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Voice outcome indicators for unilateral vocal fold paralysis surgery: a review of the literature

G. Desuter[1,3] · M. Dedry[1] · B. Schaar[1] · J. van Lith-Bijl[1,2] · P. P. van Benthem[3] · E. V. Sjögren[3]

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Abstract

Introduction There is no consensus on which voice outcome indicators (VOIs) should be used to compare the merits of the various surgical treatments for unilateral vocal fold paralysis (UVFP). Authors performed a literature review to identify which VOIs are most frequently used and most relevant, in terms of significant change in pre- and post-operative measurements, to assess UVFP surgical treatments.

Method A Medline/Pubmed literature review was performed and the most frequently used VOIs were identified using a Pareto diagram. For these most frequently used VOI's, the number of studies that showed a statistically significant change in pre- and post-operative results were compared to the total number of studies found using that same VOI, this portion was expressed in percent. This percentage was defined as the "percentage of significance" and used to assess changes of each VOI.

Results Eleven VOIs were identified using the Pareto analysis. These were, in decreasing order of frequency of citation: maximum phonation time (MPT), jitter, Shimmer, video-stroboscopic examination, noise to harmonic ratio (NHR/HNR), mean air flow (MeAF), fundamental frequency (F0), "Infrequent Perceptional Scales", GRBAS scale, mean subglottic pressure (MSGP). MPT, MeAF, factor G of GRBAS-I, Jitter, shimmer and VHI-30 had respective "percentage of significance" of 90, 86, 85, 74, 68 and 64%, respectively.

Conclusion The results indicate that MPT, MeAF and GRBAS-I, represent the top-three most frequently used and the most relevant VOIs in terms of "percentage of significance". VHI-30 showed a relatively low rate of use and low "percentage of significance". The role of Jitter and Shimmer remains unclear. Finally, MSGP and the F0 appear to be less relevant VOIs for the evaluation of UFVP surgical treatments in terms of significant change in pre- and post-operative measurements.

Keywords Unilateral vocal fold paralysis UVFP · Thyroplasty · Injection laryngoplasty · Larynx reinnervation · Outcome

Introduction

Abduction in unilateral vocal fold paralysis (UFVP) causing dysphonia, dysphagia and "phonatory" dyspnea, represents a defined pathological entity for which many different surgical treatments have been proposed over the years. Although diverse in their approach these surgeries all primarily seek closure of the glottis during phonation. Unfortunately, there is no consensus on which voice outcome indicators (VOIs) should be used to compare the merits of these various treatments. If voice quality assessment is thought to be necessarily multidimensional, some authors have advocated, in the recent literature, the need for disease-specific sets of VOIs. This paper is a Medline/Pubmed-based review and evaluation of the literature focusing on VOIs that have been utilized for the assessment of UVFP surgical treatments.

The primary aim of this review was to determine the frequency of use of every VOI that has been utilized to assess patient's voice, after surgical treatment for UVFP, using a Pareto diagram. Having determined the most frequently used VOI's according to the Pareto diagram, the secondary aim of this review was to report their pre- and post-intervention results. The ultimate goal of the review was to identify which

✉ G. Desuter
gauthier.desuter@uclouvain.be; gdesuter@post.harvard.edu

[1] Otolaryngology, Head and Neck Surgery Department, Voice and Swallowing Clinic, Cliniques Universitaires Saint-Luc, Université catholique de Louvain, 10 avenue Hippocrate, suite 407, 1200 Brussels, Belgium

[2] Otolaryngology Department, Flevoziekenhuis, Almere, The Netherlands

[3] Otolaryngology, Head and Neck Surgery Department, LUMC, University of Leiden, Leiden, The Netherlands

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VOIs are most frequently used and most relevant in terms of significant change in pre- and post-operative measurements when it comes to assess UVFP surgical treatments.

Methods

In October 2016, a systematic search was performed in Medline/Pubmed to identify articles published after 1990 on assessment of UVFP surgical treatments. Using the following medical subject heading (MeSH) and subheadings, "Vocal Cord Paralysis/Diagnosis" [MeSH] OR "Vocal Cord Paralysis/Surgery" [MeSH] OR "Vocal CordParalysis/Therapy" [MeSH], a total of 3052 articles were found. Two thousand two-hundred ninety-five articles (2295) were published after 1990. The first selection was based on the exclusion criteria. Seven hundred sixty articles (760) were selected after title reading. Abstracts of these 760 were reviewed. One hundred and fifty-six (156) of these articles were selected for extensive reading. Eventually, 72 of these 156 articles met the inclusions criteria and were analyzed [1–72].

Exclusion and inclusion criteria are listed in Table 1. Figure 1 shows the flowchart of article selection.

An extensive data bank was set up. Type of study, type of surgical intervention(s), type of VOI used and their values,

Table 1 Exclusion criteria are listed on the left column, Inclusion criteria are listed on the right column

Exclusion criteria	Inclusion criteria
Meta-analysis	
Studies published before 1990 referenced in the « PubMed » database	Studies published after 1990 referenced in the « PubMed » database
Other pathologies than unilateral vocal fold paralysis	Unilateral vocal fold paralysis
No intervention or unspecified intervention	Intervention (medialization thyroplasty, injection, arytenoid adduction, reinnervation)
Post-surgery outcomes non available or reported in correlation	Voice outcome indicator before and after surgery
Outcomes in dead subjects	Studies on human living subjects
Studies about surgical complications	
Case studies	
Animal studies	

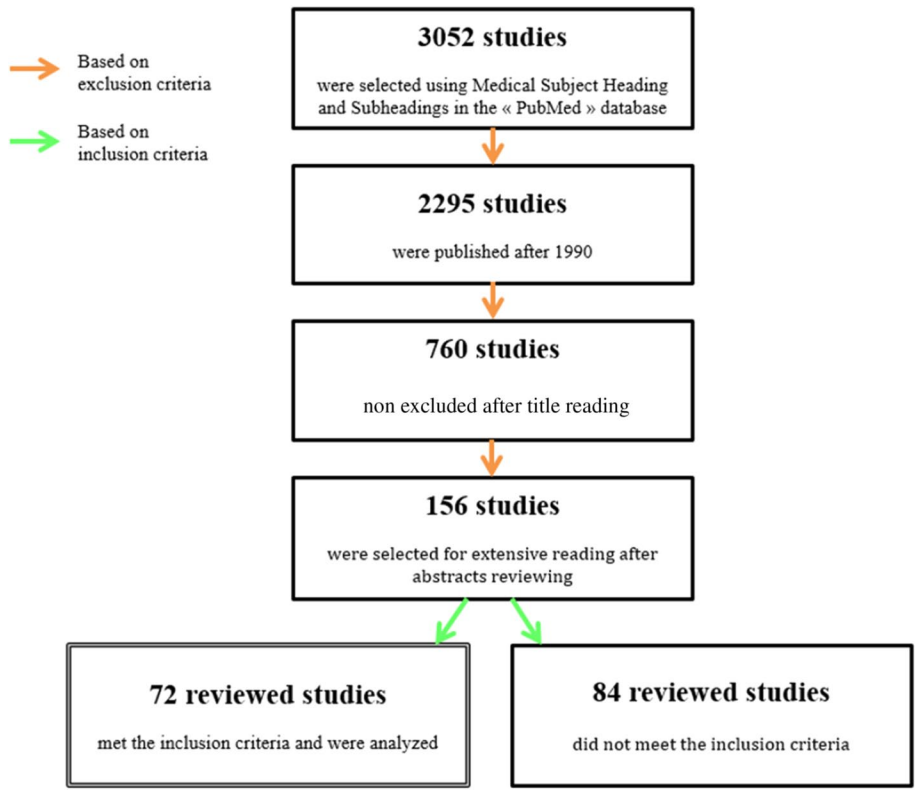

Fig. 1 Flowchart of article selection

Table 2 Frequency of use of the different VOIs utilized in the literature, their overall percentages of use and the cumulative percentage of all VOIs

	Frequency	Percentage (%)	Cumulative percentage (%)
MPT	45	13.5	13.6
Jitter	33	9.9	23.5
Shimmer	32	9.6	33.1
Videostroboscopy	30	9.0	42.2
NHR	27	8.1	50.3
Mean air flow	22	6.6	56.9
Fundamental frequency	22	6.6	63.6
Homemade perceptual scales	17	5.1	68.7
GRBAS-I	16	4.8	73.5
Mean subglottic pressure	10	3.0	76.5
VHI-30	9	2.7	79.2
Intensity	8	2.4	81.6
Glottal flow rate	6	1.8	83.4
NNE	6	1.8	85.2
CAPE-V	4	1.2	86.4
VHI-10	3	0.9	87.3
V-RQOL	3	0.9	88.3
Laryngeal airway resistance	3	0.9	89.2
Pitch range	3	0.9	90.1
Frequency range	3	0.9	91.0
Pitch perturbation quotient	3	0.9	91.9
Amplitude perturbation quotient	3	0.9	92.8
Phrase grouping	2	0.6	93.4
Word per minute	2	0.6	94.0
Maximum intensity range	2	0.6	94.6
Sound pressure level	2	0.6	95.2
Standard deviation of F0	2	0.6	95.8
Phonetogram	2	0.6	96.4
Vocal performance questionnaire score	1	0.3	96.7
NHP	1	0.3	97.0
Voice symptoms scale	1	0.3	97.3
Voice outcomes survey	1	0.3	97.6
SR-36	1	0.3	97.9
Forced vital capacity	1	0.3	98.2
Intra-abdominal pressure	1	0.3	98.5
Peak expiratory flow	1	0.3	98.8
Forced expiratory volume in 1 s	1	0.3	99.1
Peak inspiratory flow	1	0.3	99.4
Volume O2 maximum	1	0.3	99.7
S/Z ratio	1	0.3	100.0
Total	332	100.0	

along with the time interval from the intervention date to the moment of assessment, were collected. The total frequency of use of each VOI was classified in descending order. A Pareto diagram that combines bars showing individual values by descending order and a line graph showing the cumulative percentage of data was drawn. Using the Pareto diagram, the most frequently used VOIs, accounting for 80% of the total VOIs, were identified. Once the most frequently used VOIs had been identified, their pre- and post-intervention mean values were compared.

Two choices regarding VOI grouping were made by the authors. (a) The number of citations of noise to harmonic ratio and harmonic to noise ratio (NHR and HNR) VOIs were merged. Authors postulate that NHR and HNR represented the same VOI differing only by a software setting swopping the numerator and denominator of the same ratio. (b) Inversely, the number of citations of VHI-30 and VHI-10 was not merged. Authors postulated that they represented two different—although similar—VOIs that were based on different validation studies in different languages.

Concerning the GRBAS-I score, only the general score (G) will be considered.

The pre- and post-intervention mean values of the VOIs selected using the Pareto diagram were compared. One post-intervention VOI result was considered for each surgical technique and each time interval of post-intervention assessment. The same pre-intervention data were used in case of studies comparing (1) multiple techniques and (2) post-intervention at multiple time points. This explains why post-intervention data were more numerous than pre-intervention data.

Boxplot graphs were used to display pre- and post- intervention means. Line graphs were preferred to boxplot graphs when no clear post-operative trends in the voice outcome could be found.

Finally, for these most frequently used VOIs, the number of studies that showed a statistically significant change in pre- and post-operative results (≤ 0.05) was compared to the total number of studies found using that same VOI, this portion was expressed in percent. This percentage was defined as the "percentage of significance" and used to assess changes of each VOI.

Results

Fifty-three (73.6%) out of 72 studies were prospective. Some of these 72 studies evaluated more than one type of procedure. In total, 107 procedures were reported. Some articles did compare the outcomes of combined procedures. Surgeries of UVFP that were reported were, respectively, medialization or type 1 thyroplasty (ML) (56.1%), arytenoid adduction (AA), usually combined with ML (18,7%), injection laryngoplasty (IL) (17.8%), larynx reinnervation (LR) (6.5%) and arytenoidopexy (AP),usually combined with ML (0.9%).

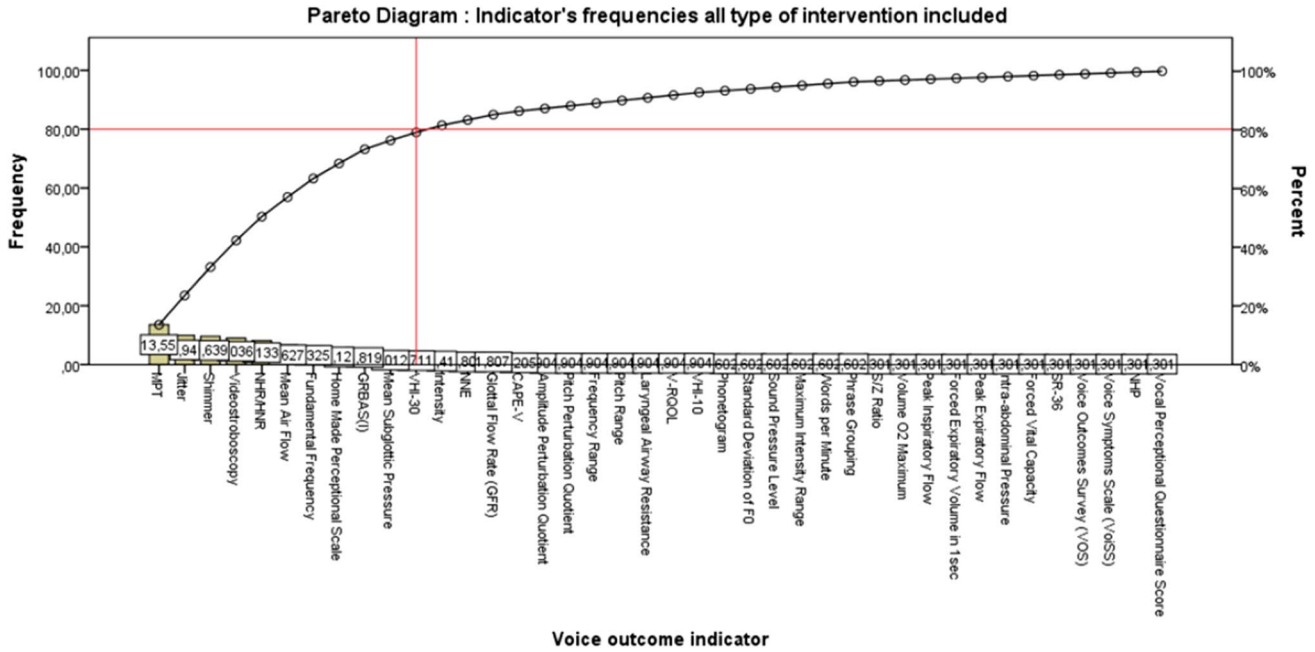

Fig. 2 Pareto diagram of all the VOIs that were listed

Table 3 Number of pre-op data, means of pre-intervention mean values; number of post-op data, means of post-interventions mean values, number of pre-post data delta available, for each VOI

Voice outcome indicators	n Pré	Pré (*M, SD*)	n Post	Post (*M, SD*)	n Delta	Delta (M, *SD*)
MPT (s)	52	5.69 (1.78)	66	12.41 (3.51)	66	6.57 (3.3)
Mean airflow (ml/s)	28	460 (185.21)	31	224.28 (59.84)	31	261.93(175.56)
GRBAS-I (factor G)	13	2.27 (0.67)	18	0.9 (0.38)	18	1.46(0.5)
HNR (dB)	10	8.8 (1.83)	15	11.6(2.08)	15	4.1 (0.9)
Jitter (%)	35	5.17 (3.29)	46	1.76 (0.8)	46	3.27 (2.88)
Shimmer (%)	31	11.22(4.82)	39	5.11 (2.07)	39	5.66(4.11)
VHI-30	14	76.36 (13.87)	16	30.86(11.21)	16	48.91 (20.44)
NHR (dB)	15	0.27 (0.02)	20	0.17(0.14)	20	0.1 (0.15)
Mean subglottic pressure (cm H_2O)	11	9.58 (3.93)	14	8.8 (4.5)	14	2.77 (2.63)
F0 (Hz)	24	172.74 (38.49)	36	166.93 (28.12)	36	25.33 (26.99)

The most reported interval for post-operative voice outcome analysis was 6 months (60 articles), whereas 1 month (50 articles), 3 months (49 articles) and 1 year (48 articles) intervals were also commonly reported. Table 2 shows the details of VOI frequency of citation in descending order with their cumulative percentage. Figure 2 displays the frequency of VOIs use and the 80% cumulative percentage cut-off point within a Pareto Diagram.

Eleven VOIs accounted for 80% of all reported VOIs, when it comes to assessment of voice after surgery for UVFP. These were, in decreasing order of frequency of citation: maximum phonation time (MPT), jitter, shimmer, video-stroboscopic examination, noise to harmonic ratio (NHR/HNR), mean air flow (MeAF), fundamental frequency (F0), "Infrequent Perceptional Scales", GRBAS scale, mean subglottic pressure (MSGP) and the original Jacobson's Voice Handicap Index (VHI-30) [73].

All the voice perceptional scales that were found in the literature whether validated, and used by only one team were grouped together in VOI "infrequent Perceptional Scales". By definition, such scales could not be compared. Likewise, video-stroboscopic examinations results could not be compared due to the lack of protocol standardization. Accordingly, the pre- and post-intervention results of the remaining nine VOIs were analyzed.

Table 3 shows means of pre-intervention values compared to means of post-interventions values for each VOI, at every given post-operative time-point. Table 4 shows the percentage

Table 4 Proportion of studies showing significant results ($p \leq 0.05$) between pre-operative and the first post-operative assessments, for each VOI

Voice outcome indicators	*P*-values ≤ 0.05	% Significance
MPT (s)	47/52 (0 NS; 5 NA)	90.38
Mean airflow (ml/s)	24/28 (2 NS; 2 NA)	85.71
GRBAS-I (factor G)	11/13 (0 NS; 2 NA)	84.61
HNR(dB)	8/10 (0 NS; 2 NA)	80
Jitter (%)	26/35 (5 NS; 4 NA)	74.29
Shimmer (%)	21/31(6 NS; 4 NA)	67.74
VHI-30	9/14 (2 NS; 3 NA)	64.29
NHR(dB)	7/15 (5 NS; 3 NA)	46.67
Mean subglottic pressure (cm H20)	5/11(3 NS;3 NA)	45.45
F0 (Hz)	8/24 (6 NS; 10 NA)	33.33

The last column translates this proportion into a "percentage of significance"

NS not significant, *NA* not available

of studies showing "*P*-values ≤ 0.05" versus studies with "*P*-values > 0.05 and no *P*-values available", for each VOI. For this table, only the first post-operative assessment was considered, no matter how many post-operative assessments were provided by the study. This percentage was defined as the percentage of significance.

In seven out of the nine VOIs, we found that a high percentage of the studies showed a significant difference in the pre- and post- measurements. The pre- and post-intervention means of these seven studies are displayed in Fig. 3. Figure 4 displays the pre- and post-interventions means of the remaining two VOIs, MSGP and the F0. Here no clear post-operative trends in the voice outcome could be found.

Discussion

This study is a literature review performed to reveal the most frequently cited VOIs used for UVFP surgical treatment assessment. Using the Pareto technique, eleven VOIs were found to account for 80% of the total number of indicators cited. Although the frequency of use of these VOIs may indirectly reflect their accessibility and/or facility to measure, it does not mean per se, that these VOIs are the most appropriate or accurate for the specific purpose of UVFP surgical treatments assessment. Nevertheless, if one could propose a standardized set of VOIs, its implementation could be made easier if they are already frequently used by surgeons.Very recently, Siu et al. performed a systematic review of the literature comparing outcomes of interventions for unilateral vocal fold paralysis. They concluded that "*lack of standardization in outcome measures and differences in reporting outcome data make generalizability between studies difficult*" [74]. Hypothetically, an ideal standardized set of VOIs should be significant as well as accessible.

A notable effort has been made by the European Laryngological Society to standardize the description of vocal fold motion impairment as well as to propose a basic protocol for functional assessment of all voice pathologies, especially for investigating the efficacy of treatments [75, 76]. No data is available about the use of such standardizations of protocols. A survey performed in 2010 among U.S. board certified otolaryngologists conducted by Young et al., reported that only 50% of respondents performing medialization thyroplasties report collecting pre-operative voice recordings [77]. This suggests an underuse of pre- and post-intervention voice assessment, which is probably not only restricted to the US.

In an attempt to simplify but also make the voice assessment more accurate and significant, some authors looked at tailoring the voice assessment to the disease that is under scrutiny. Dastolfo et al. followed this strategy and demonstrated that pre- and post-operative changes in aerodynamic measurements were shown to be very significant in UVFP treatment evaluations. They specifically advocate airflow in the "all-voiced sentence" as a routine voice laboratory measure for UVFP patients [78].

Of the nine VOIs that were selected using the Pareto analysis, three VOIs have a "percentage of significance" of more than 80%, Table 4. Maximum phonation time (MPT) appears to be the most used and the second most significant VOI in terms of pre- and post-operative change. Its use for UVFP treatment assessment has been frequently advocated since an initial article by Lundy et al., published in 2004, stated that "*the intra-operative measure of MPT appears to be an adequate predictor of the postoperative-*thyroplasty- *outcome"* [36]. Determination of MPT is easy to perform and does not require specific equipment. There are, however, still some recording conditions and patient collaboration issues concerning the MPT. Likewise, MPT has been reported as less sensitive than MeAF to characterize laryngeal dysfunction [79].

GRBAS-I general score (G), for grade of dysphonia, represents a widely used perceptional scale. Overall voice quality is scored from 0 to 3 by listener. Inter- as well as intra-rater reliability is satisfactory [36] and there should be no obstacle to its widespread use. Nevertheless, the GRBAS-I scale has its drawbacks. It has been recently demonstrated that the GRABAS evaluation should be blind [80] and that a particular attention should be paid to task design when it comes to perceptional analysis [81].

MeAF represents a more complex VOI than the previous ones. The MeAF is a similar VOI to airflow in the "all-voiced sentence", which was shown by Dastolfo's team to be very significant in measuring the pre–post UVFP

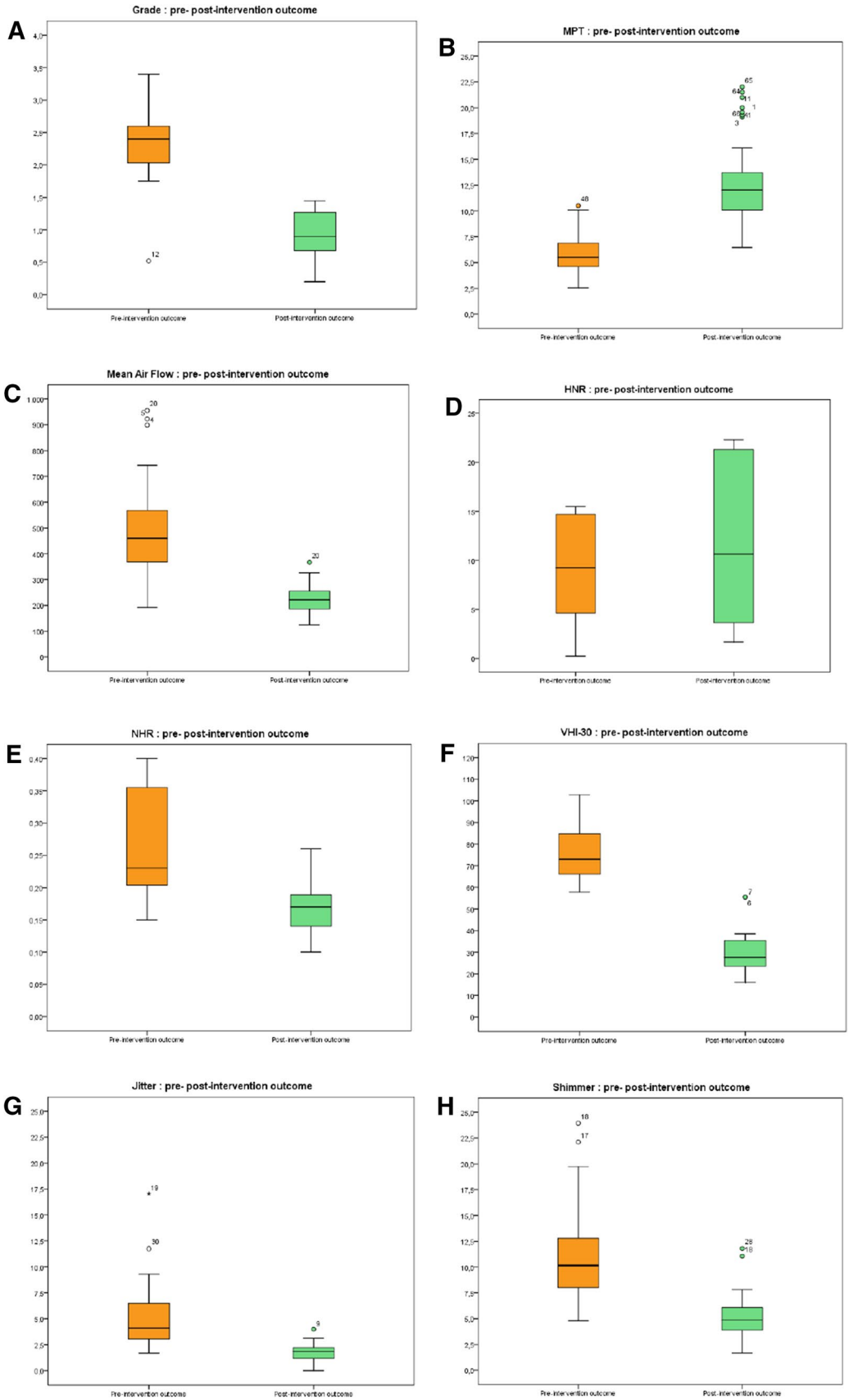

Fig. 3 Pre- and post-interventions results of G score of GRBAS-I (**a**), MPT (**b**), MeAF (**c**), HNR (**d**), NHR (**e**), VHI-30 (**f**), Jitter (**g**) and Shimmer (**h**)

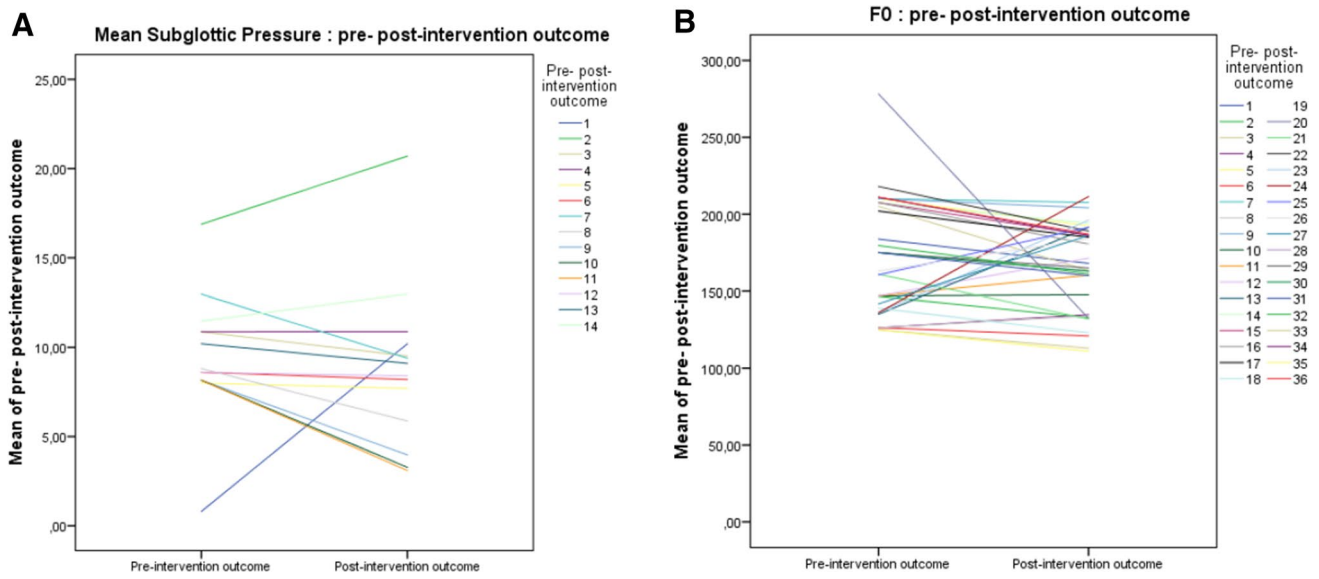

Fig. 4 Pre- and post-interventions results of MSGP (**a**) and F0 (**b**)

surgical treatment. Access to this VOI can be an issue considering the need of a pneumotachograph to be able to measure it, it is therefore somewhat reassuring to find the MeAF in our short list. Phonatory Quotient (PQ), a ratio between Vital Capacity and MPT that correlates with MeAF, could represent a valid surrogate.

Jitter and Shimmer are, respectively, ranked at fifth and sixth places in terms "percentage of significance" (Table 4). They are usually provided systematically by most voice laboratory software tools available on the market. This may explain their frequency of use, even though, their respective usefulness is questionable. As a matter of fact, Shimmer has a "percentage of significance" of only 68% and Jitter of 74%. Also, Jitter is calculated with the f0, which is in itself a VOI with low significance. VHI-30 ranking is low in terms of frequency of use and significance ratio. Merging of the VHI-30 and VHI-10 would not have changed these results significantly. Mean subglottic pressure and the Fundamental Frequency do not show clear outcome tendencies after UVFP treatment, and thus, despite being widely reported, do not seem to have much added value.

The limits of this review must certainly be underscored. First, this review has been done using exclusively the Pubmed research tool. Nevertheless, we believe that the majority of the articles published on the subject, have been included although some publications might have not been considered. The sole published review on the specific topic of VOIs to assess UVFP treatments—all-together—is the recently published article by Siu et al. mentioned above.

Second, ML interventions are over-represented in comparison to IL interventions. This does not reflect the reality of practice. The main reason of this discrepancy lies in the selection and inclusion criteria of the studies that favored ML interventions. Many publications concerning IL did not exclusively deal with UFVP patients and did not systematically present pre- and post-op results data.

Third, the extensive databank—more than 150 excel sheets—that has been created, may have been subject to coding errors or bias.

Fourth, raw data of these numerous studies could not be collected, limiting the validity of our conclusions. The presented outcome results are means of means. Likewise, the percentage of significance represents a ratio between studies showing statistical differences and studies showing no statistical differences or no statistical data at all. Furthermore, the fact that authors are more likely to publish significant results rather than non-significant results represents a clear bias.

Finally, this study may overlook VOIs that might be very relevant but not widely reported in the literature. Also, a statistical difference in pre- and post-operative VOI may not necessarily correspond to a clinically relevant change for the patient and the surgeon and for many VOIs there is still some uncertainty as to what the normal value and a clinically significant difference should be.

Conclusion

The goal of this review was to crossmatch frequency of use and relevance in terms of significant change in pre- and post-operative measurements of VOIs used in the evaluation of treatments of UVFP. The results indicate that MPT, MeAF and GRBAS-I represent the top-three VOIs in terms of significance within the most frequently used VOI's. The

VHI-30 showed a relatively low rate of use and low "percentage of significance". The role of the Jitter and Shimmer remains unclear. Finally, MSGP and the F0 appear to be less relevant VOIs for the evaluation of UVFP surgical treatments in terms of significant change in pre- and postoperative measurements.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights statement This article does not contain any studies with human or animals performed by any of the authors.

Informed consent Informed consent collection is not applicable to this study.

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