study was to conduct a comparative evaluation of the efficacy and safety of endocardial radiofrequency ablation of septal hypertrophy (ERASH) versus alcohol septal ablation (ASA) in patients with symptomatic hypertrophic obstructive cardiomyopathy (HOCM) who remained refractory to optimal medical therapy. Specifically, we sought to determine whether ERASH, as a catheter-based alternative to ASA, could achieve comparable reduction in LVOTG, symptom relief, and functional capacity, while maintaining an acceptable procedural risk profile. The study was a single-center, open-label, prospective, randomized pilot comparison.

Patient population

Eligible patients had symptomatic obstructive HCM with resting or provocable LVOTG ≥50 mmHg despite optimized medical therapy; IVS thickness ≥16 mm; and NYHA class ≥III or progressive class II with significant daily-life limitation.

All patients were evaluated in a specialized heart-failure outpatients clinic. Baseline assessment included transthoracic echocardiography (TTE), clinical status, and optimization of pharmacotherapy. Cardiac MRI, genetic testing, 24-h Holter monitoring, and sudden cardiac death risk stratification were done.

Each patient had TTE performed at screening (pre-randomization) and at 3-, 6-, and 12-month follow-up. LV

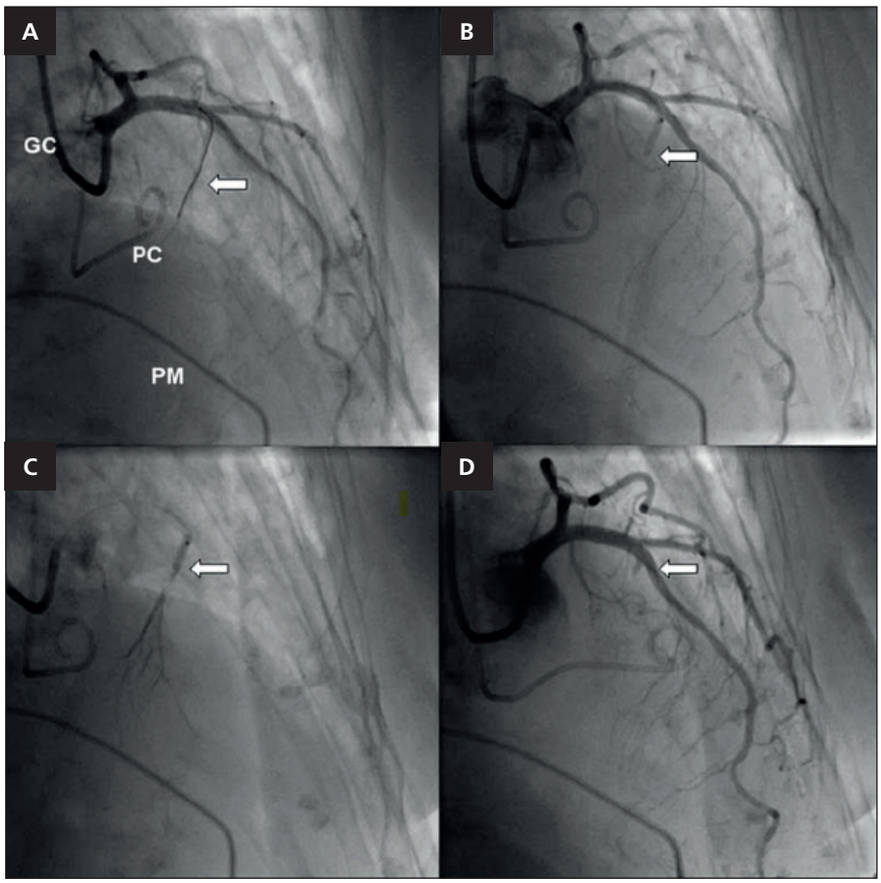

Fig. 1 – Principle of the alcohol septal ablation. (A) Introduction of the guidewire to ramus septalis, (B) occlusion of the artery with ballon, (C) introduction of the alcohol, (D) obstruction of artery, arteficial infarction.

dimensions, IVS thickness, left atrial diameter, left ventricle ejection fraction (LVEF), presence of SAM, and diastolic parameters were obtained from standard parasternal long-axis and apical four-chamber views. LVOTG was measured by continuous-wave Doppler at rest and during Valsalva maneuver.

Patients who agreed with interventional method of treatment underwent coronary angiography due to check anatomy of coronary arteries. That was a part of screening protocol.

After we checked inclusion criteria and informed consent was signed, patients were randomized to ASA or ERASH group

Alcohol septal ablation

A temporary RV pacing lead was placed before ASA for brady-arrhythmia backup. Left coronary angiography delineated septal branches. A pigtail catheter recorded LV--to-aortic gradients at rest and with provocation (Valsalva maneuver). An over-the-wire balloon catheter was positioned in the target septal branch; echocontrast injection confirmed myocardial territory (echo-guided approach). Ethanol (96%) was administered, approximately 2 mL, followed by 10-min balloon occlusion and repeat gradient assessment. Final angiography excluded non-target injury/no-reflow. Temporary pacing remained *in situ* for ~24 h; telemetry monitoring continued for ≥48 h in in Intensive Care Unite (ICU) up to 5 days total. Alcohol dose limits and pacemaker thresholds followed center protocol (**Fig. 1**).

Endocardial radiofrequency ablation of septal hypertrophy

Procedure was performed in a standard electrophysiology laboratory. For ablation, via v. femoralis l. dx., Agilis stearable sheath for transeptal aproach was introduced and for retrograde approach 9F standard sheath to the right femoral artery was introduced. An 8F standard ablation catheter with irrigation tip and contact force technology TactiCath™ SE (Abbott, Chicago, IL, USA), or THERMOCOOL SMARTTOUCH® (Biosense Webster, Diamond Bar, CA, USA) were used for ablation. The rest of catheters: decapolar 7F catheter to coronary sinus, quadrupolar catheter on His and intracardiac ultrasound probe was inserted via left femoral vein. Electroanatomy map of the left ventricle was created with 3D electroanatomical mapping system EnSite Precision™ Mapping System (Abbott, Chicago, IL, USA) or CARTO®3 System, (Biosense Webster, Diamond Bar, CA, USA). The whole procedure was performed with multichannel electrophysiology diagnostic system LabSystem PRO EP Recording System (Boston Scientific, Marlborough, MA, USA) and intracardiac ultrasound (ICE) AcuNav® (Siemens, Biosense-Webster) (**Fig. 2**). Measurements of LVOTG in rest and after Valsal-

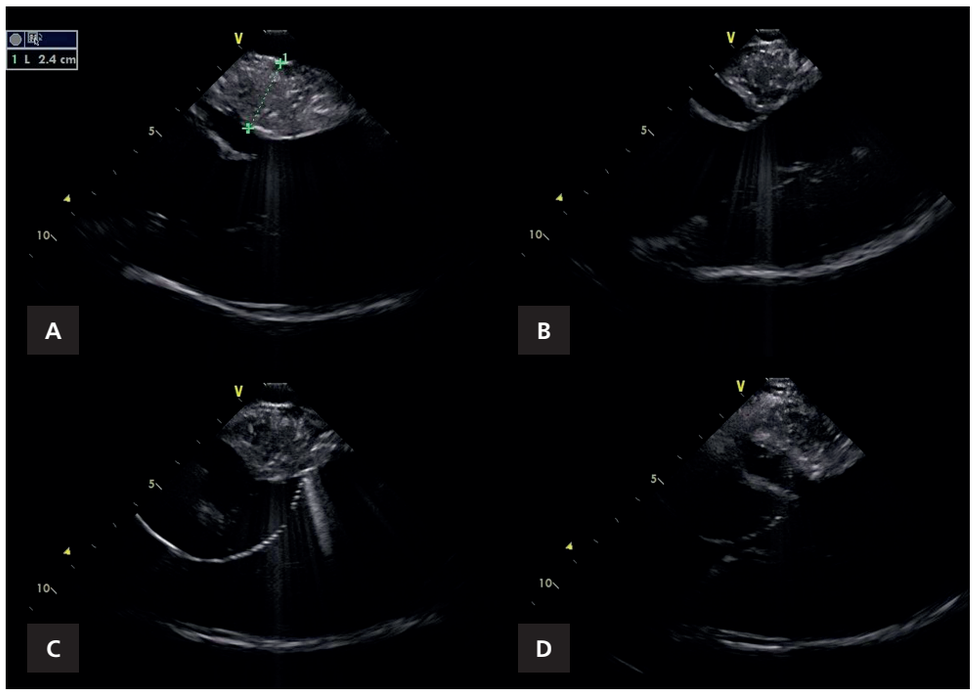

Fig. 2 – Endocardial radiofrequency ablation of septal hypertrophy, images from intracardial ultrasound. (A) Hypertrophic septum, (B) contact of catheter with myocardium, (C, D) creating ablation lessions.

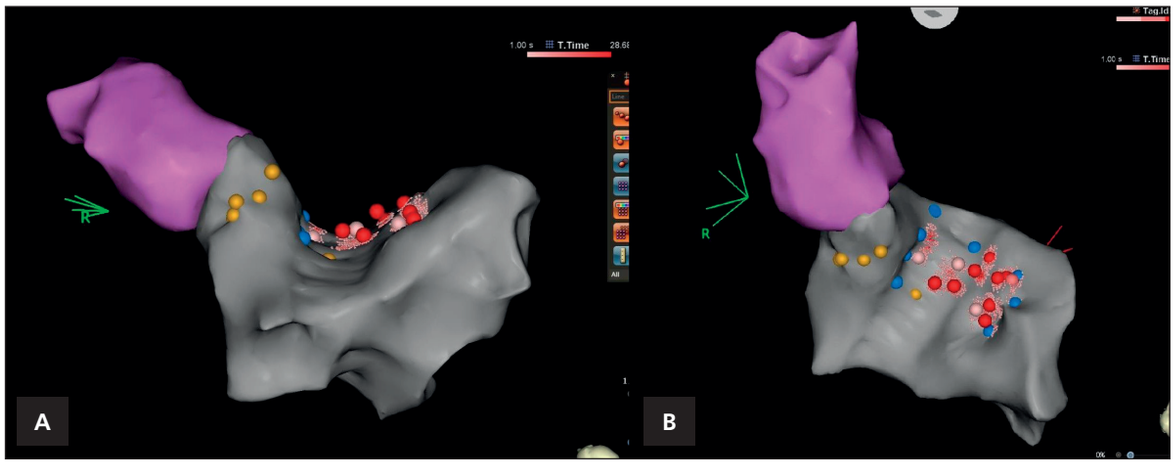

Fig. 3 – Three dimensional electroanatomical map of the left ventricle (grey) and ascendent aorta (violet) created during ERASH. (A) The hypertrophic septum is clearly visible as an imprint in the left ventricle model. Blue dots are tags created during mapping of the left ventricle and bordering septal hypertrophy. Yellow points marked conduction system. White and red points marked regions of the radiofrequency ablations. (A) Modified inferior projection, (B) anteroposterior projection.

va maneuver were performed with pigtail catheter. His potentials were marked to the electroanatomy map to avoid demage of the conduction system (**Fig. 3**). Ablation targeted the basal septum at the mitral–septal contact zone, with iterative reassessment of gradients. Anticoagulation was hold with ACT about 300. Radiofrequency ablation of the sepum was done with power 35–40 W and irrigation 30 ml/min under the ICE and 3D mapping control. After ablation, measurements of gradient were performed with pigtail catheter again. Post-procedure, patients were monitored on the arrhythmology unit for arrhythmias and complications eventually.

Clinical follow-up

Follow-up visits occurred at 3, 6, and 12 months for clinical assessment, TTE, ECG/Holter, and medication adjustment. At 12 months, we obtained 6-minute walk test. Patients continued routine care thereafter.

Statistical analysis

Statistical analysis was performed with the programming language R in the integrated development environment R studio. Results with a *p*-value below 0.05 were considered statistically significant. Continuous variables are presented as mean ± standard deviation (SD) or median

(interquartile range). Categorical variables are presented as numbers with percentages. Data were tested for normality using Shapiro-Wilk test and graphically using Q-Q plots and histograms. Mann–Whitney test was used to determine differences in continuous variables between two groups. Chi-square test was used to determine an association in categorical variables.

Results

Baseline patient characteristics

Between May 2021 and February 2023 a total of 19 patients was enrolled and randomized to the ERASH group (n = 10) or ASA group (n = 9). Baseline characteristics are comparable, only ERASH group had a trend to the higher BMI (29.4 vs. 25.8 kg/m², p = 0.055). Most patients were highly symptomatic, with median NYHA class III in both groups at baseline (p = 0.087). For details see **Table 1**.

Baseline echocardiographic parameters did not differ significantly between groups. Mean interventricular septal (IVS) thickness was similar (18.5 mm in ERASH vs. 18 mm in ASA, p = 0.123), as resting and provocable LVOT gradients were (p = 0.905 and p = 0.252, respectively). Systolic anterior motion (SAM) of the mitral valve was present in nearly all patients (100 % in ERASH, 88.9% in ASA; p = 0.957). Left atrial diameter was significantly larger in the ASA group (50 mm vs. 41.5 mm; p = 0.037).

Periprocedural results

Procedural parameters are shown in **Table 2**. Procedure time was significantly longer in the ERASH group (median 180 vs. 30 minutes, p <0.001), reflecting the complexity of 3D mapping and ablation strategy. However, fluoroscopy time (7,18 min for ASA group vs 6,24 min for ERASH group, p = 0.391) and radiation dose (11151 mGy/cm² vs 11000 mGy/cm², p = 0.967) were similar between groups.

Table 1 – Baseline characteristics of patients

Baseline characteristics	ASA (N = 9)	ERASH (N = 10)	*p*-value
Male	4 (44,4)	3 (30.0)	0.861
Age	60 (48–70)	67 (61–70)	0.595
BMI (kg/m²)	29.43 (27.77–30.02)	25.82 (23.51–27.61)	0.055
Initial NYHA	3 (3–3)	2.5 (2.5–3)	0.087
6M walking test (m)	405 (300–462.5)	336 (318.7–404.4)	0.606
Hypertension	4 (44.4)	8 (80.0)	0.259
Diabetes mellitus type 2	2 (22.2)	2 (20.0)	>0.999
Medication			
Calcium blockers	9 (100.0)	10 (100.0)	–
Betablockers	6 (66.7)	8 (80.0)	0.891
Anticoagulant therapy or antiplatelet therapy	5 (55.6)	3 (30.0)	0.508
Echocardiography parameters			
Ejection fraction (%)	65 (65–75)	72.5 (70–75)	0.209
LVOTG in rest before (mmHg)	90 (67–153)	99 (53–133)	0.905
LVOTG Valsalva before (mmHg)	140 (90–200)	105 (72–128)	0.252
SAM	8 (88.9)	10 (100.0)	0.957
IVS thickness (mm)	18 (17–18)	18.5 (17–22)	0.123
LA diameter (mm)	50 (45–54)	41.5 (39–47)	0.037
E (m/s)	0,96 (0.86–1.06)	0,84 (0.62–0.99)	0.230
E´ med (m/s)	0.06 (0.05–0.06)	0.05 (0.04–0.05)	0.099
E´ lat (m/s)	0.07 (0.06–0.1)	0.06 (0.06–0.07)	0.134
E/E´ med	17.22 (15.5–19.5)	17.05 (13–21.25)	0.284
E/E´ lat	12.29 (9.45–17.37)	14.83 (10–16.83)	0.633
LV diameter	43 (39–48)	39.5 (37–46)	0.413
Mi regurgitation			
1	1 (11.1)	0 (0.0)	0.409
1.5	4 (44.4)	7 (70.0)	
2	1 (11.1)	0 (0.0)	
2.5	3 (33.3)	2 (20.0)	

Table 2 – Periprocedural parameters

Periprocedural parameters	ASA (N = 9)	ERASH (N = 10)	*p*-value
Procedure time (minutes)	180 (124–223)	30 (22–35)	<0.001
X ray time (min)	7.18 (5.8–18.8)	6.24 (4–10.51)	0.391
X ray dose (mGy/cm^2)	11151 (8191–21030)	11000 (8000–21500)	0.967
Number of RFA	17 (16–35)	–	–
Time of RFA	577 (483–891)	–	–
LVOTG beginning of procedure / in rest (mmHg)	72 (19–107)	103 (77–113)	0.270
LVOTG beginning of procedure / Valsalva (mmHg)	155 (73–166)	205 (105–250)	0.066
LVOTG end of procedure / rest (mmHg)	20 (7.5–57)	22.5 (8–68)	>0.999
LVOTG end of procedure / Valsalva (mmHg)	54.5 (41–130.5)	67 (49–128)	0.896
LVOTG delta in rest (mmHg)	56.5 (10.1–64.5)	73.5 (33–95)	0.3281
LVOTG delta Valsalva (mmHg)	40.9 (12.5–104)	108.5 (39–131)	0.09121

Table 3 – Periprocedural complications

Periprocedural complications	ASA (N = 9)	ERASH (N = 10)
Hemodynamically significant effusion	0	2
Complete AV block requiring pacemaker implant	0	1
Temporary pacing required	1	0
Onset of LBBB	0	1
Onset of RBBB	5	1
Jugular vein trombosis	1	0

Table 4 – Follow-up at 3 months

Follow-up at 3 months	ASA (N = 9)	ERASH (N = 10)	*p*-value
LVOTG rest (mmHg)	22 (8–62)	18 (13–21)	0.682
LVOTG Valsalva (mmHg)	55 (12–111)	44.5 (25–59)	0.967
SAM	7 (77.8)	7 (70.0)	0.567
IVS thickness (mm)	16 (14–17)	15.5 (12–18)	0.967
LVEF (%)	62 (55–65)	66 (60–70)	0.157
LA diameter (mm)	46 (40–51)	43 (41–46)	0.346
E (m/s)	0.83 (0.71–1.43)	0.76 (0.64–0.87)	0.449
E´ med (m/s)	0.06 (0.05–0.07)	0.05 (0.04–0.06)	0.218
E´ lat (m/s)	0.08 (0.08–0.09)	0.06 (0.05–0.07)	0.020
E/E´ med	16.05 (10.44–23.75)	13.65 (12.57–17.75)	0.722
E/E´ lat	11.81 (7.94–17.03	12.7 (8.88–14.5)	0.964
LV diameter (mm)	42 (41–47)	42.5 (38–48)	0.837

Both groups showed substantial reduction in LVOT gradients immediately after the procedure. In the ERASH group, median resting gradient decreased from 103 mmHg to 22.5 mmHg and provocable gradient from 205 mmHg to 67 mmHg. In the ASA group, resting gradient declined from 72 mmHg to 20 mmHg and provocable gradient from 155 mmHg to 54.5 mmHg. Intergroup differences in postprocedural gradients were not statistically significant.

Periprocedural complications were more frequent in the ERASH group. Two patients developed a hemodynamically significant pericardial effusion requiring drainage. One patient developed a complete AV block necessitating permanent pacemaker implantation, and another required temporary pacing. Notably, both cases of complete AV block occurred in patients with preexisting right bundle branch block. One patient developed new-onset left bundle branch block. In the ASA group, one transient complete AV block resolved during hospitalization. Five patients developed new right bundle branch block, and one experienced jugular vein thrombosis associated with temporary pacing. For details see **Table 3**.

Table 5 – Follow-up at 6 months

Follow-up at 6 months	ASA (N = 9)	ERASH (N = 10)	*p*-value
LVOTG rest (mmHg)	16 (10–24)	20 (17–33)	0.513
LVOTG Valsalva (mmHg)	55 (30–111)	49.5 (34–61)	0. 548
SAM	16 (15–17)	12.5 (11–15)	0.032
IVS thickness (mm)	5 (55.6)	3 (30.0)	0.474
LVEF (%)	65 (60–70)	66 (60–70)	>0.999
Diameter left atrium (mm)	50 (39–53)	43.5 (38–46)	0.059
E (m/s)	0.8 (0.64–1.47)	0.79 (0.59–0.91)	0.315
E´ med (m/s)	0.06 (0.06–0.06)	0.05 (0.04–0.06)	0.165
E´ lat (m/s)	0.07 (0.07–0.07)	0.06 (0.05–0.08)	0.074
E/E´ med	10.5 (10–24.83)	15.17 (13.29–18.25)	0.525
E/E´ lat	11.43 (9.14–21)	11 (9.83–14.33)	0.489
LV diameter (mm)	44 (44–47)	42.5 (41–45)	0.592

Table 6 – Follow-up at 12 months

Follow-up at 12 months	ASA (N = 9)	ERASH (N = 10)	*p*-value
Echocardiography parameters			
Ejection fraction (%)	65 (62.5–67.5)	70 (65–70)	0.163
LVOTG in rest (mmHg)	15.5 (9–26)	17.5 (10–25)	0.9291
LVOTG Valsalva before (mmHg)	68.5 (20–90)	41 (28–45)	0.306
SAM	2 (22.2)	7 (70.0)	0.1547
IVS thickness (mm)	15.5 (14–17.5)	15.5 (14–20)	0.9642
Diameter of left atrium (mm)	50 (39–53)	42.5 (39–45)	0.078
E (m/s)	0.67 (0.53–1.11)	0.7 (0.58–1.1)	0.896
E´ med (m/s)	0.06 (0.06–0.07	0.06 (0.05–0.06)	0.059
E´ lat (m/s)	0.08 (0.07–0.09)	0.06 (0.05–0.06)	0.002
E/E´ med	9.29 (7.17–24.83)	13.4 (9.67–21.33)	0.469
E/E´ lat	8.75 (7.46–12.92)	13.5 (9.67–18.33)	0.138
LV diameter (mm)	44.5 (42–48)	46 (41–48)	0.656
Mi regurgitation			
1	4 (44.4)	2 (20.0)	0.171
1,5	3 (33.3)	5 (50.0)	
2	1 (11.1)	0 (0.0)	
Initial NYHA	2.25 (2–2.5)	1.75 (1.5–2)	0.202
6M walking test (metres)	311.95 (255–343.6)	395.9 (381–436)	0.242
Medication			
Ca blockers	5 (55.6)	3 (30.0)	0.508
Betablockers	9 (100.0)	9 (90.0)	>0.999
Anticoagulation therapy or antiplatelet therapy	4 (44.4)	3 (30.0)	0.860

Follow-up

Follow-up at 3 months

At 3 months, both groups maintained lower LVOT gradients. Resting gradients were 18 mmHg (ERASH) vs. 22 mmHg (ASA), and provocable gradients were 44.5 mmHg vs. 55 mmHg, respectively (p = NS). Septal thickness slightly decreased in both groups (15.5 vs. 16 mm, p = 0.967), and LVEF remained preserved. For details se **Table 4**.

Follow-up at 6 months

At 6 months, the resting and provocable LVOT gradients remained stable: 20 mmHg (ERASH) vs. 16 mmHg (ASA) at rest; 49.5 mmHg vs. 55 mmHg with Valsalva. Septal thickness and left atrial diameter showed continued

downward trends without significant differences. Diastolic indices remained stable. A significantly lower residual SAM grade was observed in the ERASH group (median 12.5 mm vs. 16 mm; $p = 0.032$). For details see **Table 5**.

Follow-up at 12 months

At 12 months, both groups maintained improved hemodynamic and symptomatic status. Resting LVOT gradients were 17.5 mmHg (ERASH) and 15.5 mmHg (ASA), with provocable gradients 41 mmHg vs. 68.5 mmHg (p = NS). IVS thickness remained similar between groups. NYHA functional class improved from baseline to 2.25 (ERASH) and 1.75 (ASA) ($p = 0.202$). Six-minute walk distance improved in both groups, with a trend to bigger improvement in the ERASH cohort (395.9 m vs. 311.9 m, $p = 0.264$). Mild to moderate mitral regurgitation persisted in several patients, but no progression was noted. Diastolic function parameters (E/E') and LA size showed the modest improvement without statistical significance. For details see **Table 6**.

Discussion

Endocardial radiofrequency ablation is an established therapeutic modality for cardiac arrhythmias; its adaptation for the treatment of obstructive hypertrophic cardiomyopathy (ERASH) represents an innovative catheter-based alternative to traditional septal reduction therapies. ERASH could reduce left ventricular outflow tract gradients reproducibly and improve symptoms in carefully selected patients with hypertrophic obstructive cardiomyopathy.

In this pilot randomized study, we performed a comparison of ERASH and alcohol septal ablation and our findings suggest that both modalities achieved significant periprocedural reductions in LVOT gradients, with comparable fluoroscopy time and radiation exposure. Procedure duration was longer in the ERASH group, likely reflecting the complexity of endocardial mapping and lesion delivery. While both techniques were generally safe, the overall complication rate was higher in the ERASH group – predominantly related to pericardial effusion and conduction system disturbances. Probably also due to learning curve of operaters, and notably, the occurrence of complete atrioventricular block was observed primarily in patients with pre-existing right bundle branch block. These findings underscore the importance of a precise conduction system mapping, intracardiac echocardiography guidance, and individualized risk assessment.

Septal myectomy and ASA remain the current standard-of-care options for patients with drug-refractory obstructive HCM. However, the recent introduction of cardiac myosin inhibitors, such as mavacamten, has altered the therapeutic landscape by offering a pharmacologic means of gradient reduction, potentially decreasing the need for septal reduction therapy in selected patients. Despite these new treatment, ERASH may hold distinct value for patients who are not candidates for ASA or myectomy – particularly those with unsuitable septal artery anatomy, or high surgical risk. ERASH reduces LVOT obstruction not by extensive septal thinning but through the creation of focal myocardial hypokinesis at the mitral–septal contact point, which disrupts systolic anterior motion of the mitral valve. This effect highlights the importance of accurate lesion depth, and controlled delivery of radiofrequency energy using contact force-sensing catheters and advanced mapping systems.

The safety profile of ERASH must be carefully considered. The risk of high-grade atrioventricular block necessitates detailed mapping of the His-Purkinje system, cautious energy titration. ERASH should be approached with caution in patients with baseline RBBB, given the potential for iatrogenic left bundle branch block to aquire complete heart block. Furthermore, the risk of pericardial effusion, although low, needs real-time imaging with ICE, adherence to anticoagulation protocols, and precise post-procedural observation.

Limitations

This study was limited by a small sample size and potentionally, learning curve effects could have influenced outcomes in the ERASH group. Larger, multicenter trials with standardized imaging protocols and long-term follow-up are needed.

Conclusion

In conclusion, this pilot randomized comparison, ERASH and ASA achieved significant reductions in LVOTG with symptomatic improvement at 12 months. Procedure duration was longer with ERASH but fluoroscopy time/dose were similar. Complications were more frequent with ERASH, particularly pericardial effusion. Probably it was associated with standard potential risk and complications of radiofrequency catheter ablation with transseptal approach. Secondly, conduction disturbances in patients with baseline RBBB. Pacemaker implant was needed in one case, in second case just temporary pacing with following restitution of sinus rhythm. This means amount of complete AV block occured in 11,1 % almost comparable amount to ASA procedure known from registers. Careful patient selection, conduction system mapping, and ICE guidance are essential for this method. Larger, multicenter trials are warranted to define long-term efficacy, safety, and patient selection criteria.

Septal myectomy and ASA remain the current standard-of-care options for patients with drug-refractory obstructive HCM. However, ERASH may represent a valuable and effective option for selected patients, particularly those with challenging anatomy or contraindications to ASA.

Conflict of interest

All authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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Ethical statement

The study was approved by the Ethics Committee of St. Anne's University Hospital in Brno.

Informed consent

The patients signed informed consent to participate in the study.

References

1. Elliott PM, Anastasakis A, Borger MA, et al. 2014 ESC Guidelines on diagnosis and management of hypertrophic cardiomyopathy: the Task Force for the Diagnosis and Management of Hypertrophic Cardiomyopathy of the European Society of Cardiology (ESC). Eur Heart J 2014;14:2733–2779.
2. Maron BJ, Maron MS, Semsarian C, et al. Genetics of hypertrophic cardiomyopathy after 20 years. J Am Coll Cardiol 2012;60:705–715.
3. Sen-Chowdhry S, Jacoby D, Moon JC, et al. Update on hypertrophic cardiomyopathy and a guide to the guidelines. Nat Rev Cardiol 2016;13:651–675.
4. Shah JS, Esteban MT, Thaman R, et al. Prevalence of exercise-induced left ventricular outflow tract obstruction in symptomatic patients with non-obstructive hypertrophic cardiomyopathy. Heart 2008;94:1288–1294.
5. Braunwald E, Seidman CE, Sigwart U, et al. Contemporary evaluation and management of hypertrophic cardiomyopathy. Circulation 2002;106:1312–1316.
6. Ommen SR, Mital S, Burke MA, et al. 2020 AHA/ACC Guideline for the Diagnosis and Treatment of Patients With Hypertrophic Cardiomyopathy: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation 2020;142:558–631.
7. Heitner SB, Jacoby D, Lester SJ, et al. Mavacamten Treatment for Obstructive Hypertrophic Cardiomyopathy: A Clinical Trial. Ann Intern Med 2019;4:741–748.
8. Olivotto I, Oreziak A, Barriales-Villa R, et al. Mavacamten for treatment of symptomatic obstructive hypertrophic cardiomyopathy (EXPLORER-HCM): a randomised, double-blind, placebo-controlled, phase 3 trial. Lancet 2020;396:759–769.
9. Desai MY, Owens A, Geske JB, et al. Myosin Inhibition in Patients With Obstructive Hypertrophic Cardiomyopathy Referred for Septal Reduction Therapy. J Am Coll Cardiol 2022;80:95–108.
10. Desai MY, Owens A, Wolski K, et al. Mavacamten in Patients With Hypertrophic Cardiomyopathy Referred for Septal Reduction: Week 56 Results From the VALOR-HCM Randomized Clinical Trial. JAMA Cardiol 2023;8:968–977.
11. Kaski JP, Arbelo E. The 2023 ESC guidelines for the management of cardiomyopathies: the 10 commandments. Eur Heart J 2024, 1;45:1101.
12. Maron BJ, Rowin EJ, Casey SA, et al. Hypertrophic Cardiomyopathy in Adulthood Associated With Low Cardiovascular Mortality With Contemporary Management Strategies. J Am Coll Cardiol 2015;12:1915–1928.
13. Heric B, Lytle BW, Miller DP, et al. Surgical management of hypertrophic obstructive cardiomyopathy. Early and late results. J Thorac Cardiovasc Surg 1995;110:195–206.
14. Yu EH, Omran AS, Wigle ED, et al. Mitral regurgitation in hypertrophic obstructive cardiomyopathy: relationship to obstruction and relief with myectomy. J Am Coll Cardiol 2000;36:2219–2225.
15. Stassano P, Di Tommaso L, Triggiani D, et al. Mitral valve replacement and limited myectomy for hypertrophic obstructive cardiomyopathy: a 25-year follow-up. Tex Heart Inst J 2004;31:137–142.
16. Brignole M, Auricchio A, Baron-Esquivias G, et al. 2013 ESC guidelines on cardiac pacing and cardiac resynchronization therapy: the task force on cardiac pacing and resynchronization therapy of the European Society of Cardiology (ESC). Developed in collaboration with the European Heart Rhythm Association (EHRA). Europace 2013;15:1070–1118.
17. Sigwart U. Non-surgical myocardial reduction (ASA). Lancet 1995;346:211–214.
18. Veselka J, Krejčí J, Tomašov P, et al. Long-term survival after alcohol septal ablation for hypertrophic obstructive cardiomyopathy: a comparison with general population. Eur Heart J 2014;7:2040–2045.
19. Lawrenz T, Lieder F, Bartelsmeier M, et al. Predictors of complete heart block after transcoronary ablation of septal hypertrophy: results of a prospective electrophysiological investigation in 172 patients with hypertrophic obstructive cardiomyopathy. J Am Coll Cardiol 2007;49:2356–2363.
20. Veselka J, Jensen MK, Liebregts M, et al Long-term clinical outcome after alcohol septal ablation for obstructive hypertrophic cardiomyopathy: results from the Euro-ASA registry. Eur Heart J 2016;37:1517–1523.
21. Gersh BJ, Maron BJ, Bonow RO, et al. American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. 2011 ACCF/AHA Guideline for the Diagnosis and Treatment of Hypertrophic Cardiomyopathy: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. Developed in collaboration with the American Association for Thoracic Surgery, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. J Am Coll Cardiol 2011;58:212–260.
22. Sorajja P, Ommen SR, Holmes DR Jr, et al. Survival after alcohol septal ablation for obstructive hypertrophic cardiomyopathy. Circulation 2012;126:2374–2380.
23. Shelke AB, Menon R, Kapadiya A, et al. A novel approach in the use of radiofrequency catheter ablation of septal hypertrophy in hypertrophic obstructive cardiomyopathy. Indian Heart J 2016;68:618–623.
24. Lawrenz T, Kuhn H. Endocardial radiofrequency ablation of septal hypertrophy. A new catheter-based modality of gradient reduction in hypertrophic obstructive cardiomyopathy. Z Kardiol 2004;93:493–499.
25. Lawrenz T, Borchert B, Leuner C, et al. Endocardial radiofrequency ablation for hypertrophic obstructive cardiomyopathy: acute results and 6 months' follow-up in 19 patients. J Am Coll Cardiol 2011;1:572–576.
26. Emmel M, Sreeram N, deGiovanni JV, et al. Radiofrequency catheter septal ablation for hypertrophic obstructive cardiomyopathy in childhood. Z Kardiol 2005;94:699–703.
27. Sreeram N, Emmel M, de Giovanni JV. Percutaneous radiofrequency septal reduction for hypertrophic obstructive cardiomyopathy in children. J Am Coll Cardiol 2011;58:2501–2510.
28. Crossen K, Jones M, Erikson C. Radiofrequency septal reduction in symptomatic hypertrophic obstructive cardiomyopathy. Heart Rhythm 2016;13:1885–1890.
29. Beaser AD, Sobacki J, Aziz Z, et al. Targeted radiofrequency septal ablation to reduce outflow tract gradient in symptomatic hypertrophic obstructive cardiomyopathy: Initial feasibility cohort. Heart Rhythm 2018;15:644–645.