REVIEW ARTICLE

Percutaneous Intramyocardial Septal Radiofrequency Ablation (Liwen Procedure) for Hypertrophic Cardiomyopathy: A Decade of Evolution, Clinical Experience and Future Perspectives

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Received September 15, 2026; revision requested September 22, 2026; accepted December 8, 2026

Abstract: Hypertrophic cardiomyopathy (HCM) is an inherited cardiomyopathy. For patients with obstructive hypertrophic cardiomyopathy (oHCM) who remain symptomatic despite medical therapy, septal reduction therapy can be performed. Surgical septal myectomy and alcohol septal ablation are the treatments for relieving left ventricular outflow tract obstruction and can effectively improve patients' quality of life. In recent years, percutaneous intramyocardial septal radiofrequency ablation (PIMSRA/Liwen procedure) has emerged as a novel treatment for oHCM. This review traces its ten-year development from animal experiments to clinical application, covering technical principles, safety, and efficacy. Additional potentially extended applications are being explored, including non-obstructive HCM and other coexisting cardiac conditions. Future directions include longer-term follow-up, and multicenter collaboration to validate efficacy and safety in HCM patients. This review summarizes the current knowledge on PIMSRA/Liwen procedure and raises several issues that deserve further investigation.

Key words: Hypertrophic obstructive cardiomyopathy; Ventricular Septum; Radiofrequency ablation; Septal reduction therapy

Advanced Ultrasound in Diagnosis and Therapy 2026; 04: 385-393 DOI: 10.26599/AUDT.2026.260038

Hypertrophic cardiomyopathy (HCM) is an inherited cardiac disease, with prevalence generally recognized ranging from 1:200 to 1:500 [1-3]. Obstructive hypertrophic cardiomyopathy (oHCM) accounts for approximately two-thirds of all HCM cases [4], and is characterized by left ventricular outflow tract (LVOT) obstruction caused by asymmetric septal hypertrophy. LVOT obstruction constitutes a major risk factor for debilitating symptoms and adverse prognosis in patients with oHCM [3,5,6]. Accordingly, septal reduction therapy (SRT) aimed at decreasing septal thickness and relieving LVOT obstruction for patients with drug-refractory symptoms. The two established SRT modalities are surgical myectomy (SM) and alcohol septal ablation (ASA) [3,7,8]. SM has long been regarded as the traditional "gold standard" [9], however, it requires median sternotomy, cardiopulmonary bypass, and its success is highly dependent on surgical expertise and institutional volume [10]. ASA, although less invasive, is contingent upon suitable septal perforator anatomy and carries a non-negligible risk of conduction disturbances and arrhythmias [11,12]. Percutaneous intramyocardial septal radiofrequency ablation (PIMSRA/Liwen procedure), has emerged as a novel, mini-

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mally invasive SRT that delivers targeted radiofrequency energy to the hypertrophied septum under continuous real-time echocardiographic guidance, offering a potential treatment for oHCM patients [13-16].

Mechanism of PIMSRA/Liwen Procedure

Under real-time echocardiographic guidance, a radiofrequency ablation needle is introduced via a percutaneous trans-apical approach and positioned within the hypertrophied interventricular septum (Fig. 1A). Radiofrequency energy is then applied, producing resistive heating within the myocardium and raising local tissue temperature to above 80°C. The resulting thermal injury causes protein denaturation, tissue desiccation, and irreversible coagulative necrosis. Concomitant thermal occlusion of regional micro vessels further reduces local perfusion. Subsequent contraction of the necrotic myocardium leads to thinning of the interventricular septum and widening of the left ventricular outflow tract, thereby alleviating obstruction and improving symptoms [14,17].

Echocardiography serves as the core imaging modality for PIMSRA/Liwen procedure: preprocedural planning, intraprocedural real-time navigation, and postprocedural monitoring for both efficacy and safety. Pre-procedurally, transthoracic echocardiography (TTE) and exercise stress echocardiography are used to define morphologic and hemodynamic subtypes to inform precise ablation planning. Intra-proceduraly, real-time TTE guides needle advancement into the target hypertrophied septal myocardium. During ablation, TTE demonstrates hyperechoic ablation zones and confirms adequate overlap of these oval-shaped lesions, preventing residual untreated areas. Its unique strength lies in the ability to obtain numerical measurements concurrently during ablation. Post-procedurally, standardized TTE follow-up is performed to assess improvement in interventricular septal thickness and left ventricular outflow tract (LVOT) gradient [13].

Feasibility Exploration of the PIMSRA/Liwen Procedure

In healthy sheep and canine models, laser or radiofrequency ablation of the interventricular septum was performed via a percutaneous trans-apical approach. No major adverse events occurred, mild pericardial effusion developed in a few animals and resolved spontaneously. Septal thickness decreased at follow-up in animals that

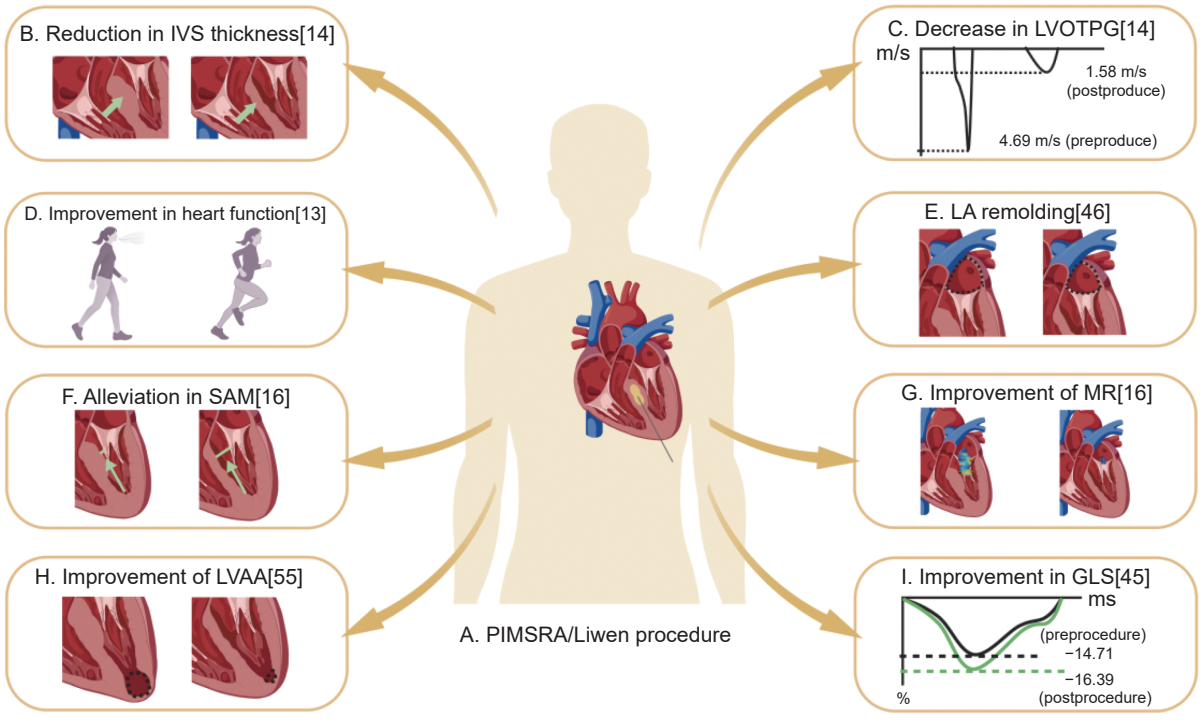


Figure 1 Multidimensional favorable outcomes of PIMSRA/Liwen procedure. (A) Percutaneous intramyocardial septal radiofrequency ablation (PIMSRA/Liwen procedure); (B) Reduction in interventricularseptum thickness. (the arrow indicates interventricular septum); (C) Decrease in left ventricular outflow tractpeak gradient; (D) Improvement in heart function; (E) Left atrial remolding (the area enclosed by the blackcurve indicates the size of left atrial); (F) Alleviation in systolic anterior motion (the green straight linerepresents the distance between the anterior mitral leaflet and the interventricular septum); (G) Improvement of mitral regurgitation; (H) Improvement of left ventricular apical aneurysm (the area enclosedby the black curve indicates the size of the ventricular aneurysm); (I) Improvement in global longitudinalstrain. PIMSRA, Percutaneous intramyocardial septal radiofrequency ablation; IVS, interventricular septum; LVOTPG, left ventricular outflow tract peak gradient; LA, left atrial; SAM, systolic anterior motion; MR, mitralregurgitation; LVAA, left ventricular apical aneurysm; GLS, global longitudinal strain.

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underwent ablation [15,18-20]. The IVS thickness of the ablated area significantly decreased (from 8.7 ± 0.6 mm at baseline to 2.9 ± 1.0 mm at 12 months) was recorded in the investigation [15]. A mean reduction of 5.2 mm in ablated-segment IVS thickness was reported by Fu et al. [18]. Collectively, these preclinical findings support the efficacy and safety of this novel approach.

Comparative studies of laser and radiofrequency ablation have been performed [20,21]. At the same accumulated thermal energy, the volume of the coagulation necrosis zone formed by laser ablation was larger than that formed by radiofrequency ablation, but with more pronounced central carbonization, which may reduce laser energy transmission and potentially limit ablation efficacy [21]. However, under the optimal parameters, radiofrequency ablation was associated with shorter total ablation time, a larger ablation zone, and less carbonization [20]. Based on these findings, radiofrequency ablation was ultimately selected for the clinical treatment.

Safety, Efficacy and Multidimensional Favorable Outcomes of PIMSRA/Liwen Procedure

After the feasibility of the approach was validated in animal experiments, the Hypertrophic Cardiomyopathy Center at Xijing Hospital, a quaternary referral center, obtained approval by the institutional ethics committee in accordance with the ethical standards of the Declaration of Helsinki. After a multi-disciplinary discussion and obtaining the patient's informed consent, we performed the world's first PIMSRA/Liwen procedure for the treatment of oHCM in 2016 [22], the study was registered at clinicaltrials.gov (NCT02888132), and subsequently conducted a series of studies on its safety and efficacy [13,14,16,23-29].

Explore the safety of PIMSRA/Liwen procedure

The retrospective study [25] enrolled 571 consecutive adult patients who underwent PIMSRA/Liwen procedure between October 2016 and June 2024 at Xijing Hospital, and is the largest-sample investigations among available published literature on this procedure. During the 30-day follow-up, 61 (10.7%) patients experienced major adverse cardiovascular event (MACE), including 4 all-cause deaths (0.7%), 24 cases of cardiac tamponade requiring pericardiocentesis (4.2%), 11 cases of cardiac tamponade requiring mini thoracotomy in the setting of tamponade physiology (1.9%), 5 cases of cardiac arrest (0.9%), 1 case of ventricular tachycardia (0.2%), 4 cases of ventricular fibrillation (0.7%), 0 case of appropriate implantable cardioverter-defibrillator discharge (0.0%), 9 cases of cardiogenic shock (1.6%), and 2 cases of stroke (0.4%), 1 case of new third-degree atrioventricular block (0.2%) with spontaneous recivery. No patients required permanent pacemaker implantation after the procedure [25]. This finding may be explained by the percutaneous intramyocardial approach and real-time monitoring of 12-lead electrocardiogram in the PIMSRA/Liwen procedure. We recommend maintaining a safe margin of 3 mm between the border of the ablated region and the endocardium of the left or right ventricle, with the needle tip kept strictly 8 to 10 mm away from the distal end of the membranous septum. Apart from these constraints, ablation energy was delivered with gradual increment and strict control,and it was confined within the interventricular septum and did not directly involve the conduction system beneath the endocardium. Continuous ECG monitoring was performed throughout the procedure, allowing prompt adjustment of the ablation strategy if rhythm changes occurred. Collectively, these measures reduce the risk of conduction system injury [13].

A meta-analysis by Liebregts et al. [30] (4804 patients) reported periprocedural mortality rates of 1.3% for ASA and 2.5% for SM. In light of the potentially less-developed periprocedural care in the early days and limited operator experience, after excluding these earlier studies, the periprocedural mortality rates of the two procedures were comparable (ASA: 1.3% vs SM: 1.1%). Another meta-analysis by Osman et al. [31] (8453 patients) reported lower periprocedural mortality with ASA than with SM (1.2% vs 2.0%), but the study noted that most SM studies were conducted earlier than ASA studies, which may account for the observed difference. When early reports are not considered, the periprocedural mortality rates of both procedures are approximately 1%. Regarding pacemaker implantation, the two meta-analyses yielded similar results, both demonstrating a higher pacemaker implantation rate after ASA than SM (approximately 10% vs 4%-5%). Table 1 summarizes the key characteristics of the three septal reduction therapies. Although no rigorous propensity score-matched study has yet directly compared PIMSRA/Liwen with SM or ASA, based on existing research, PIMSRA/Liwen procedure periprocedural mortality was 0.7% and permanent pacemaker implantation rates was 0% [25]. However, its safety outcomes warrant further validation through larger, multicenter, and prospective studies.

Systolic anterior motion (SAM) is a well-recognized cause for unexplained or sudden hypotension in the cardiac perioperative setting [32-34]. Meanwhile, hypotension may further exacerbate SAM and LVOT obstruction, creating a vicious cycle that renders patients poorly responsive to vasoactive agents [35-38]. In the study by Zhou et al. [14], one patient who died within 30 days after the PIMSRA/Liwen procedure had significant per-

Table 1 Comparison of three septal reduction therapies

Items	PIMSRA/Liwen procedure	SM	ASA
Approach	Percutaneous intramyocardial	Open-chest approach via median sternotomy	Percutaneous catheter‐based
Mechanism	Radiofrequency ablation	Resection	Chemical ablation
Scarring	YES, homogeneous	NO	YES, heterogeneous
Intraoperative imaging	TTE	TEE	Fluoroscopy+MCE
Fluoroscopy	None, Echo-only	Not typically required	Required (fluoroscopy for coronary angiography)
Cardiopulmonary bypass	NO	YES	NO
Constrained by coronary anatomy	NO	NO	YES

PIMSRA, percutaneous intramyocardial septal radiofrequency ablation; SM. surgical myectomy; ASA, alcohol septal ablation; TTE, transthoracic echocardiography; TEE, transesophageal echocardiography; MCE, myocardial contrast echocardiography.

sistent SAM, despite the initiation of fluid therapy and vasoconstrictors. Therefore, optimizing preload and afterload condition should be emphasized to avoid provoking or aggravating SAM and outflow tract obstruction [9].

The probability of cardiac tamponade requiring mini thoracotomy is 1.9% [25]. Pre-procedural compute tomography angiography planning and intra-procedural color Doppler guidance for evaluating the puncture route and reducing the risk of puncture-related pericardial effusion [13]. Injury to septal branches caused by radiofrequency needles may result in a variety of vascular-related complications, including ventricular septal hematoma, and aneurysm. Such vascular complications are uncommon. Some required no intervention, whereas others achieved full recovery after coil embolization [14,27,39].

Verify the efficacy of PIMSRA/Liwen procedure

PIMSRA/Liwen procedure was first performed clinically in 2016 in a 70-year-old female patient with oHCM (KY20162042-1). At six-month follow up, the septal thickness was reduced to from 28 to 18 mm. the peak LVOT PG reduced from 153 to 44 mmHg and the symptoms were significantly relieved. No left bundle branch block (LBBB) or right bundle branch block (RBBB) was observed. This case provided preliminary evidence for the efficacy and safety of PIMSRA/Liwen procedure in human subjects [22].

On the basis of the initial results from the first human case, two subsequent studies involving 9 and 15 patients further evaluated the short-term efficacy of PIMSRA/Liwen procedure. In both studies, at 6-month follow-up, IVS thickness decreased [9-patient study: from 21.5 ± 2.6 to 12.9 ± 1.9 mm, 15-patient study: from 25.0 (21.0) to 14.0 (12.0) mm], resting and provoked LVOT peak gradient also declined [resting: from 83.3 ± 32.4 to 11.8 ± 5.7 mmHg and 88.0 (66.0) to 11.0 (6.0) respectively; provoked: from 147.8 ± 58.0 to 25.5 ± 11.4 mmHg and 117.0 (81.0) to 25.0 (20.0) mmHg, respectively], lending support to the short-term efficacy of PIMSRA/Liwen procedure [13,24]. These observations were further confirmed in a larger cohort with extended follow-up. In a study of 200 patients with a median follow-up of 19 months, reductions in septal thickness and LVOT gradients were consistently observed, accompanied by improvement in NYHA functional class and a reduction in SAM severity, suggesting that the treatment effect was maintained despite the larger sample size and longer follow-up [14]. Longer-term follow-up accessed the durability of the response. In a study [16] with 5-year follow-up, septal thickness was reduced compared with baseline (from 22.0 ± 5.0 to 11.5 ± 3.0 mm), and both resting and provoked gradients were lower than baseline values [resting: from 95.0 (48.2) to 9.0 (7.5) mmHg; provoked: from 130.5 (89.0) to 21.0 (19.1) mmHg], indicating favorable long-term efficacy of PIMSRA/Liwen procedure.

Beyond the experience at Xijing Hospital, studies from multiple centers [27-29] have also reported consistent reductions in LVOT gradient and septal thickness after PIMSRA/Liwen procedure, as shown in table 2, supporting the reproducibility of the procedure.

Along with the improvements in septal thickness and LVOT obstruction, a series of favorable changes were observed (Fig. 1) [40]: (1) Symptomatic improvement, including NYHA functional class [13,14,16,24,26-28], 6-minute walk distance [14,26,28], total exercise time [13,14,24], and Kansas City Cardiomyopathy Questionnaire (KCCQ) score [28]; (2) Multiple studies [13,16, 22,24,28] have demonstrated that the PIMSRA/Liwen procedure, without any intervention on the mitral valve, significantly reduces mitral regurgitation due to the alleviation of the SAM phenomenon [e.g., regurgitation volume from 4.3 (1.4) mL to 0.5 (0.0) mL]; (3) Improvement in myocardial ischemia. Myocardial contrast echocardiography demonstrated significant improvement in global and regional left ventricular microcircula-

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Table 2 Efficacy of PIMSRA in patients with oHCM

First Author, Year	Period	N	Age, year	Follow-up, months	Max IVS Thickness, mm	Peak LVOTPG, mmHg		NYHA Ⅲ-Ⅳ, %	MR		SAM grade 3, *n* (%)	LAVI, mL/m²	LVEF, %
						resting	provoked		Moderate -Severe, %	mL			
Xijing HCM center													
Zuo L, 2018[22]	2016-2017	1	70	6	28/18	153/44	-	-	-	7/3	-	65.7/47.9	65/-
Liu L, 2018[23]	-	1	26	6	-	88/10	-	-	-	-	-	-	-
Liu L, 2019[24]	2016-2017	9	46.1 [a]	6	21.5/12.9 [a*]	83.3/11.8 [a*]	147.8/25.5 [a*]	77.8/0*	-	3.2/0.7[a*]	-	-	-
Liu L, 2018[13]	-	15	40.7 [a]	6	25.0/14.0 [b*]	88.0/11.0 [b*]	117.0/25.0 [b*]	60/-	-	4.3/0.5[b*]	-	41.9/29.6 [b*]	-
Zhou M, 2022[14]	2016-2020	200	46.9 [a]	19 (44) [b]	24.0/17.3 [a*]	79.0/14.0 [b*]	127.0/47.0 [b*]	71.0/4.0*	-	-	53.0/3.0*	49.5/35.9 [a*]	60.2/59.2 [a*]
Ta S, 2024[16]	2016-2017	27	44.3 [a]	60 (6.0) [b]	22.0/11.5 [a*]	95.0/9.0 [b*]	130.5/21.0 [b*]	63.0/0*	44.7/11.5*	-	40.7/0*	60.8/51.3 [a*]	61.5/59.7 [a]
Zhang J, 2025[26]	2017-2023	12	48.7 [a]	12 (12) [b]	22.0/15.5 [b*]	82.5/15.5 [b*]	110.0/19.0 [b*]	66.7/8.3*	-	-	-	48.2/40.8 [b*]	56.9/62.2 [b*]
Yao L, 2021[41]	2019-2020	45	46.8 [a]	6	24.0/17.0 [b*]	65.0/14.0 [b*]	-	26.7/0*	-	-	-	-	59.3/58.8 [a]
Li J, 2022[45]	2016-2019	70	46.6 [a]	12	21.6/15.6 [a*]	83.5/13.5 [b*]	118.3/47.0 [b*]	62.9/-	-	-	-	52.0/37.8 [a*]	60.0/62.0 [a]
Zuo L, 2020[42]	2016-2018	30	45.0 [b]	12	23.3/14.4 [a*]	95.0/12.5 [b*]	-	43.3/-	-	5.8/2.0[b*]		47.6/35.0 [a*]	62.6/59.3 [a]
Other center													
Xie X, 2024[27]	2020-2023	76	55.7 [a]	14(11.5) [b]	23.6/19.1 [b*]	70.0/20.0 [b*]	104.3/41.4 [b*]	51.0/0*	-	-	-	42.1/40.3 [b*]	71.2/69.1 [a*]
Wang C, 2024[28]	-	31	53 [a]	6	22.9/17.5 [a*]	83.2/23.4 [a*]	109.7/33.4 [a*]	71.0/3.2 *	41.9/6.5 *	-	-	32.3/23.9 [a*]	64.7/64.5 [a]
Wang S, 2025[29]	2019-2023	42	44.8 [a]	15(7.0) [a]	22.5/17.0 [b*]	58.5/11.5 [b*]	-	-	-	-	-	-	60.0/63.0 [b*]
Dai S, 2023[46]	2021	13	51.5 [a]	6	23.2/16.8 [a*]	64.9/14.3 [a*]	-	30.8/-	-	-	-	-	64.6/62.7 [a]

Data are presented as mean, mean(SD), median, median(IQR) or %. [a] Data are presented as mean. [b] Data are presented as median. *P<0.05.

PIMSRA, Percutaneous intramyocardial septal radiofrequency ablation; IVS, interventricular spetum; LVOTPG, left ventricular outflow tract-peak gradient; LVOT, left ventricular outflow tract; NYHA, New York Heart Association; MR, Mitral Regurgitation; SAM, Systolic Anterior Motion(of mitral valve); LAVI, Left Atrial Volume Index; LVEF, Left ventricular Ejection Fraction; SD, standard deviation; IQR, interquartile range.

tory perfusion after PIMSRA/Liwen procedure, with improvement persisting at 12 months [41]; (4) Improvement in electrocardiographic indices: the QRS wave amplitude reductions in lead V1 and Sokolow–Lyon index may be good indicators for evaluating the postprocedure interventricular septal remodeling [42]; (5) Myocardial strain is a sensitive parameter of left ventricular systolic performance [43,44]. In a study of 70 patients with oHCM, three-dimensional speckle-tracking echocardiography was used to evaluate changes in myocardial mechanics after PIMSRA/Liwen procedure. Left ventricular global longitudinal strain (GLS) magnitude showed no significant change immediately after the procedure but improved significantly at 1 year compared with baseline (baseline: 14.7 ± 0.5, immediately: 14.1 ± 0.5, 1-year: 16.4 ± 0.5, $P < 0.05$), suggesting progressive recovery of left ventricular systolic performance [45]; (6) We also observed improvement in left ventricular diastolic function: left atrial conduit strain, E/e' [28], and left atrial volume index [13,14,16,22,26-28]. Left atrial conduit strain could be considered as an indicator of left ventricular diastolic dysfunction and left ventricular remodeling after PIMSRA/Liwen procedure. In a study by Dai et al. [46], conduit strain improved significantly (from 10.7% to 16.6% at 6 months, $P < 0.05$).

Other Potentially Extended Applications of the PIMSRA/Liwen Procedure

PIMSRA/Liwen procedure has been validated by multiple clinical studies for its safety and efficacy in adult patients with oHCM, and is recommended by guidelines in China as a therapeutic option for drug-refractory oHCM [47-49]. This technique is being explored in a variety of special clinical scenarios: (1) Adult non-obstructive HCM (NoHCM); (2) oHCM with comorbidities: residual obstruction after ASA, high LVOT gradient after surgical-aortic-valve-replacement, concomitant coronary artery disease and apical ventricular aneurysm; (3) Fabry disease (FD); (4) Intraoperative myocardial biopsy; (5) Cardiac tumors. Given that most of these potentially extended applications remain exploratory with limited evidence, strict assessment by an experienced multidisciplinary team is required before clinical implementation.

Among these extended applications, adult patients with nonobstructive hypertrophic cardiomyopathy (NoHCM) are of particular interest. Approximately 15% of patients with NoHCM have drug-refractory symptoms without effective invasive therapies and may be listed for heart transplantation [50]. The time window for transplantation is narrow, with a 10-23% chance of death while on the waiting list [51]. In response to the clinical treatment needs of patients with NoHCM, Wang et al. [52] performed PIMSRA/Liwen procedure for the first time to treat 20 drug-refractory NoHCM patients with severe septal hypertrophy (≥ 28 mm). Improved clinical symptoms and myocardial function, thinned IVS and no serious complications were observed at the last available follow-up (median period: 15 months). Although the feasibility of PIMSRA/Liwen procedure for NoHCM has been demonstrated in this study, further clinical investigation is still needed to guide the selection of septal reduction therapy.

Preoperative multimodality imaging can be integrated to delineate the residual obstructive region and guide ablation of the culprit segment. In a study of 12 patients with residual obstruction after ASA, PIMSRA/Liwen procedure was successfully performed, with no mortality or permanent pacemaker implantation within 30 days. Improvements were observed in IVS thickness, LVOT gradient, and NYHA functional class [26]. Moreover, a case report have shown that in patients with severe residual LVOT obstruction after ASA, the procedure resulted in a significant reduction in LVOT gradient and improvement in cardiac function at 1-month follow-up, without procedure-related complications [53]. These preliminary observations suggest that PIMSRA/Liwen procedure may be a potential therapeutic option for patients with failed ASA, although further evidence is needed.

The concomitant PIMSRA/Liwen procedure and off-pump minimally invasive direct coronary artery bypass (MIDCAB) through a single minimally invasive access is a feasible and promising strategy for patients with coexisting oHCM and coronary artery disease (CAD). This approach effectively relieved LVOT obstruction and ameliorated myocardial ischemia, with significant improvement in postoperative cardiac function. At 1-month follow-up, the LVOT gradient decreased (from 66 to 9 mmHg). Compared to traditional approaches, it offering reduced trauma and faster recovery [54].

For apical aneurysm, the puncture route can be modified by adjusting needle insertion direction and echo probe orientation to ablate the basal septum while avoiding cardiac chamber entry and pericardial tamponade [55].

PIMSRA/Liwen procedure had been used to treat both Fabry disease patients with LVOT obstruction [56,57] and cardiac tumors who are poor candidates for conventional surgery or systemic therapy [58]. In the diagnostic evaluation of cardiomyopathy and cardiac tumor, myocardial/tumors biopsy of the PIMSRA/Liwen procedure can also be performed, providing tissue specimens for pathological diagnosis [56,58].

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Conclusion and Future Perspectives

The safety and efficacy of PIMSRA/Liwen procedure in adult patients with oHCM have been validated in multiple centers [13,14,16,22-24,27-29], with follow-up ranging from short- to long-term and including relatively large cohorts. Although findings have been reported by other centers, a substantial proportion of the available evidence originates from Xijing Hospital. Independent multicenter validation remains relatively limited, it is hoped that this technique will be extended internationally and further validated through multicenter studies with larger sample sizes and longer follow-up. In addition, the PIMSRA/Liwen procedure is being explored in several clinical scenarios beyond its original indication, but current evidence in these areas remains limited to small case series or case reports. Further studies are needed to validate the role of this technique in these emerging indications. Meanwhile, using artificial intelligence-assisted and multimodal imaging fusion to optimize LV apical the puncture trajectory, ablation target, energy parameters, and ablation extent, thereby improving procedural precision and safety.

Acknowledgements

Not applicable.

Authors' Contributions

LWL and JL conceived of and designed the study; SND and JL drafted the manuscript; LWL, DH.H and SJT revised the article. All authors contributed to editorial changes in the manuscript. All authors read and approved the final.

Funding

This study was supported by National Natural Science Foundation of China (Grant No. 82230065, 82572237, 82603858); Noncommunicable Chronic Diseases-National Science and Technology Major Project (Grant No. 2023ZD0504500); Shaanxi Provincial Key Laboratory of Technological Innovation and Translation in Ultrasound Medicine (2025ZY1-SZDSYS-24); Shaanxi Provincial Health Commission Research Innovation Platform for Clinical and Basic Research on Hypertrophic Cardiomyopathy (2024PT-05).

Data Availability

Data sharing is not applicable to this article.

Declarations

Ethics approval and consent to participate

Not applicable.

Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article.

Consent for publication

Not applicable.

References

[1] Semsarian C, Ingles J, Maron MS, Maron BJ. New perspectives on the prevalence of hypertrophic cardiomyopathy. J Am Coll Cardiol 2015;65:1249-1254.

[2] Maron BJ, Gardin JM, Flack JM, Gidding SS, Kurosaki TT, Bild DE. Prevalence of hypertrophic cardiomyopathy in a general population of young adults. Echocardiographic analysis of 4111 subjects in the CARDIA Study. Coronary Artery Risk Development in (Young) Adults. Circulation 1995;92:785-789.

[3] Ommen SR, Ho CY, Asif IM, Balaji S, Burke MA, Day SM, et al. 2024 AHA/ACC/AMSSM/HRS/PACES/SCMR Guideline for the management of hypertrophic cardiomyopathy: a report of the american heart association/american college of cardiology joint committee on clinical practice guidelines. Circulation 2024;149:e1239-1311.

[4] Maron MS, Olivotto I, Zenovich AG, Link MS, Pandian NG, Kuvin JT, et al. Hypertrophic cardiomyopathy is predominantly a disease of left ventricular outflow tract obstruction. Circulation 2006;114:2232-2239.

[5] Maron MS, Olivotto I, Betocchi S, Casey SA, Lesser JR, Losi MA, et al. Effect of left ventricular outflow tract obstruction on clinical outcome in hypertrophic cardiomyopathy. N Engl J Med 2003;348:295-303.

[6] Nishimura RA, Seggewiss H, Schaff HV. Hypertrophic obstructive cardiomyopathy: surgical myectomy and septal ablation. Circ Res 2017;121:771-783.

[7] Maurizi N, Antiochos P, Owens A, Lakdawala N, Saberi S, Russell MW, et al. Long-Term outcomes after septal reduction therapies in obstructive hypertrophic cardiomyopathy: Insights From the SHARE Registry. Circulation 2024;150:1377-1390.

[8] Pavo N, Hengstenberg C. Management von kardiomyopathien. Herz 2024;49:22-32.

[9] Ommen SR, Mital S, Burke MA, Day SM, Deswal A, Elliott P, et al. 2020 AHA/ACC Guideline for the Diagnosis and Treatment of Patients With Hypertrophic Cardiomyopathy: Executive Summary: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation 2020;142:e533-557.

[10] Olivotto I, Ommen SR, Maron MS, Cecchi F, Maron BJ. Surgical myectomy versus alcohol septal ablation for obstructive hypertrophic cardiomyopathy. Will there ever be a randomized trial? J Am Coll Cardiol 2007;50:831-834.

[11] Spirito P, Rossi J, Maron BJ. Alcohol septal ablation: in which patients and why? Ann Cardiothorac Surg 2017;6:369-375.

[12] Nagueh SF, Groves BM, Schwartz L, Smith KM, Wang A, Bach RG, et al. Alcohol septal ablation for the treatment of hypertrophic obstructive cardiomyopathy. A multicenter North American registry. J Am Coll Cardiol 2011;58:2322-2328.

[13] Liu L, Li J, Zuo L, Zhang J, Zhou M, Xu B, et al. Percutaneous intramyocardial septal radiofrequency ablation for hypertrophic obstructive cardiomyopathy. J Am Coll Cardiol 2018;72:1898-1909.

[14] Zhou M, Ta S, Hahn RT, Hsi DH, Leon MB, Hu R, et al. Percuta-

neous intramyocardial septal radiofrequency ablation in patients with drug-refractory hypertrophic obstructive cardiomyopathy. JAMA Cardiol 2022;7:529-538.
[15] Liu F, Fu J, Hsi D, Sun C, He G, Hu R, et al. Percutaneous intramyocardial septal radiofrequency ablation for interventricular septal reduction: an ovine model with 1-year outcomes. Cardiology 2020;145:53-62.
[16] Ta S, Li J, Hsi DH, Hu R, Lei C, Shan B, et al. Percutaneous intramyocardial septal radiofrequency ablation after 5-year follow-up. Heart 2024;110:792-799.
[17] Shah DR, Green S, Elliot A, McGahan JP, Khatri VP. Current oncologic applications of radiofrequency ablation therapies. World J Gastrointest Oncol 2013;5:71-80.
[18] Fu J, Sun C, Liu F, Hu R, Hsi DH, Tuo S, et al. Transthoracic echocardiography guided percutaneous laser ablation of the interventricular septum: A successful sheep model for septal thickness reduction and one year follow-up. Int J Cardiol 2019;280:135-141.
[19] Zhang X, Liu L, Sun C, He G, Zuo L, Zheng M, et al. Study of ultrasound-guided percutaneous laser ablation for canine ventricular septum. Chin J Ultrasonogr 2015;24:996-999.
[20] Duan S, Wu Y, Wang S, Chang Z, Zhang Y, Liu Z, et al. A comparative experimental study of ultrasound-guided percutaneous interventricular septal myocardial ablation in dogs using laser and radiofrequency. Chin J Ultrasonogr 2020;29:717-721.
[21] Li W, Liu J, Huang T, Zhong X, Yang D, Xie X, et al. Lesion outline and thermal field distribution of ablative in vitro experiments in myocardia: comparison of radiofrequency and laser ablation. BMC Cardiovasc Disord 2020;20:454.
[22] Zuo L, Sun C, Yang J, Liu B, Zhou M, Guo R, et al. Percutaneous trans-apex intra-septal radiofrequency ablation of hypertrophic cardiomyopathy. Minim Invasive Ther Allied Technol 2018;27:97-100.
[23] Liu L, Liu B, Li J, Zhang Y. Percutaneous intramyocardial septal radiofrequency ablation of hypertrophic obstructive cardiomyopathy: a novel minimally invasive treatment for reduction of outflow tract obstruction. EuroIntervention 2018;13:e2112-2113.
[24] Liu L, Zuo L, Zhou M, Li J, Zhou X, He G, et al. Efficacy and safety of transthoracic echocardiography-guided percutaneous intramyocardial septal radiofrequency ablation for the treatment of patients with obstructive hypertrophic cardiomyopathy. Chin J Cardiol 2019;47:1-8.
[25] Yin J, Ta S, Wang J, Hsi DH, Shan B, Li J, et al. Predictive value of existing prediction models for short-term outcomes after percutaneous intramyocardial septal radiofrequency ablation. Cardiology 2026;1:1-11.
[26] Zhang J, Hsi DH, Ta S, Wang J, Wang B, Ma H, et al. Percutaneous intramyocardial septal radiofrequency ablation for hypertrophic cardiomyopathy with residual obstruction after alcohol septal ablation. Can J Cardiol 2025;41:2397-2406.
[27] Xie X, Chen S, Cui Y, Zhou Z, Lu J, Du Z, et al. Midterm outcomes of percutaneous intramyocardial septal radiofrequency ablation for hypertrophic cardiomyopathy: a single - center, observational study. J Am Heart Assoc 2024;13:e034080.
[28] Wang C, Guo W, Duan H, Qin J, Wang F, He T, et al. Follow - Up study of percutaneous intramyocardial septal radiofrequency ablation in the treatment of hypertrophic obstructive cardiomyopathy with HFpEF. Echocardiography 2024;41:e15930.
[29] Wang S, Tan J, Xiao H, Tao L. Clinical efficacy of Liwen procedure for obstructive hypertrophic cardiomyopathy: A retrospective study in a single center. Chin J Thorac Cardiovasc Surg 2025;32:819-823.
[30] Liebregts M, Vriesendorp PA, Mahmoodi BK, Schinkel AFL, Michels M, Ten Berg JM. A systematic review and meta-analysis of Long-Term outcomes after septal reduction therapy in patients with hypertrophic cardiomyopathy. JACC Heart Fail 2015;3:896-905.
[31] Osman M, Kheiri B, Osman K, Barbarawi M, Alhamoud H, Alqahtani F, et al. Alcohol septal ablation vs myectomy for symptomatic hypertrophic obstructive cardiomyopathy: Systematic review and meta - analysis. Clin Cardiol 2018;42:190-197.
[32] Maron BJ, Maron MS. Hypertrophic cardiomyopathy. Lancet 2013;381:242-255.
[33] Fujita Y, Kagiyama N, Sakuta Y, Tsuge M. Sudden hypoxemia after uneventful laparoscopic cholecystectomy: another form of SAM presentation. BMC Anesthesiol 2015;15:51.
[34] Makhija N, Magoon R, Balakrishnan I, Das S, Malik V, Gharde P. Left ventricular outflow tract obstruction following aortic valve replacement: A review of risk factors, mechanism, and management. Ann Card Anaesth 2019;22:1-5.
[35] Shan B, Li J, Shi Z, Han C, Zhang J, Zhao J, et al. Predictive value of estimated plasma volume for postoperative hypotension in percutaneous intramyocardial septal radiofrequency ablation treating for hypertrophic obstructive cardiomyopathy. BMC Cardiovasc Disord 2024;24:177.
[36] Ibrahim M, Rao C, Ashrafian H, Chaudhry U, Darzi A, Athanasiou T. Modern management of systolic anterior motion of the mitral valve. Eur J Cardiothorac Surg 2012;41:1260-1270.
[37] Lasala JD, Tsai J, Rodriguez-Restrepo A, Atay SM, Sepesi B. Systolic anterior motion of the mitral valve-the mechanism of postural hypotension following left intrapericardial pneumonectomy. J Thorac Dis 2017;9:E354-357.
[38] Monaco F, D'Amico F, Barucco G, Licheri M, Novellis P, Ciriaco P, et al. Mitral valve systolic anterior motion in robotic thoracic surgery as the cause of unexplained hemodynamic shock: from a case report to recommendations. J Clin Med 2022;11:6044.
[39] Wu B, Zhou Y, Lu J, Cui Y, Zhou Z, Lin W, et al. Interventricular septal hematoma caused by percutaneous intramyocardial septal radiofrequency ablation successfully treated with coil embolization. JACC Cardiovasc Interv 2023;16:722-724.
[40] Jiang S, Li H, Zhang L, Mu W, Zhang Y, Chen T, et al. Generic diagramming platform (GDP): a comprehensive database of high-quality biomedical graphics. Nucleic Acids Res 2024;53:D1670-1676.
[41] Yao L, Zuo L, Wang J, Lu X, Zhao J, He J, et al. Evaluation of myocardial microcirculation perfusion in patients with hypertrophic obstructive cardiomyopathy after Liwen procedure by myocardial contrast echocardiography. Chin J Ultrasonogr 2021;30:927-931.
[42] Zuo L, Hsi DH, Zhang L, Zhang Q, Shao H, Liu B, et al. Electrocardiographic QRS voltage amplitude improvement by intramyocardial radiofrequency ablation in patients with hypertrophic obstructive cardiomyopathy and one year follow up. J Electrocardiol 2020;61:164-169.
[43] Saito M, Okayama H, Yoshii T, Higashi H, Morioka H, Hiasa G, et al. Clinical significance of global two-dimensional strain as a surrogate parameter of myocardial fibrosis and cardiac events in patients with hypertrophic cardiomyopathy. Eur Heart J Cardiovasc Imaging 2012;13:617-623.
[44] Maron MS, Wells S. Myocardial strain in hypertrophic cardiomyopathy: A force worth pursuing? JACC Cardiovasc Imaging 2019;12:1943-1945.
[45] Li J, Zhang J, Shi Y, Sievert H, Taub CC, Bertog S, et al. Myocardial mechanics of percutaneous intramyocardial septal radiofrequency ablation. Heart 2023;109:289-296.
[46] Dai S, Wu L, Duan H, Wang H, Song X, Guo W, et al. Analysis of left atrial function after percutaneous intramyocardial septal

radiofrequency ablation in hypertrophic cardiomyopathy. Cardiology 2023;148:38-47.
[47] National Heart Failure Committee, Chinese Heart Failure Association of Chinese Medical Doctor Association, Heart Failure Group of Chinese Society of Cardiology of Chinese Medical Association, Editorial Board of Chinese Journal of Heart Failure and Cardiomyopathy. 2022 Chinese guideline for hypertrophic cardiomyopathy. Chin J Heart Fail Cardiomyopathy 2022;6:80-105.
[48] The Joint Committee of Cardiomyopathy Specialty Alliance,National Center for Cardiovascular Diseases/Cardiovascular Precision Medicine Branch of China International Exchange and Promotive Association for Medical and Health Care. 2023 Guideline for Diagnosis and Treatment of Patients With Hypertrophic Cardiomyopathy. Chin Circ J 2023;38:1-33.
[49] The Cardiomyopathy Specialty Alliance of National Center for Cardiovascular Diseases, Cardiovascular Precision Medicine Branch of China International Exchange and Promotive Association for Medical and Health Care. 2025 Chinese guideline for the management of cardiomyopathies. Mol Cardiol China 2025;25:6793-6837.
[50] Olivotto I, Cecchi F, Poggesi C, Yacoub MH. Patterns of disease progression in hypertrophic cardiomyopathy: an individualized approach to clinical staging. Circ Heart Fail 2012;5:535-546.
[51] Rowin EJ, Maron BJ, Kiernan MS, Casey SA, Feldman DS, Hryniewicz KM, et al. Advanced heart failure with preserved systolic function in nonobstructive hypertrophic cardiomyopathy: underrecognized subset of candidates for heart transplant. Circ Heart Fail 2014;7:967-975.
[52] Wang H, Li J, Hsi DH, Li W, Ta S, Jiao Y, et al. Percutaneous intramyocardial septal radiofrequency ablation: a novel treatment for drug-refractory non-obstructive hypertrophic cardiomyopathy with severe septal hypertrophy. Heart 2025;111:e325334.
[53] Xu Y, Yu T, Pu Z. Percutaneous Intramyocardial Septal Radiofrequency Ablation Relieving Residual Left Ventricular Outflow Tract Obstruction Following Alcohol Septal Ablation. CASE 2022;6:340-343.
[54] Li X, Xie S, Yu Z. Concomitant Liwen procedure and minimally invasive direct coronary artery bypass via a single access: a first-in-human case report. Eur Heart J Case Rep 2026;10:ytag312.
[55] Zhang R, Zhao F, Wang J, Qin Y, Wang T, Chu A-A. Case Report: Integrated echocardiographic assessment guided Liwen procedure for treating obstructive hypertrophic cardiomyopathy with ventricular aneurysm. Front Cardiovasc Med 2023;10:1278457.
[56] Yin J, Yang S, Yang F, Li J, Zhao Y. Percutaneous intramyocardial septal radiofrequency ablation for a Fabry disease patient. Eur Heart J Cardiovasc Imaging 2025;26:1081.
[57] Shi X, Yang F, Wang J, Han C, Liu L. Echocardiography-guided percutaneous intramyocardial septal radiofrequency ablation procedure for the treatment of Fabry disease: a case report. Eur Heart J Case Rep 2025;9:ytae660.
[58] Huang J, Lei C, Hsi DH, Zheng M, Ma H, Ta S, et al. Echocardiography-guided radiofrequency ablation for cardiac tumors. JACC CardioOncol 2024;6:560-571.