



# A Master Mind Game Code Algorithm Approach to Help Surgical Decision-Making between Retropharyngeal Fat Grafting and Pharyngoplasty for the Treatment of Velopharyngeal Incompetence

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## Abstract

**Introduction** Velopharyngeal insufficiency (VPI) is a controversial pathology with many surgical options.

**Objective** To compare pharyngoplasty and retropharyngeal fat grafting and to build a prognostic tool to achieve perfect speech.

**Methods** Retrospective observational cohort study of 114 patients operated for VPI from 1982 to 2019 in a single tertiary center. The instrumental assessment was made using an aerophonoscope and nasofibroscope. The variables sex, age, genetic syndromes, and type of diagnosis were analyzed with logistic regression model adjusted with propensity score. To generalize results and to build a surgical predictive tool, a marginal analysis concludes the study.

**Results** Among the patients (median [range] age 7 [4–48]), 63 (55.26%) underwent pharyngoplasty and 51 (44.74%) graft. The graft group had no complication, but it had a failure rate of 7.84%. The pharyngoplasty group had no failure, but one patient had postoperative obstructive sleep apnea. The marginal analysis demonstrated that age lower than 7 years, cleft lip and palate, absence of syndrome, and intermittent VPI were important predictive factors of good result regardless of surgical technique.

**Conclusions** Without a statistical demonstration of the superiority of pharyngoplasty over graft, and in the uncertainty of literature background, our perfect-speech patient profile represents an important tool for a postoperative forecast of results in which, like in the Master Mind game, every feature has to be considered not individually but as a pattern of characteristics whose association contributes to the outcome.

## Keywords

- ▶ inadequate velopharyngeal closure
- ▶ clinical decision-making
- ▶ transplantation
- ▶ autologous
- ▶ pharyngeal pedicled flap
- ▶ speech intelligibility
- ▶ predictive medicine

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## Introduction

Velopharyngeal insufficiency (VPI) is a very controversial pathology in terms of definition, diagnosis, and management. Some authors define velopharyngeal dysfunction as the inability to completely close velopharyngeal port during speech, with a subclassification into velopharyngeal insufficiency, for anatomic impairments; velopharyngeal incompetence, for neuromuscular dysfunctions; and velopharyngeal mislearning, for maladaptive articulation patterns,<sup>1</sup> which helps clarify any possible ambiguity of the acronym VPI by giving the “I” etiologic specificity.<sup>2–5</sup> Other authors<sup>6</sup> prefer to use the term *insufficiency*, regardless of the etiology due to the inability of clinical tools to definitely determine the origin of the defect.

There is no consensus in the literature regarding the severity scale of VPI. All French authors accept the Borel-Maisonny (BM) classification for speech assessment of VPI,<sup>7</sup> translated and compared with other international scales.<sup>8</sup> For other languages’ speakers, many classifications of speech assessment exist: the Scandleft protocol,<sup>9</sup> the cleft audit protocol for speech-augmented (CAPS-A),<sup>10</sup> the Pittsburgh-weighted speech score (PWSS),<sup>11</sup> the SVANTE-N,<sup>12</sup> and the velopharyngeal composite score summary.<sup>13</sup> The majority of studies in the literature report perceptual speech assessment using a nonvalidated, in-house scale.<sup>14</sup>

The diagnosis of VPI must be multidisciplinary: speech and instrumental assessment must be combined. Regarding instrumental assessment, every institution chose between a combination of nasoendoscopy (NE) alone, multiplanar videofluoroscopy (MPVF) alone or a combination of the two. Dynamic magnetic resonance imaging (MRI) is not yet widespread in clinical practice. For this reason, the Golding-Kushner scale, developed in 1990 by an international study group, despite the demonstrated intra and interrater reliability,<sup>15</sup> cannot always be applied because of the lack of uniformity in the instrumental assessment. A systematic review of the literature to resolve discrepancies in clinical practice between speech nasality and instrumental velopharyngeal closure size did not find correspondence in auditory-perceptual assessment and instrumental findings.<sup>16</sup>

Everyone agrees that it is important to include speech therapy in the multidisciplinary management of VPI when a surgical treatment is needed.

The surgical treatment of VPI is classified in palatal procedure (intravelar veloplasty,<sup>17</sup> Furlow Z-plasty,<sup>18</sup> push-back procedures<sup>19–22</sup>), pharyngoplasty procedures (pharyngeal flap pharyngoplasty,<sup>23</sup> and dynamic sphincter pharyngoplasty<sup>24</sup>), and posterior pharyngeal wall augmentation (with various materials<sup>25</sup>), but no surgery has been shown to be superior to others in terms of efficacy and safety.

The definition of treatment success and the outcome measurement vary widely in the literature. Some authors define resolution of VPI as postoperative normal speech, others are satisfied with a postoperative improvement of VPI.<sup>26,27</sup> Other authors use the need of revision as the primary poor outcome.<sup>28,29</sup> Other defines success as the elimination of the symptomatic manifestations of the VPI

and the maintenance of a sufficient nasal airway for quiet breathing with lips closed and secretion drainage.<sup>2</sup>

In this background, our primary purpose is to compare the efficacy of pharyngoplasty and retropharyngeal autologous fat grafting (AFG) in reducing the Borel-Maisonny (MB) level. Another objective of the study is to identify the characteristics of patients with a perfect speech pattern following surgery.

## Materials and Methods

### Patients: Inclusion Criteria

A retrospective observational cohort study was performed on 244 consecutive patients who underwent velopharyngeal surgery for the treatment of VPI between 1982 and 2019. One hundred thirty patients were excluded from the study because their medical records and/or their postoperative follow-up (12 months) were incomplete. We included 114 patients who underwent speech surgery of all ages and genders. We included all etiologies (cleft palate, cleft lip and palate, submucous cleft palate, and isolated IVP).

All patients were French locutors.

The ethic committee of the university hospital has approved this study (reference number: 2018\_IRB\_MTP\_04-06).

### Preoperative Evaluations

Patients with velopharyngeal dysfunction initially have their speech assessed by a speech therapist and a pediatric plastic surgeon using standardized perceptual speech assessment<sup>9</sup> and an instrumental assessment to reduce the interjudgement subjective variability with the aerophonoscope SARK-ORQUAL GROUP, 2C and RD model. (PAU CEDEX 9-FRANCE). The patients were classified according to the BM score<sup>7</sup> (see ►Table 1) before (BMpre) and after surgical treatment (BMpost). Other variables collected were the diagnosis of VPI, the presence of syndromes or genetic alteration, and complications.

The preoperative protocol assessment includes nasoendoscopy (NE) with a Storz End Tricam SLPAL 2022020 device (Karl Storz SE & Co. KG, Tuttlingen, Germany) performed in the outpatient department under local anesthesia. With a standardized speech performance evaluation of all French phonetic repertoire, we performed an in vivo observation of the velopharyngeal functional anatomy, according with the standardized classification of the International Working Group<sup>30</sup>: degree and localization of the velopharyngeal gap, muscular compensatory mechanisms of the pharyngeal wall, and posterior pharyngeal wall pulsations to discard a megadolichocrotid or an aberrant course of vertebral artery (►Fig. 1). All patients received a preoperative ear, nose, and throat (ENT) assessment to study the ear function and adenoid pad involution state, and, if still present, a prophylactic adenoidectomy was performed at least 6 months before speech surgery for complete wound healing before the pharyngeal procedure. Preoperative adenoidectomy facilitates visualization and dissection of the pedicle, and this also allows for better visualization of the quantity and volume of the flap. A preoperative risk assessment of

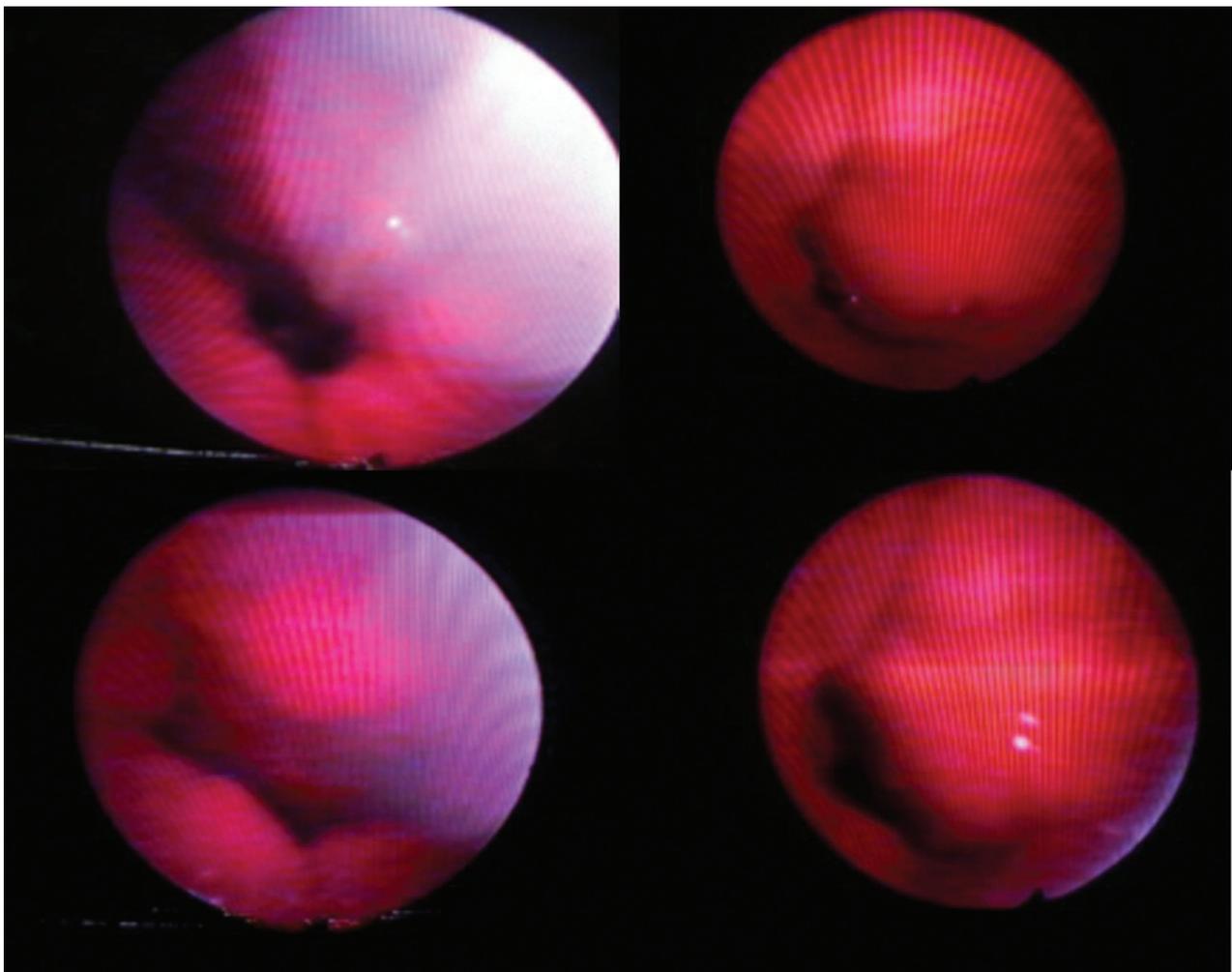
**Table 1** Borel-Maisonnay score

Grade	Clinical speech pattern
1	Normal phonation without any nasal leak
1-2	Normal phonation with intermittent nasal air leak, excellent intelligibility
2B	Phonation with continuous nasal air leak, but good intelligibility
2M	Phonation with continuous nasal air leak and poor intelligibility
3	Important air leak. Continuous compensatory articulation and glottic efforts (nasal grimace, glottal stops or phonemes substitutions). Bad intelligibility

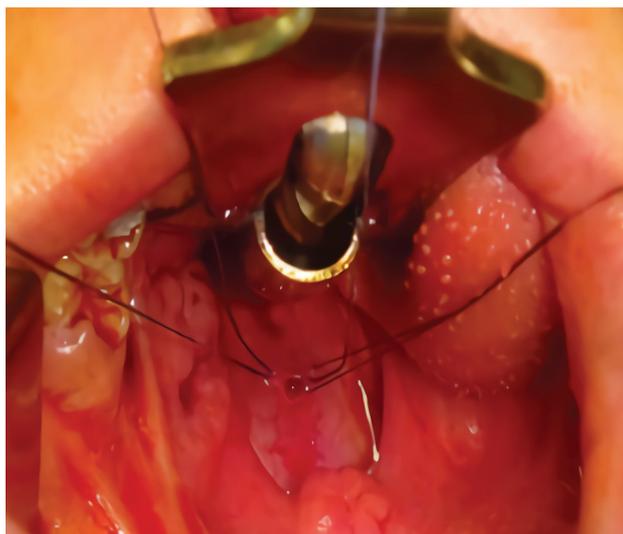
obstructive sleep apnea (OSA) is planned by another service of our hospital with the French version Spruyt and Gozal questionnaire and, if necessary, a polysomnographic study was performed.<sup>31</sup> In all patients with syndromic pattern, an MR scan was performed preoperatively to study the presence of aberrant branches of the internal carotid artery that could be a relative surgical contraindication.<sup>32</sup>

### Surgical Procedure

Autologous fat grafting, introduced in our institution in 2006, is indicated for patients with a small pharyngeal gap (defined as a gap of less than half of the maximum space present during nasal breathing in fibroscopic images) and good velar or lateral wall mobility. The endoscopic findings guide the injection's site and the amount of fat tissue required (► **Fig. 2** and ► **Fig. 3**). Patients with a large gap (defined as a gap of equal to or greater than half of the maximum space present during nasal breathing in fibroscopic images), hypotonic velar and pharyngeal movement, or a BM score of 3, on the other hand, were not considered eligible for AFG, and a pharyngoplasty with more or less wide centralized superior flaps, described by San Venero Roselli, was scheduled instead because of the presence of compensatory mechanisms (nasal grimace, glottal stops, or phonemes substitutions) that prevent speech rehabilitation. A palatal procedure has been associated in a small percentage of patients for velar lengthening or fistula repair. A single senior surgeon, in all cases, performed the AFG procedure. The pharyngoplasty procedure was performed by two senior surgeons of the same team. In the case of AFG, fat tissue from the umbilical or trochanteric area was harvested and prepared according to



**Fig. 1** Fibroscopic views. Upper left: view of a short palate at rest. Lower left: short and dysraphic palate during phonation. Upper right: normal palate at rest. Lower right: normal palate during phonation.



**Fig. 2** Intraoperative image of fat graft: preparation of the infiltration site.



**Fig. 3** Intraoperative image of fat graft: gentle infiltration.

the Coleman technique,<sup>33</sup> and infiltrated only into the retropharyngeal wall according with the Bardot<sup>34</sup> description and Bishop “state of the art”<sup>35</sup>. A gentle palpation of the retropharyngeal wall, to detect aberrant branches of the internal

carotid artery, prevents middle cerebral artery infarction or embolism. The postoperative protocol included 7 days of antimicrobial treatment with amoxicillin. Discharge from the hospital was scheduled the day after the intervention.

More invasive procedures include superior pharyngeal flap with the technique described by Padgett and Sanvenero-Rosselli,<sup>36</sup> and dynamic sphincteroplasty, described by Orticochea.<sup>24</sup> All patients received an intensive observation for the first postoperative day. The discharge from the hospital was scheduled for 1 week after the surgery. During the hospitalization, mixed diet and antibiotic prophylaxis with amoxicillin is prescribed.

### Postoperative Evaluation

Early return to the speech therapist is very important for the success of these functional surgeries that provide proprioceptive help for the functional approximation of the velopharyngeal sphincter structures. In case of more invasive procedure, it is necessary to wait a recovery time of a month. In the case of AFG, recovery is faster, and speech rehabilitation must start strictly in the first week after the operation. The first postoperative speech evaluation with the same perceptual and instrumental assessment with aerophonescope to classify patients according with BM classification is scheduled in an outpatient department the first week after discharge, in absence of surgical complications (infections or pain) for all patients. Subsequent clinical checks are foreseen at 1, 3, 6, 12 months postoperative; thereafter an annual follow up visit was recommended. We consider a stable result at 12 months postoperatively as demonstrated by Denadai<sup>37</sup> and another of our paper with a long follow-up.<sup>38</sup>

Only if the speech result was insufficient, a postoperative NE is repeated, but not before six months from surgery.

### Statistical Analysis

#### Descriptive Statistics

Two efficacy endpoints were considered: the change in BM between post and pretreatment and perfect speech after surgery (BM<sub>post</sub> = 1). The distributions of variables were investigated using the Shapiro-Wilk test. The Chi-squared and the Wilcoxon-Mann Whitney tests were used, respectively, for categorical and continuous variables. A multivariable regression model estimated the conditional efficacy of pharyngoplasty versus AFG: a multiple linear regression for BM change, and a multiple binomial logistic regression for perfect speech model. Model selection was performed using the Akaike information criterion.<sup>39</sup> The linear model correctness was assessed by analysis of linearity, heteroskedasticity, and normality of residuals. The perfect speech logistic model was assessed by Hosmer and Lemeshow goodness of fit,<sup>40</sup> specification test and standardized Pearson residual analysis. Finally, a propensity score assessed by stratifying the score in five quintiles in marginal efficacy estimates obtained by regressing the two outcomes, performed and checked as previously described in the perfect speech model, was used to obtain the best balancing of covariates in compared subjects. The predicted average BM change and average

probability of perfect speech were also estimated for every combination of variables: genetics, diagnosis, BMpre, and age (< 7 years vs  $\geq$  7 years). Seven years was used as cutoff because this is a cutoff crucial age to achieve a good result, as we demonstrated in another paper.<sup>38</sup> The significance level used in the analysis was 5%. The objectives of the study were strictly exploratory; no formal statistical power analysis was performed. No missing data were observed. Analyses were conducted using the statistical package STATA version 16.0 (StataCorp LLC, College Station, TX, USA).

## Results

We collected data on 114 patients aged from 4 to 48 years, 63 (55.26%) of whom underwent pharyngoplasty and 51 (44.74%) underwent AFG (►Table 2). The baseline BM value was significantly higher than in the pharyngoplasty group ( $p < 0.001$ ). The age of patients undergoing AFG was significantly higher than that of patients treated with

pharyngoplasty, both when age was considered continuous ( $p < 0.001$ ) and categorical ( $p < 0.001$ ). The mean follow-up was 19.5 years.

In the AFG group, 11 patients underwent a myoplasty or Z-plasty during speech surgery, and 4 underwent fistula repair. In the pharyngoplasty group, there were 10 myoplasties or Z-plasties, and 6 fistula repairs was performed. In the AFG group, we had no pharyngeal or general complications (pain, hematoma, infection, scar from the fat-collecting site, bleeding, embolism, migration of the graft) according to the Clavien–Dindo classification.<sup>41</sup> In the pharyngoplasty group, only one patient had a diagnosis of postoperative OSA. This patient had a preoperative BM score of 2m, a diagnosis of CP (Cleft Palate), without a syndromic pattern, and a postoperative BM score of 2b. We had a failure rate of 7.8%, relative to 4 cases. A further Sanvenero–Rosselli pharyngoplasty postgraft was performed because of an unsatisfactory speech result (2 of the 34 patients with a preoperative score of 2b and 2 of the 7 patients with a preoperative score of 2m). An average of

**Table 2** Characteristics of patients by treatment (pharyngoplasty versus AFG). a) . In the AFG group, we can find 3 22q11, 9 Pierre Robin sequences, 1 Stickler syndrome, 1  $\alpha$  glucosidase deficiency and muscular dystrophy, 1 Van der Woude syndrome, 1 cerebrocosto-mandibular syndrome, and 1 oculo-auriculo-temporal syndrome. The genetic pattern of pharyngoplasty patients was: 7 22q11, 4 Pierre Robin sequences, 1 Pierre Robin and syringomiel scoliosis, 1 chromosome 13 abnormality, 1 47-trisomy XXX, 1 49-trisomy XXXY, 1 foetal alcoholism, 1 Moebius syndrome, and 1 Jacobsen syndrome

		Pharyngoplasty (n = 63)		AFG (n = 51)		p*
		N	%	N	%	
Sex	Female	36	57.14	26	50.98	0.511
	Male	27	42.86	25	49.02	
Diagnostic of genetic impairments or syndrome <sup>a</sup>	No	45	71.43	34	66.67	0.584
	Yes	18	28.17	17	33.33	
Diagnosis	CLP	30	47.62	21	41.18	0.137
	CP	22	34.92	26	50.98	
	iIVP	11	17.46	4	7.84	
Age category	<7 years	46	73.02	19	37.25	< 0.001
	$\geq$ 7 years	17	26.98	32	62.75	
BM-pre	1–2	2	3.17	10	19.61	< 0.001
	2b	22	34.92	34	66.67	
	2m	11	17.46	7	13.73	
	3	28	44.44	0	/	
BM-post	1	37	58.73	27	52.94	0.233
	1–2	17	26.98	17	33.33	
	2b	8	12.70	4	7.84	
	2m	0	/	3	5.88	
	3	1	1.59	0	/	
Complete recovery (BM-post = 1)	Yes	37	58.73	27	52.94	0.536
	No	26	41.27	24	47.06	

Abbreviations: AFG, autologous fat grafting; BMpre, Borel-Maisonny score before the procedure; CI, confidence interval; CLP; CP, Cleft Palate; iIVP, isolated velopharyngeal insufficiency; OR, odds ratio.

\*assessed by Pearson chi-squared test.

1.23 interventions per patient were performed (63 fat injections in 51 patients). The reinjection was performed once in 40 patients, twice in 7 patients, and three times in 2 patients.

### Propensity Score

Based on the Akaike information criterion, the best logistic model predicting the treatment group contained the variables sex, age, genetics, baseline BM, and the interaction term between age and genetics. The Hosmer and Lemeshow test showed a satisfactory goodness of fit ( $p = 0.88$ ), while the Pearson standardized residual analysis showed absence of outliers. Finally, the specification link test confirmed the right variables selection (linear predicted value:  $p = 0.002$ ; squared predicted value:  $p = 0.809$ ). The propensity score value was stratified into quintiles, and none of the strata contained empty cells in terms of treated patients. The standardized difference of means within strata was lower than 0.1 in the case of age, and Chi-squared tests did not highlight any significant differences concerning the categorical covariates. A graph showing the treatment-specific propensity scores overlapping is reported in **Fig. 4**.

### BM Change from Baseline

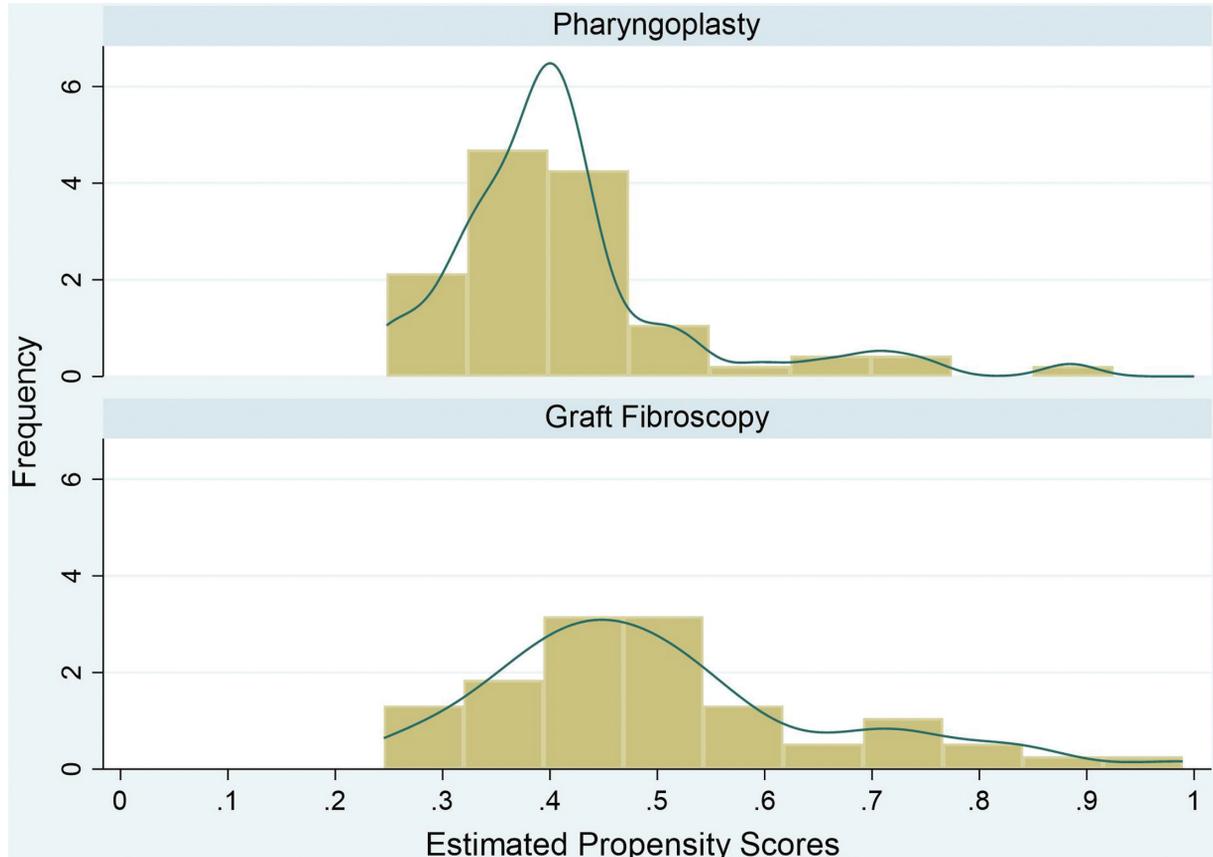
The median decrease in BM in the pharyngoplasty group was -2 (IQR: -4, -1) while in the graft group it was -1 (interquartile range [IQR]: -2, -1). The unadjusted difference between pharyngoplasty and graft was -1.17 points (95% confidence

interval [CI]: -1.58, -0.76) when estimated by naïve simple linear regression. After adjustment by the best subset of covariates, the difference was -0.20 (95% CI: -0.58, 0.19). Interestingly, the multivariable model suggested a possible interaction between age and baseline BM. In fact, at increasing age, in patients with worst baseline BM (BM = 3), a poorer change is observed when compared with baseline BM of 2m, 2b, or 1-2 (**Table 3**).

When the variables were merged into a propensity score to remove the unbalance, the marginal effects of pharyngoplasty and graft were -1.48 (95% CI: -1.78, -1.18) and -1.39 (95% CI: -1.64, -1.15), respectively (average difference -0.09; 95% CI: -0.50, -0.33).

### Complete Recovery after Surgery

Thirty-seven (58.73%) and 27 (52.94%) patients underwent perfect speech (BM<sub>post</sub> = 1) after pharyngoplasty and AFG, respectively. The unadjusted difference in proportions did not reach statistical significance ( $p = 0.55$ ). The logistic multivariate model, including baseline BM, age category (above or under 7 years), diagnosis, and presence of genetic disorders, provides a non-statistically significant difference in efficacy between the two surgical techniques (odds ratio [OR]: 1.28; 95% CI: 0.49, 3.36). Similarly, when the effect is marginally estimated through propensity score, the possibility of perfect speech of patients treated with pharyngoplasty is not significantly higher than that of those treated



**Fig. 4** Frequency distribution of propensity scores between the two considered treatments. The overlap of the distributions of patient characteristics was verified for each score quintile.

**Table 3** Delta BM (post-pre) adjusted estimate of pharyngoplasty versus graft and possible predictors assessed by multiple linear regression. Adjusted squared-R: 0.57.  $N = 114$ . Reference categories: graft, female, BMpre = 3, BMpre = 3 × age, CLP

Outcome: bmpost-bmpre	Coeff	p	95% CI	
Pharyngoplasty	-0.20	0.31	-0.58	0.19
Male	0.18	0.29	-0.15	0.50
Age	0.16	0.01	0.04	0.29
BMpre = 1–2	3.56	0.00	2.31	4.82
BMpre = 2b	3.02	0.00	2.07	3.98
BMpre = bm	3.14	0.00	1.30	4.98
BMpre = 1–2 × age	-0.18	0.02	-0.33	-0.03
BMpre = 2b × age	-0.17	0.01	-0.30	-0.04
BMpre = 2m × age	-0.32	0.04	-0.63	-0.01
CP	0.28	0.11	-0.06	0.62
iIVP	0.06	0.82	-0.45	0.57

Abbreviations: BMpre, Borel-Maisonny score before the procedure; CI, confidence interval; CP, Cleft Palate; iIVP, isolated velopharyngeal insufficiency; OR, odds ratio.

**Table 4** Assessed by multiple logistic regression. Pseudo squared-R: 0.08.  $N = 114$ . Reference categories: graft, BMpre = 3, no genetic disorders, < 6.5 years, CLP

Outcome: complete recovery	OR	p	95% CI	
Pharyngoplasty	1.33	0.56	0.50	3.51
BMpre = 1–2	7.20	0.06	0.90	57.90
BMpre = 2b	1.15	0.82	0.36	3.69
BMpre = 2m	0.78	0.70	0.21	2.86
> 6.5 years	0.55	0.20	0.22	1.38
Genetics	1.40	0.53	0.49	3.94
CP	0.37	0.06	0.14	1.03
iIVP	0.56	0.37	0.16	1.98

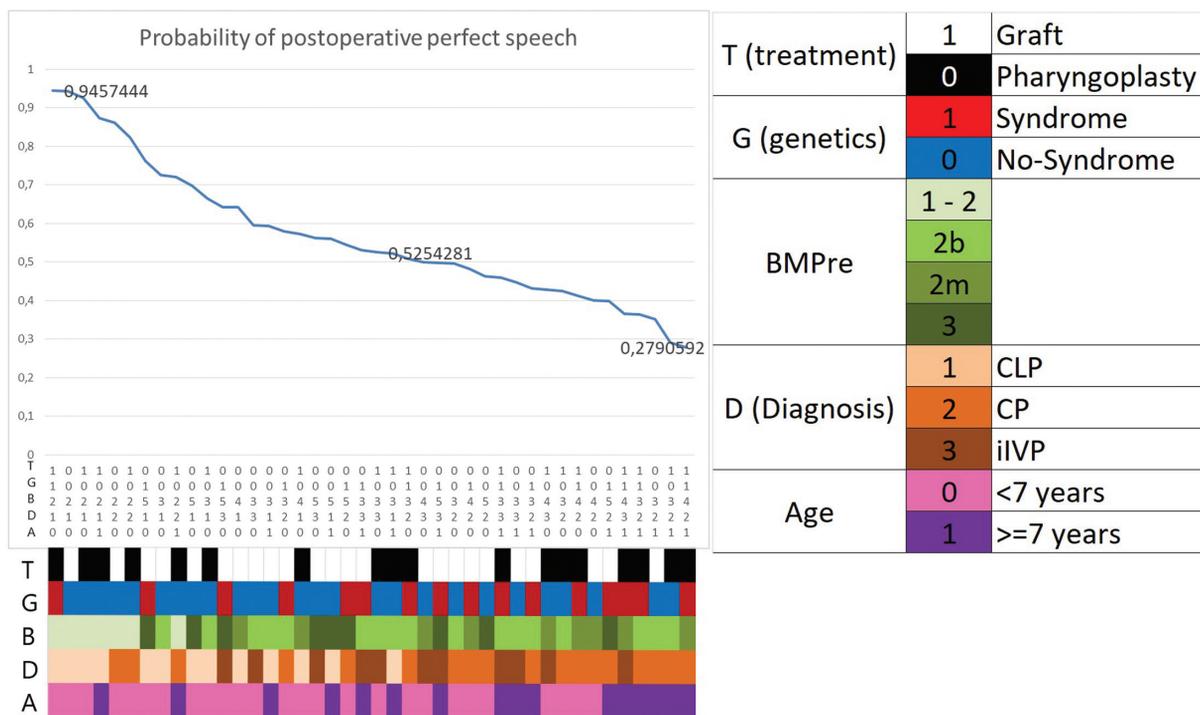
Abbreviations: BMpre, Borel-Maisonny score before the procedure; CI, confidence interval; CP, Cleft Palate; iIVP, isolated velopharyngeal insufficiency; OR, odds ratio.

with AFG (OR: 1.02; 95% CI: 0.38, 2.72). The average predicted probabilities of recovery considering patients' characteristics are reported in ►Table 4.

## Discussion

There is no consensus in the literature regarding the best treatment protocol for speech surgery, no procedure demonstrates superiority over others. A large review of outcomes in terms of speech, need of further surgery, and occurrence of OSA after VPI surgery,<sup>14</sup> on a total of 4,011 patients, concludes that randomized controlled trials are fraught with

difficulty. It could be because VPI is a rare complication. The wide pattern of etiologies involved in these pathologies, and the small number of patients do not allow a statistically effective randomization, with the ethical problem present in any randomization decision in pediatric age. In our study, we have not demonstrated superiority of any of the two surgical techniques evaluated. First, the higher median decrease of BM score postoperatively obtained by pharyngoplasty compared with AFG, without statistical significance, could be attributable to assignment of patients with more severe BMpre score to the more invasive therapeutic treatment. This is because the presence of compensatory mechanisms—like articulatory compensations, glottis sounds, and raucity—was considered a contraindication for AFG. Second, the observation that increasing age in patients with worst baseline BM determine poorer changes in BMpost, confirm that the presence of this compensatory mechanisms, prevent speech rehabilitation, because phoniatric rehabilitation is more effective until 7 years of age. Probably, after the 7th year, the compensatory mechanisms that parasitizing speech take on characteristics of irreversibility. The age of 7 years is confirmed as an important predictive factor of good result for grafting,<sup>38</sup> and now we confirm this result for the pharyngoplastic treatment too. In terms of failures or complication rate, AFG did not demonstrate complications, but it had a failure rate of 7.84%, resolved with a further pharyngoplasty with good results. On the other end, pharyngoplasty as a first-line treatment has not registered any failure, but we had a patient with a diagnosis of OSA. To obtain a prediction of outcomes that can be useful in surgical decision-making, many statistical tools can be employed. There are studies in the literature dedicated to predicting features associated with poor surgical outcomes. They have shown that age, severity of VPI, history of cleft palate, and syndromic association may affect outcomes, but without consistent results across studies.<sup>26,42,43</sup> Our study aims to predict features associated with a perfect speech result after surgical treatment of VPI. To achieve the probability of good outcome, from logistic regression of our dataset, we calculated the marginal analysis to obtain a generalization of the pattern of features necessary to achieve perfect postoperative speech. The decoding board we have obtained represents the association of clinical and therapeutic characteristics that the patient has to include to reach a complete recovery of VPI. The colors help to visualize the contribution of every feature to the probability of obtaining good results. Like in the Mastermind game, in which the codebreaker tries to guess the pattern, in both order and color, it is not the feature alone that individually contributes to that probability but the association between different characteristics. As we can see in ►Fig. 5, we can visually observe that there are features more frequently represented in the more favorable probability area: age younger than 7 years, lesser preoperative degree of severity of VPI, and the absence of genetic alterations. We can state that the association of younger age, the absence of genetic malformations and the lesser severity of preoperative VPI, are good prognostic factors to achieve a perfect result after surgery, despite the surgical technique



**Fig. 5** Perfect speech probability after surgery with marginal analysis. In this figure, we can appreciate the probability to achieve a perfect speech result after surgery on the basis of this variable: T) treatment: AFG in white and pharyngoplasty in black; G) genetics: genetic alteration or syndrome present in red, none in blue; B) BMPre: with a darker green tinge increasing depending on the preoperative VPI severity D) diagnosis: CLP in light orange, CP in orange, isolated IVP in dark orange. A) age: less than 7 years in pink, and more than 7 years in violet. As we can observe, on the left side of the figure we have the features associated with a high probability of better outcome, on the right side the feature with a less probability of postoperative perfect speech. For a probability of perfect speech of 94.5%, we need the following features: a patient with less than 7 years with a syndrome, a preoperative intermittent VPI, and a previous cleft lip and palate, operated with pharyngoplasty. For a probability of 27% we need a patient of more than 7 years, with a syndrome, a continuous nasal air leak without good intelligibility, a previous cleft palate, operated with a pharyngoplasty. We can observe a pattern distribution of variable along the probability trend: age less than 7 years, a previous diagnosis of cleft lip and palate, an intermittent VPI without syndrome seem to be correlated with a better outcome, despite the surgical technique chosen. Like in the Mastermind game, all features are to be considered simultaneously. It represents a prognostic tool of the personal profile of the patient to obtain a perfect speech result.

performed. Our study can help surgeon to expect perfect outcomes and better inform patients and families before the intervention, in a discipline in which a partial result is often the only possible result in a significant percentage of patients, despite of surgical technique. It is interesting that surgical technique is not an important feature to predict a perfect result. It seems that AFG and pharyngoplasty achieve the same results. Surgery for VPI, even if perfectly performed from a technical point of view, is not able to correct VPI if performed in a poorly selected patient, as it would increase upper respiratory tract complications.<sup>44</sup> This is why it is very important that these techniques are selected based on the individual features of the patients. Our study offers a predictive tool to personalize the treatment even if imaging findings cannot provide objective measurements.

Our study has many limitations. First, our casuistic considers only patients treated with AFG and pharyngoplasty, associated with palatal procedure in some cases. Palatine surgery was not considered among the variables, as it is an auxiliary and complementary surgical gesture of the speech driving surgery,<sup>45-48</sup> and we have shown in a previous work that this element does not change the results.<sup>38</sup> In the pharyngoplasty group, most of all received a superior pharyngeal flap de-

scribed by Sanvenero Rosselli, only four patients were operated with an orticochea sphincteroplasty and we did not consider these patients independently. Secondly, one of the most important decision tools is in vivo findings obtained with NE, but our NE data was too descriptive to be used in a computational model. Third, the screening for OSA has been performed by another service of the hospital with a simple clinical interview before polysomnography, without a validated instrument for the detection of OSA. Fourth, from the diagnostic point of view, we did not differentiate between cleft palate and cleft lip and palate, as we consider all genetic alterations as a same variable, but the range of syndromic manifestations is very heterogeneous; in particular, half of isolated VPIs were syndromic patients, with syndromes such as 22q11 microdeletion, with a predictable poorer prognosis, more OSA and need of further surgery.<sup>14,49-53</sup> From the speech assessment point of view, we did not analyze global intelligibility, nasality, and nasal air emission, but there are features not linear on which surgery has poor control,<sup>54</sup> and speech assessment is not blind as recommended by Sommerlad et al.,<sup>17</sup> but an instrumental assessment with aerophonoscope can help the objectification of results. Another confounding factor is that there is no matching that could be important to

generalize results in the choice of surgical technique. Autologous fat grafting was introduced in our institution in 2006. This means that all patients operated from 1982 to 2006 received pharyngoplasty. After that date, surgical indications were based on the VPI severity and fibroscopic findings, and it is difficult to compare between fat graft in small VPI gap and flap in large gap, which represents another challenge. Finally, our case series is limited in numerical terms.

Classical literature, dominated by retrospective series comparison studies, where reliability is inevitably preconceived by significant sources of bias, lacks evidence on the best surgical technique. Most of studies are comparisons of groups of patients without basic homogeneity with respect to the degree of VPI and associated deformities, or cases who received pharyngeal surgery by operators with different levels of qualification. Few randomized trials have been performed and only comparing pharyngoplasty procedures without significant differences among techniques: Karling et al. compared the size of the flaps of two pharyngeal flap technique,<sup>55</sup> Randall et al. compared upper and lower flap pharyngoplasties,<sup>56</sup> Ysunza et al.<sup>57</sup> and the multicentric “VPI Surgical Trial Group”<sup>58</sup> compared upper flap pharyngoplasty and sphincteroplasty. The same result has been found in another study comparing the two techniques in two centres in France.<sup>23</sup> In addition to the three RCPs mentioned,<sup>13,57,58</sup> other studies have shown great variability between different surgeons and hospitals in this surgery.<sup>59,60</sup> We can therefore summarize that it is possible to obtain good results with both techniques, but with a significant learning curve.

Velopharyngeal treatment presents many surgical alternatives to pharyngoplasty, and the choice of better technique is controversy<sup>61–63</sup>. Studies that compare double-Z plasty with either flap pharyngoplasty or sphincteroplasty have not found significant differences in results.<sup>64,65</sup> According to Swanson, who in 2015<sup>66</sup> states that severe cases of VPI associated with significant palatal foreshortening or limited palatal mobility typically require a more invasive intervention, open pharyngoplasty and palatoplasty techniques carry significant risk, including hemorrhage, oronasal fistula, and obstructive sleep apnea (OSA).<sup>66,67</sup> For patients with mild to moderate VPI and small velopharyngeal gaps instead, injection augmentation pharyngoplasty with AFG offers a low risk outpatient alternative. In a recent review of the literature,<sup>14</sup> de Baclam demonstrate that there is no significant difference in outcome across various surgical procedures for the treatment of VPI (palatal muscle repositioning, pharyngoplasty procedures, and posterior pharyngeal wall augmentation). Despite this, sphincter pharyngoplasty has a complication rate of 6.4%, although the larger series of AFG do not show any surgical complication.<sup>38</sup> All open procedures (pharyngoplasty, sphincteroplasty and palatoplasty techniques) has historically been associated with risk of airway compromise. The complication rate has been estimated to be 5.3% of cases. The most common complication is prolonged postoperative mechanical ventilation. Further complications include hemorrhage, oronasal fistula, and OSA. Readmission and reoperation is estimated in the order of 1.3% of patients.<sup>66</sup> In

the literature, there is only a case of OSA after AFG due to rapid weight gain,<sup>68</sup> compared with an incidence of up to 90% of patients who underwent pharyngoplasty.<sup>69</sup> The most common complications of AFG are embolism,<sup>70</sup> fat reabsorption,<sup>71</sup> and the need of a secondary injection, which could be considered as a failure or as an opportunity to refine the surgical result with a safe technique.<sup>72</sup> Aside from choosing the filling material,<sup>73</sup> AFG demonstrates efficacy and safety equivalent to those of more invasive approaches in mild-to-moderate patients, thus limiting hospitalization times, pain, feelings of oppression or suffocation, and costs of care. From a technical point of view, AFG is easier to perform, with a short learning curve. There are authors that propose AFG as a first-line treatment of VPI in severe cases too, because this technique does not cause scars or alter the anatomy of the velopharyngeal port, thus allowing a good background for further surgical techniques;<sup>74</sup> furthermore, it does not alter maxillary growth,<sup>75,76</sup> which would make repeat speech surgery more challenging.<sup>77–79</sup>

## Conclusions

Given the limited literature background of speech surgery, we compared two surgical techniques for the management of VPI and built a perfect speech patient profile with the aim to provide a decision-making tool to surgeons for a postoperative forecast of the surgical result. More multicentric studies with larger datasets and the possibility to modulate specific variables are necessary in the future to better understand this surgical variability. The progress of data management could help to build a multidisciplinary VPI community across institutions to share standardized data. This broad collaboration could help to personalize treatment and select the best procedure for the each patient.

## Conflict of Interests

The authors have no conflict of interests to declare.

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