

Research Paper

Perceptual Speech Outcomes and Videofluoroscopic Findings After Radical Intravelar Veloplasty

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Citation Tavakoli M, Rezaei P, Tahmasebifard N, Abdali H, Derakhshandeh F. Perceptual Speech Outcomes and Videofluoroscopic Findings after Radical Intravelar Veloplasty. *Iranian Rehabilitation Journal*. 2026; 24(3):321-332. <http://dx.doi.org/10.32598/irj.2026.2614.2>

doi <http://dx.doi.org/10.32598/irj.2026.2614.2>

Article info:

Received: 16 Dec 2025

Revised: 11 Apr 2026

Accepted: 02 May 2026

Keywords:

Radical intravelar veloplasty (IVVP), Velopharyngeal (VP) insufficiency, Speech outcomes, Secondary palatoplasty, Hypernasality (HN)

ABSTRACT

Objectives: Velopharyngeal (VP) insufficiency is a persistent complication after primary palatoplasty that adversely affects speech. Radical intravelar veloplasty (IVVP) has been proposed as a secondary reconstructive technique to restore VP function. This study aimed to evaluate speech outcomes and VP closure following radical IVVP in patients with non-syndromic cleft palate.

Methods: This retrospective audit comprised 94 patients who underwent perceptual speech evaluations pre- and postoperatively. Parameters assessed included hypernasality (HN), audible nasal emission (ANE), and non-oral errors (NOEs). In a subgroup of 53 patients, single-view lateral videofluoroscopy was used to measure the VP closure ratio (VPCR). Statistical analyses were performed using Wilcoxon and paired t-tests, and ordinal logistic regression ($P < 0.05$).

Results: Postoperative assessments at a minimum of 6 months (median follow-up: 15 months) demonstrated significant reductions in HN ($P < 0.001$, $r = 0.65$), ANE ($P = 0.001$, $r = 0.33$), and NOE ($P < 0.001$, $r = 0.43$). VPCR improved significantly (from 0.48 to 0.7, $P < 0.001$, $r = 0.07$), and complete closure was achieved in 13 patients. The fistula rate decreased significantly from 21.2% to 7.4% ($P = 0.002$). The ordinal logistic regression model indicated that Preoperative NOEs ($\beta = -1.59$, odds ratio [OR] = 0.2, $P = 0.02$), age at surgery ($\beta = 0.08$, OR = 1.08, $P = 0.04$), and postoperative VPCR ($\beta = -0.29$, OR = 0.75, $P = 0.05$) were statistically significant predictors of the outcome (All $P \leq 0.05$).

Discussion: Radical IVVP achieves significant functional improvement across key speech parameters and VP function in appropriately selected cleft palate patients. However, VPCR alone is insufficient to fully predict resonance outcomes.

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Highlights

- This study retrospectively evaluated speech outcomes and VP function after radical IVVP in non-syndromic cleft palate patients.
- Postoperative assessments showed statistically significant improvements in HN, nasal emission, and VP closure ratio.
- Despite measurable gains, over 60% of patients continued to require further surgical intervention.
- Higher age at surgery and preoperative NOEs were associated with poorer perceptual outcomes.
- Findings suggest IVVP can contribute to improved speech in selected cases, but outcomes remain variable and influenced by multiple factors.

Plain Language Summary

The study shows that a type of surgery called radical intravelar veloplasty (IVVP) can help improve speech in people with insufficiency palatal valve closure. After surgery, the patients' speech problems improved. It also showed that speech outcomes improved using a special imaging technique. Factors, such as the patient's age at the time of surgery and how well they spoke before surgery, strongly affect the results. The findings suggest that early treatment, personalized speech exercises for each patient, and careful post-surgical speech assessment are crucial.

Introduction

Velopharyngeal insufficiency (VPI) is characterized by incomplete closure of the velopharyngeal (VP) port during speech or swallowing, typically due to anatomical or functional deficits. Despite advances in primary cleft palate repair techniques, residual VPI persists at a significant rate of 10–40%, frequently leading to speech disorders, such as hypernasality (HN), nasal emission, and compensatory articulation errors [1–5].

Several secondary surgical procedures, including pharyngeal flap, sphincter pharyngoplasty, posterior pharyngeal wall augmentation, and palatal re-repair, have been employed to address persistent VPI [2, 6, 7]. Blacam et al. in a systematic review, reported that after pharyngeal flap surgery, improved resonance and normal resonance were observed in 79.9% and 75.6% of cases, respectively. Similar results were reported for sphincter palatoplasty (78.7% and 61.4%), palatoplasty procedures (73.2% and 57.5%), and pharyngeal wall augmentation (76.9% and 51.3%), respectively [8].

Among these, palatal re-repair has gained attention for its potential to restore velar function while offering lower morbidity and a reduced risk of obstructive sleep apnea. This technique repositions the abnormally oriented le-

tor veli palatini muscles to a more functional posterior alignment and was initially developed and validated in a large series of palatal re-repairs, specifically targeting restoration of VP function. The technique achieves this through radical/extensive dissection to meticulously isolate and reattach the individual levator muscles directly to each other, effectively reconstructing the velar muscular sling. This anatomical control and direct levator-to-levator repair are key factors contributing to its proven efficacy in challenging secondary cases [6–11].

Palatal re-repair is not a novel surgical technique but represents an evolution of intravelar veloplasty (IVVP) principles described for several decades. Historically, this approach has been reported under different terminologies, including radical IVVP and secondary muscle repositioning, rather than as a distinct category. Radical IVVP, a variant of palatal re-repair, focuses on complete dissection and anatomical repositioning of the levator veli palatini muscles to restore a functional velar sling.

Sommerlad et al. reported that over 80% of patients with VPI exhibited either normal nasality and nasal air-flow or only mild, inconsistent HN and nasal emission (NE) following palatal re-repair [9]. Elsherbiny et al. reported highly significant improvements in nasality, NE, articulation, and overall speech scores following palatal re-repair. Postoperatively, 66.7% of patients achieved

normal or borderline speech, whereas 24.3% exhibited further improvement [6]. In another study, 65% of patients achieved surgical success characterized by the elimination or reduction of HN; 55% demonstrated adequate nasality, while 10% showed a decrease in HN from moderate to mild. Postoperative normal nasality was observed only among children (73%), indicating superior outcomes in younger patients [12]. A systematic review and meta-analysis assessing the effectiveness of palatal re-repair for VPI treatment found that 61% of patients achieved a resolution of consistent HN following the procedure. The technique of palatal re-repair encompasses three main categories: Furlow double-opposing Z-plasty, radical IVVP, and radical IVVP with palatal lengthening [7]. This paper specifically focuses on the outcomes associated with radical IVVP.

Radical IVVP, a variant of palatal re-repair, has been performed by the Isfahan craniofacial and cleft research center (ICCT) since 2010 to address anatomical abnormalities of the palate and enhance speech and resonance outcomes. Given that perceptual evaluation is considered the gold standard for assessing speech and resonance features [1], it is crucial to evaluate the effectiveness of the radical IVVP technique offered by the ICCT through perceptual methods. In addition to perceptual assessments, instrumental evaluations, such as videofluoroscopy, provide valuable insights into the structure and function of the VP mechanism [1]. Despite varying results reported by different researchers regarding the outcome measures of this technique in correcting speech symptoms, no comprehensive audit study has been conducted to evaluate its effectiveness in Iran, specifically at ICCT. Given the continuous advancements and modifications in surgical techniques over the years, it is vital to assess the current outcomes and provide essential feedback to the surgical team for quality improvement.

This study retrospectively evaluated the outcomes of radical IVVP in non-syndromic cleft palate patients. The primary objectives included assessing perceptual speech parameters, such as HN, audible nasal emission (ANE), hyponasality (HypoN), and non-oral errors (NOEs). A secondary objective was to examine the NOEs, age at surgery, VP closure ratio (VPCR), and follow-up time as predictor factors for postoperative HN following radical IVVP.

Materials and Methods

Study design and participants

Medical records of 2,500 cleft palate patients with VPI were reviewed. Of these, 303 patients underwent radical IVVP as the final secondary surgical procedure performed by the team's surgeons between 2015 and 2020.

A total of 94 patients who underwent radical IVVP between 2015 and 2020 met the following inclusion criteria: (1) minimum age of 3 years at surgery; (2) at least 6 months between pre- and postoperative assessments; (3) normal hearing at both preoperative and postoperative evaluations; (4) normal neuromotor development (as documented in medical records); and (5) ability to produce at least two oral consonants to allow for accurate assessment of HN independent of the effect of compensatory errors on resonance. Patients with upper respiratory infections or poor-quality recordings were excluded from the analysis. Ultimately, speech characteristics and fistula rate were analyzed for the 94 patients. VPCR analysis was available for 53 patients. Figure 1 illustrates the reasons for exclusion at each step.

The present study was designed based on a conceptual framework linking 1) anatomical repair by IVVP to 2) physiological VP closure and, ultimately, 3) perceptual resonance outcomes. Within this framework, a partial discordance between objective closure metrics and perceptual speech outcomes was considered an a priori expectation, reflecting the persistence of learned compensatory speech behaviors and multi-structural contributors to resonance despite adequate anatomical repair.

HN was prespecified as the primary outcome measure. All correlations were considered secondary or exploratory analyses.

Data collection

This study was conducted as a single-center retrospective audit of routinely collected clinical data. Pre- and post-operative speech and instrumental assessments were extracted from medical records and analyzed within subjects to evaluate changes following IVVP.

Speech sampling and rating

Pre- and postoperative speech examinations were routinely conducted for every patient at the ICCT. These comprehensive records were made available to the re-

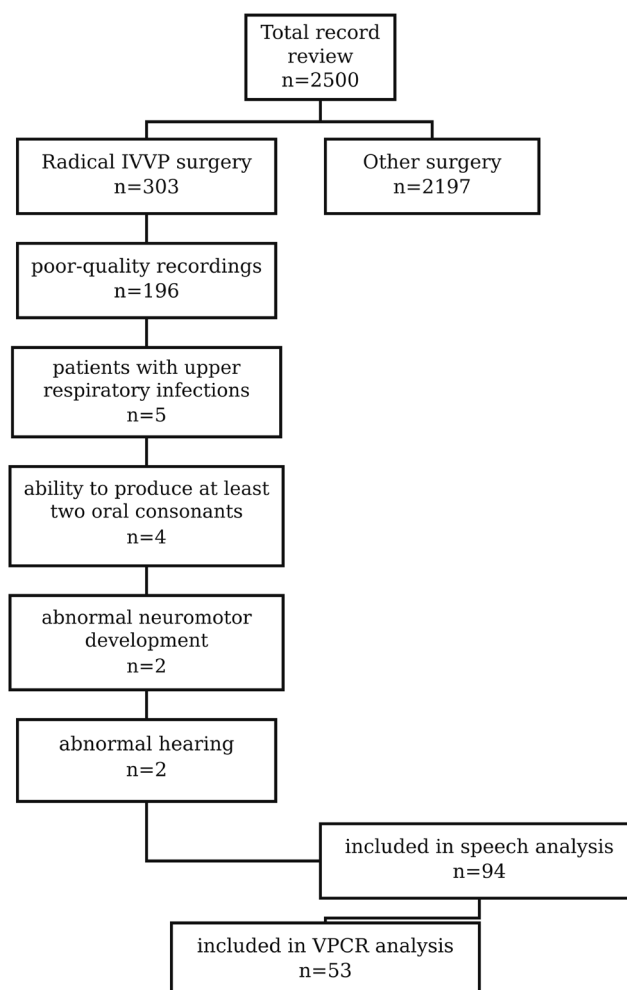


Figure 1. Diagram of exclusion patients at each step

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searchers for the audio component of the study. Standardized audio recordings were obtained in a quiet room using Olympus digital media-series recorders, 30 cm from the mouth. Speech tasks included connected speech activities, such as counting and reading a rhyme, as well as structured sentence repetition containing high-pressure consonants, designed in accordance with the universal parameters guidelines [13, 14]. Recordings were anonymized, and two speech-language pathologists performed perceptual evaluation: one with over ten years of experience and the other with three years, using the cleft audit protocol for speech-augmented (CAPS-A) protocol [13]. To ensure blinding, an independent individual not involved in the study randomly coded all recordings.

Ratings were assigned based on CAPS-A criteria

1) HN: 5-point scale (0–4). In this study, to facilitate the interpretation of the results, HN was categorized as

‘no surgery needed’ (0–2), ‘requiring surgery’ (3–4), or ‘improved’ (score reduced from 4 to 3). 2) ANE: 3-point scale (0–2). In this study, to facilitate the interpretation of the results, ANE was categorized as ‘normal’ (0) or ‘improved’ (score reduced). 3) NOEs: 3-point scale; categorized as ‘normal’ (0), ‘affected’ (1–2), or ‘improved’ (score reduced). 4) HypoN: 3-point scale (0–2). 5) These variables were compared preoperatively and at least six months postoperatively.

Fistula rate

Presence of oronasal fistula was documented pre- and postoperatively using a binary scale (0=absent, 1=present) based on intraoral examination in the patients’ clinical files.

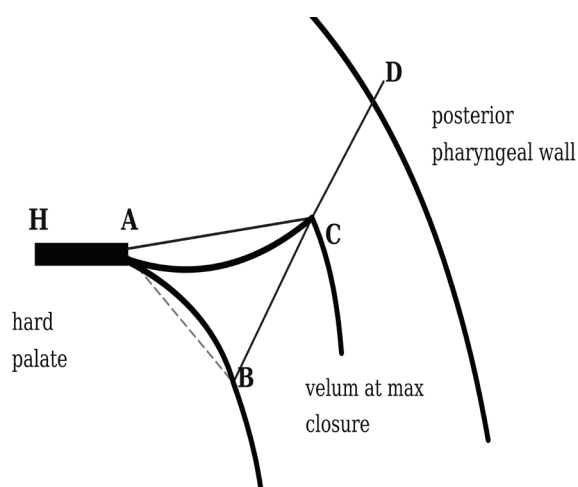


Figure 2. The VP closure ratio (BC/BD) [9]

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Velopharyngeal closure ratio

Lateral videofluoroscopy of 53 patients (both pre- and postoperative) was available in the ICCT at the time of the study. The remaining patients were excluded because they lacked either the pre- or postoperative file, or both. Furthermore, the relevant files, particularly for older patients, were not available in the records. Additionally, some patients, especially those with greater functional improvement, were unable or unwilling to undergo postoperative lateral videofluoroscopy, largely because they had to travel from distant areas.

A blinded radiologist calculated VPCR using the ratio of velar movement from rest to closure during /i/ phonation. In this calculation, 1.0 indicates full closure, and 0 indicates no movement [9]. Figure 2 visually represents this measurement.

Data analysis

Data were analyzed using SPSS software, version 24. The Wilcoxon signed-rank test was used to assess pre-post changes in speech parameters, and McNemar's test was used to assess the fistula rate. The normality of VPCR distribution was assessed using the Shapiro-Wilk test. Consequently, the VPCR data were analyzed using a paired t-test. Inter-rater reliability was calculated using Cohen's kappa statistic. A Mann-Whitney U test was conducted to compare HN severity distributions between the group with VPCR analysis and the group without VPCR analysis. Ordinal logistic regression was employed to examine predictors of postoperative HN. Statistical significance was set at $P < 0.05$.

Surgical procedure

Four surgeons performed radical IVVP, each with 4 to 7 years of experience with this technique. An operating microscope was employed to facilitate the accurate identification and repositioning of the levator veli palatini muscles, as originally described by Sommerlad et al. [9]. The procedure involved full dissection and meticulous reapproximation of the levator muscle fibers to reestablish a physiological muscle sling orientation.

Results

Patient demographics

The study included 94 non-syndromic patients (43% male, 57% female). The median age at surgery was 7 years (range: 3–38 years), and the median follow-up was 15 months (range: 6–72). Cleft types included unilateral cleft lip and palate (32%), bilateral cleft lip and palate (19%), complete cleft palate (29.8%), soft palate cleft (12.8%), and submucous cleft (6.4%) (Table 1).

Speech results

Inter-rater agreement was found to be substantial to perfect for all parameters: HN ($\kappa = 0.835$), HypoN ($\kappa = 0.781$), ANE ($\kappa = 0.92$), and NOE ($\kappa = 0.84$).

The Wilcoxon signed-rank test revealed significant postoperative improvements in HN ($P < 0.001$, $r = 0.65$), ANE ($P = 0.001$, $r = 0.33$), and NOE ($P < 0.001$, $r = 0.43$), while no significant change was observed for HypoN ($P = 0.603$).

Table 1. Patient demographics and cleft type distribution

Category	Value
Number of patients	94
Male	43% (n=40)
Female	57% (n=54)
Median age at surgery (y)	7 (range: 3–38)
Median follow-up period (m)	15 (range: 6–72)
Cleft Type	%
Bilateral cleft lip and palate	19
Unilateral cleft lip and palate	32
Cleft palate only	29.8
Soft palate cleft	12.8
Submucousal cleft palate	6.4

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Table 2 demonstrates that postoperative outcomes were not dichotomous but distributed along a clinical continuum. While 55.8% of patients exhibited a reduction in HN severity compared with preoperative levels, this improvement did not uniformly translate into surgical sufficiency. Specifically, 38.3% of patients reached a level of nasality deemed clinically acceptable, obviating the need for further surgical intervention. In contrast, 61.7% of patients continued to demonstrate residual HN of sufficient severity to warrant consideration of additional surgical management. Additionally, 50% of the patients achieved normalized ANE scores.

Fistula rate

Fistula rate decreased significantly from 21.2% (n=20) preoperatively to 7.4% (n=7) postoperatively ($P=0.002$, [95% CI, 0.07%, 0.52%]), indicating improved structural outcomes.

Velopharyngeal closure ratio

Among 53 patients with pre- and postoperative video-fluoroscopy, mean VPCR increased from 0.48 ± 0.28 to 0.70 ± 0.27 ($P<0.001$, $r=0.07$). Complete VP closure was achieved in 13 patients. The Shapiro-Wilk test indicated that the data were normally distributed ($P>0.05$).

The total sample size was divided into two independent groups: Those with VPCR data and those without VPCR data (n=41). A Mann-Whitney U test demonstrated no

statistically significant difference in HN between the two groups ($U=950.0$, $P=0.37$).

Predictor factors

Ordinal logistic regression was employed to examine the predictors of postoperative HN. The analysis utilized the Logit link function. The test of parallel lines indicated that the proportional odds assumption was satisfied ($\chi^2(15)=13.65$, $P=0.55$).

The model significantly improved prediction of the outcome compared to the intercept-only model ($\chi^2(5)=24.88$, $P<0.001$). The goodness-of-fit test indicated that the model provided an adequate fit to the data, as the deviance statistic was not significant (deviance=121.8, $df=191$, $P=1.00$).

These results highlight the significance of preoperative NOE, age at surgery, and postoperative VP closure ratio in predicting postoperative outcomes, while follow-up time does not appear to be a significant factor.

According to **Table 3**, a significant negative association was observed between preoperative NOE and the outcome. Higher preoperative NOE values were linked to a reduced likelihood of a favorable postoperative outcome. Additionally, age at the time of surgery was positively associated with the outcome.

Table 2. Speech characteristics and fistula rate pre- and postoperative

Speech Characteristic	Rating	No. (%)		P
		Preoperative	Postoperative	
HN	No need for further surgery (score 0, 1, 2)	-	36(38.3)	<0.001
	Requiring surgery (score 3)	13(13.9)	58(61.7)	
	(score 4)	8(86.1)		
	Improved* (Reduction from preoperative)	-	55(55.8)	
ANE	Normal (score 0)	29(30.9)	47(50)	0.001
	Improved	-	53(56.4)	
NOE	Normal (score 0)	26(27.7)	40(42.6)	<0.001
	Affected (score 1, 2)	68(72.3)	54(57.4)	
	Improved	-	55(55.8)	
HypoN	Absent (score 0)	66(70.2)	62(66)	0.603
	Mild (score 1)	25(26.6)	30(31.9)	
	Marked (score 2)	3(3.2)	2(2.1)	
Fistula rate	Present (score 1)	20(21.2)	7(7.4)	0.002

*P<0.05.

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Note: HN: hypernasality (absent=0, borderline=1, mild=2, moderate=3, severe=4); ANE: Audible nasal emission (absent=0, in <2 consonants=1, in ≥2 consonants); NOE: Non-oral errors (absent=0, in <2 consonants=1, in ≥2 consonants); HypoN: Hyponasality (absent=0, hyponasaled=1, denasaled=2).

The postoperative VP closure ratio was also negatively associated with the outcome, suggesting that better post-operative VP closure is associated with a higher probability of a favorable outcome (95% CI, 0.15%, 0.95%).

Follow-up time, however, did not significantly predict the outcomes. The odds ratio (OR) of 1.00 further supports the absence of a relationship between follow-up duration and the outcome.

Discussion

This study evaluated the outcomes of radical IVVP in a relatively large cohort of non-syndromic cleft palate patients. Significant improvements were observed in HN, ANE, and NOEs, along with a substantial reduction in fistula rate and a statistically significant increase in the VPCR. However, a notable proportion of patients continued to demonstrate residual HN or required additional surgical intervention, underscoring the complexity of speech management in cleft palate populations.

Table 3. The parameter estimates (location coefficients) for the predictors

Predictors	Estimate (β)	P	OR
NOE (preop)	-1.59	0.02	0.2
Age at surgery	0.08	0.04	1.08
VPCR (postop)	-1.02	0.05	0.36
Follow-up time	0	0.99	1

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The patient cohort's demographic characteristics, including a mix of cleft types and a median age of seven years at the time of surgery, reflect the heterogeneity often encountered in cleft palate populations. This variability underscores the importance of considering specific anatomical and physiological factors when interpreting the outcomes of secondary surgical interventions.

Speech results

High inter-rater reliability for the perceptual parameters validated the robustness of the rating procedures.

Hypernasality, audible nasal emission, and non-oral errors

Postoperative reductions in HN, ANE, and NOEs confirm that radical IVVP effectively improves VP function in a significant number of patients. Nevertheless, 61.7% of patients still met criteria indicating the need for further surgery, a figure that is higher than those reported in other published studies on palatal re-repair [6, 9]. This discrepancy may be attributed to multiple interacting factors.

1) Patient characteristics and sample composition: Age at the time of surgery is a crucial predictor of outcomes [15-17]. Patients who achieved normal or mild HN underwent surgery at a younger age (mean, 5.7 years) compared to those with persistent severe HN (mean, 15 years). Likewise, patients without postoperative ANE had a lower mean age at surgery. The observed associations highlight the importance of early intervention and the burden of entrenched compensatory errors in older patients.

2) Quality of primary surgeries and case complexity: Studies suggest better outcomes when both primary and secondary surgeries are performed by the same surgeon, particularly when IVVP is used for the primary repair [6, 18, 19]. In this study, many patients had previously undergone one or more suboptimal primary palatoplasties, often outside a multidisciplinary team setting. These "salvage" cases involved extensive scarring or distorted muscle anatomy, complicating re-repair. Rezaei et al. confirmed that many patients in Iran still lack access to interdisciplinary care during early childhood, which can impact subsequent treatment outcomes [20]. Limited surgical records further complicated the evaluation of these cases, and inconsistent primary-surgery quality likely contributed to the lower success rate observed.

3) Surgeon experience and variability: All procedures were performed by four surgeons with 4-7 years' experience. This contrasts with earlier studies where a single highly experienced surgeon conducted all surgeries [6, 9], which may explain variability in outcomes.

4) Differences in speech scoring systems: In prior studies such as that by Elsherbiny et al., the use of broader scoring systems, such as the Pittsburgh weighted speech score—which includes articulation as well as resonance [6]—may have yielded higher apparent success rates. In contrast, our study used CAPS-A and categorized patients strictly based on resonance and emission outcomes, which may present a more conservative estimate of success. These findings underscore the complexity of evaluating surgical outcomes in VPI and emphasize the multifactorial influences—including age, preoperative speech status, and surgical history—on perceptual speech improvements.

Hyponasality

No significant changes in HypoN were observed post-operatively ($P=0.603$), which is consistent with the anatomical selectivity of IVVP. Unlike procedures such as pharyngeal flaps or sphincter pharyngoplasties, IVVP avoids altering pharyngeal wall structures, preserving airway patency and reducing the risk of complications, such as obstructive sleep apnea [9]. These findings affirm the relative safety of radical IVVP, particularly in patients at higher risk for airway compromise.

Role of NOEs in predicting postoperative hypernasality

The regression results demonstrated that preoperative NOEs affect residual HN. In other words, speech motor control and articulation patterns play a critical role in determining surgical outcomes. This aligns with studies indicating that NOEs are more than compensatory—they reflect neuromotor or phonological processing challenges that persist even when anatomical closure is restored [21, 22].

Furthermore, NOEs often reflect entrenched compensatory speech habits developed in response to VPI. Even after surgical correction, these patterns may persist unless addressed through targeted speech therapy. Studies suggest that preoperative therapy can reduce compensatory errors and improve postoperative outcomes [23]. Moreover, the severity of NOEs may indicate more severe or long-standing VPI, potentially requiring more complex interventions and yielding lower success

rates. Early intervention is therefore critical to prevent entrenched patterns. Future research should explore the impact of combined surgical and therapeutic strategies—especially pre-surgical therapy and neurological factors influencing compensatory articulation—to improve long-term outcomes [24-26].

Age at surgery and postoperative hypernasality

Our findings highlight age as a significant predictor of postoperative speech outcomes. An OR of 1.08 suggests that increasing age is associated with a higher likelihood of more severe postoperative HN. Consistent with this, older patients demonstrated higher rates of HN and ANE. As speech and language patterns solidify with age, the window for optimal surgical impact narrows. Several factors may underlie this association. As children grow older, their speech and language systems become more firmly established. With VP dysfunction, this may reinforce maladaptive articulatory patterns that can persist even after surgical correction. Hence, prolonged exposure to VPI-related deficits before surgical intervention may result in more entrenched speech errors, leading to more severe residual HN postoperatively [15, 16, 27]. Additionally, the findings suggest that IVVP is particularly effective for eliminating VPI in children compared to adults [12]. This emphasizes the importance of early detection and timely surgical referral. Unfortunately, due to referral patterns in Iran, many patients undergo initial surgery in non-specialized centers and present to cleft teams later in childhood, after speech issues have become ingrained.

Lack of detailed surgical records also limited our ability to assess the timing and quality of prior surgeries.

Fistula rate

Our study showed a significant decrease in the fistula rate from 21.2% preoperatively to 7.4% postoperatively ($P=0.002$), demonstrating the technical reliability of IVVP in providing robust closure. These rates compare favorably with previous studies [28, 29]. However, fistula recurrence in a small subset of patients suggests the need for careful patient selection and further refinement of surgical technique in complex cases. Notably, many of our patients had undergone multiple surgeries before referral, likely contributing to a challenging tissue environment.

Velopharyngeal closure ratio and hypernasality

Although the mean VPCR increased from 0.48 to 0.7 postoperatively and complete closure was achieved in 13 patients, the VPCR and HN results should be interpreted

with caution. VPCR demonstrated an inverse association with postoperative HN, suggesting that improved VP closure is linked to reduced HN severity. While the statistical significance was borderline, the observed effect size supports the clinical relevance of VPCR as a potential predictor of speech outcomes. This implies that structural improvement alone does not guarantee perceptual normalization, supporting the view that speech outcomes are multifactorial [24].

Mangal et al. reported a moderately strong negative correlation between the grade of VP port and HN. These results suggest that more severe VPI leads to higher HN, reinforcing the importance of both perceptual and objective assessments in evaluating the impact of VPI on speech [30]. While the systematic review highlights limited and inconsistent evidence concerning the direct association between VP gap size and perceptual nasality, it also underscores the paucity of robust and methodologically rigorous literature addressing the correlation between instrumental findings and clinical speech outcomes [31].

In addition to VPCR, variables such as lateral pharyngeal wall motion, tongue position, oral cavity size, and individual neuromotor control may all affect speech resonance [24, 32, 33]. The mismatch between instrumental and perceptual findings in some cases further underscores the need for combined assessment strategies that go beyond imaging.

Single-view lateral videofluoroscopy is widely used in cleft-related outcome studies to quantify anterior-posterior velar movement and calculate the VPCR. This view provides a reproducible estimate of the relationship between the velum and the posterior pharyngeal wall. However, it does not allow for direct visualization of lateral pharyngeal wall contribution or patterns of complete peripheral closure. In our study, VPCR was measured during sustained /i/ phonation because this vowel consistently elicits maximal and stable velar elevation in a controlled, sustained context, allowing standardized frame selection and measurement reliability [9, 34]. While pressure consonants may better reflect functional speech symptoms of VPI, their dynamic and transient nature makes them less suitable for reproducible radiographic quantification in retrospective image analysis, although VPCR derived from sustained phonation may not fully generalize to connected speech or high-pressure consonant contexts [34, 35].

Follow-up time and severity of hypernasality and audible nasal emission

Follow-up time did not significantly predict speech improvement, echoing the conclusion that early, targeted intervention plays a greater role than follow-up duration alone. Structured, high-quality therapy tailored to the patient's unique deficits—rather than passive follow-up—is likely to yield better functional outcomes. This finding calls into question protocols that delay postoperative intervention in favor of “wait-and-see” approaches. Although adequate follow-up is essential to confirm the stability of postoperative speech outcomes, our findings suggest that the severity of HN is primarily determined by factors present at the time of intervention, such as age at surgery, preoperative speech characteristics, and postoperative VP closure. Prolonged follow-up alone does not appear to further modify these outcomes.

Limitations

The retrospective nature of the study, variability in prior surgeries, the absence of standardized therapy protocols, and the lack of objective tools such as nasometry or nasendoscopy reduce the generalizability and reliability of the results. Furthermore, many patients had incomplete surgical histories due to referrals from external centers, which may introduce bias and reduce data completeness. These factors limit the external validity of the findings and suggest the need for more controlled studies in the future.

Recommendation

To address these limitations, future research should focus on prospective study designs with standardized speech therapy protocols to ensure consistency in treatment. A multi-modal approach to VP assessment, incorporating objective tools such as nasendoscopy and nasometry in addition to VP closure ratio, would provide more accurate and quantifiable data, leading to a better understanding of treatment outcomes. Furthermore, model-based predictors could enhance patient selection and stratification for radical IVVP, improving the overall efficacy of the intervention. Replicating this study with a larger sample size would also increase statistical power, improve generalizability, and provide more robust evidence for the observed findings.

Conclusion

This study supports the effectiveness of IVVP in improving speech outcomes in patients with VPI, although

many patients still needed additional surgery to improve speech, especially HN. Significant reductions in HN, ANE, and NOEs were observed postoperatively in a large sample of non-syndromic cleft palate patients. Age at surgery and preoperative articulation patterns were key determinants of postoperative speech improvement, while changes in VP closure should be interpreted alongside perceptual assessments. These findings underscore the need for early intervention, individualized speech therapy, and perceptual assessments as essential components of comprehensive cleft care following secondary surgery.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of [Isfahan University of Medical Sciences](#), Isfahan, Iran (Code: IR.MUI.MED.REC.1395.815).

Funding

The paper was extracted from the master's thesis of Mehri Tavakoli, approved by the Department of Speech Therapy, Faculty of Rehabilitation Sciences, [Isfahan University of Medical Sciences](#), Isfahan, Iran.

Authors' contributions

Software: Mehri Tavakoli and Fatemeh Derakhshandeh, Parisa Rezaei; Formal analysis: Mehri Tavakoli, Fatemeh Derakhshandeh and Parisa Rezaei; Data curation: Mehri Tavakoli, Fatemeh Derakhshandeh, Parisa Rezaei, Hossein Abdali; Supervision: Fatemeh Derakhshandeh, Parisa Rezaei; Project administration: Fatemeh Derakhshandeh; Conceptualization, methodology, resources, validation, visualization, investigation and writing,: All authors.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors thank all patients for participating in this study.

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