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BIOMECHANICAL ANALYSIS OF THE VOICE AS A TOOL IN ADDRESSING VOICE PATHOLOGY: OUR EXPERIENCE

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Abstract: Objectives: Biomechanical analysis is a non-invasive method that allows obtaining, from a sound sample, a set of parameters that characterize the vocal production pattern associated with the specific architecture of each vocal fold. The objective of the present study is to understand the importance of biomechanical analysis as a support tool in clinical practice, specifically to know the algorithm to perform adequate screening in patients who consult for voice pathology. Material and methods: A systematic description of the bases of the biomechanical analysis tool for screening voice pathology is presented; intended for those environments in which the professional seeks to detect voice pathology; The action protocol for screening voice pathology established by Voice Clinical Systems is described; Finally, data obtained with the help of the tool in a sample of 137 subjects treated in the Voice pathology unit of the Vithas Arturo Soria University Hospital in Madrid, Spain are presented. Results and conclusions; The validity as a tool to evaluate the dynamics of the vocal cycle has already been established; identifies the variation in vocal behavior patterns in relation to the type of phonation and the presence of pathology; even to discriminate functional pathology. It constitutes a valid tool for the detection of voice pathology. With the application of the action algorithm for screening, it allows the pathology to be identified, the evolution and response to treatments to be monitored, and is an effective aid in decision-making that leads to referring the patient to specialized care. Adequate applied knowledge of the use of the tool is important, so specific basic training is required to obtain adequate performance.
Keywords: Biomechanical analysis; Aphonia; voice pathology; Mucous wave; screening.

INTRODUCTION AND GOALS

Voice pathology is highly prevalent [1,2] and due to the limiting impact on the patient's social and work life3. The highest incidence occurs in women compared to men [4].

Vocal fold disorders are generally associated with dysphonia which, depending on the patient's age, gender, occupation and more factors, can cause some degree of limitation in their social and work life. [7]; It can even be a cause of work absenteeism. It is important to properly guide the approach to the study of dysphonia; Its cause is not always easy to establish, since it can occur isolated or intermittently, associated or not with other symptoms5,6. There are multiple classifications of dysphonia, in general they are differentiated by organic and functional origin. [7]; by its evolution time: acute and chronic. They are usually associated with many causes, such as: acute ones associated with upper respiratory tract infections, specific vocal efforts, neck trauma, stress, etc.; disorders that usually resolve with medical treatment and vocal rest within 1 or 2 weeks; chronic ones can be associated with factors such as vocal misuse and abuse, or tobacco consumption, among others 3. These disorders usually have a slow evolution, or even begin as functional alterations whose vocal behavior ends up generating consolidated organic lesions. Therefore, early detection measures allow these pathologies to be identified in very early stages, offering very good results with treatments based on the prevention of risk factors and minimally invasive therapeutic approaches 8.

It is well known that in the study of the voice and its pathology, several approaches are required for its complete understanding; The voice professional needs objective tools that provide us with information to be able to carry out screening, diagnosis and treatment tasks. Screening work is very important not only for

diagnosis, but also for early detection of vocal pathology. [9], That is why it is important to have objective tools that allow establishing a first diagnosis and directing a correct referral of the patient to Specialized Care, correctly discriminating the type of dysphonia. [8].

The biomechanical study of the voice is an innovative tool that analyzes the structural and mechanical factors involved in the movement of the free edge of the vocal folds, using modeling based on the underlying histological structure.[10]; It allows us to identify, from a voice signal, the alteration of the phonation pattern with respect to a series of reference values. For some years now we have had biomechanical voice analysis techniques obtained from vocal modeling of a voice sample. [10,11], that describe the dynamics of the vocal folds during phonation. One of these vocal modeling tools available on the market to perform a biomechanical analysis of the voice is the one provided by the Voice Clinical Systems laboratory. [12,13].

The objective of this study is to know the methodology of biomechanical analysis of the voice, to know its protocol for screening voice pathology; and describe some examples of clinical cases from routine clinical practice.

MATERIAL AND METHODS

Below is a systematic description of the bases of the biomechanical analysis tool for screening voice pathology; intended for those environments (schools, preventive medicine, primary care centers, etc.) in which the professional seeks to detect voice pathology, without attempting to diagnose or characterize it. In addition, the action protocol is described para realizar el cribado de la patología de la voz establecido por Voice Clinical Systems[10,14].

BIOMECHANICAL VOICE ANALYSIS (ABM)

The ABM allows us to establish correlates of the biodynamics that occur in the free edges and in the glottal space during phonation. [10]. When we talk about correlates; The term is well known and applied especially in electromedicine; refers to the use of biological signals that correspond, correlate and allow us to know the functioning of a specific organ; They can be of different types, such as: electrical potentials in the electromyogram, electrocardiogram, electroencephalogram, respiratory patterns in spirometry, among others; Therefore, the voice is a biological signal and must be analyzed as such. [10-12].

The present scheme in Figure 1 represents the phases of ABM; The signal source or sound source is produced with phonation, that is, the vibration of the free edges when the subglottal air pressure exceeds the glottic with approaching vocal folds, plus the Bernoulli effect; all this under central neurological control15-16.

It is important that the signal must have a minimum share of free edges; with minimum levels of periodicity; It must be a periodic signal, if there is no participation of the free edges or it is an aperiodic signal (noise); the tool will not be able to analyze it.

The receiver is a validated microphone specific to the Smarthpone device to be used; When connected, it must point horizontally towards the mouth and be 20-30 cm away; this registers the signal; Hands-free, Bluetooth, or other non-validated microphones are not valid (Figure 2).

For an adequate correlation, as in any other study with biological signals, the quality of the sample is crucial to get closer to accurate and reliable results, maintaining the greatest possible similarity and without contamination (external noise).

There is a recording protoco [15]. The resulting

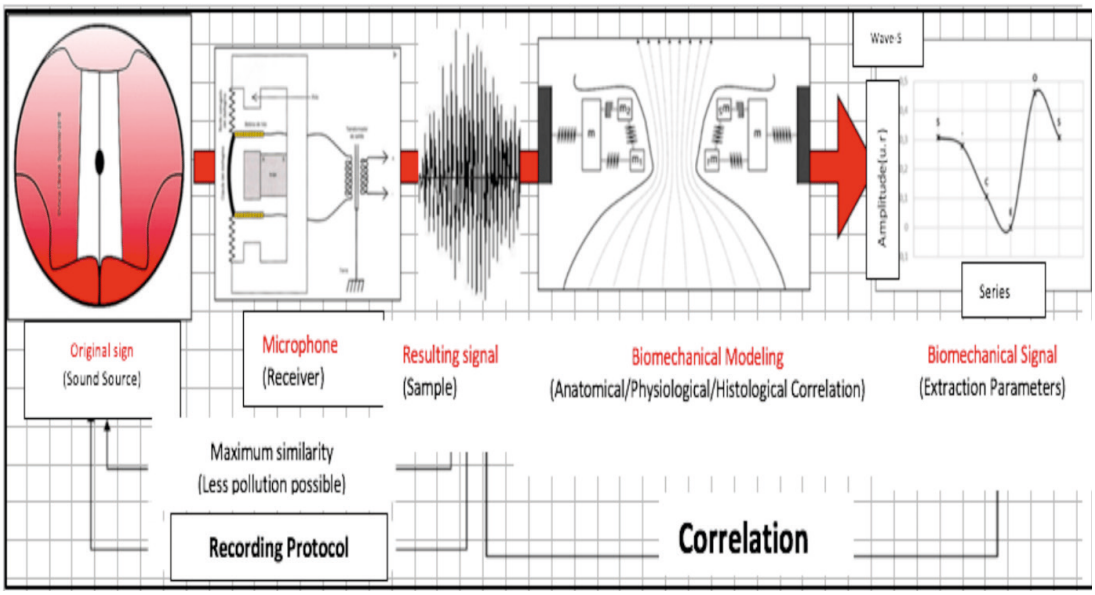

Figure 1: Scheme that represents the sequence that makes up the process carried out by the ABM tool. Taken from Voice Expert Course 2023 The Voice Clinical System.

signal will be the sample that will be sent to the laboratory; which goes through a biodynamic modeling validated by age and sex which establishes an anatomical, physiological and histological correlation; displays the results in the form of a curve or biodynamic signal of the vocal cycle; from which multiple biodynamic parameters can be extracted.

It is important to emphasize some aspects; the appropriate sample or signal must be intentional sustained phonation with the vowel /a/ from 1 to 4 sec; The vowel phonemes, specifically /a/, are the ones that allow the source signal to undergo fewer changes in the rest of the resonator tract compared to the other vowels (due to the position of the tongue, lips, soft palate, which alter or contaminate the signal). Samples of a speech segment are not valid.

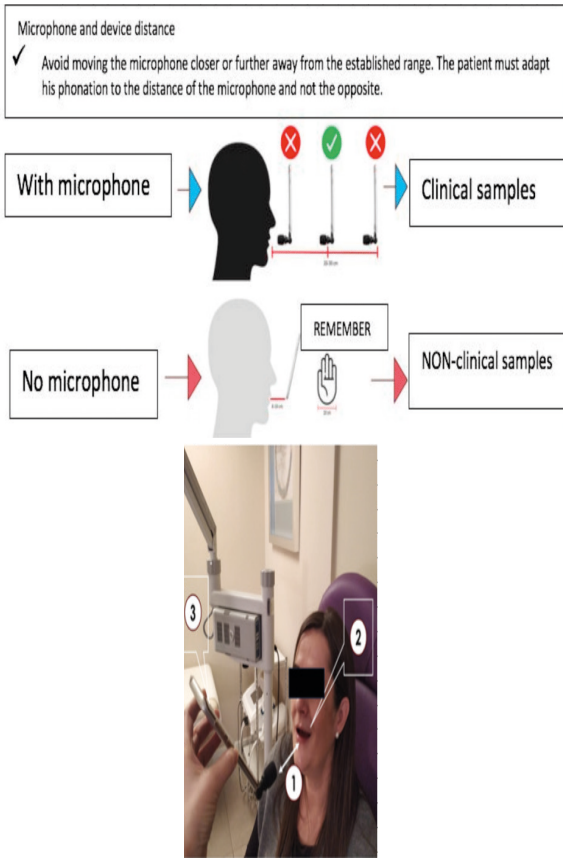

Figure 2: Recording process of the voice sample for the ABM. Taken from Voice Expert Course 2023 The Voice Clinical System.

Samples can be clinical or non-clinical; the clinic is of better quality, it is taken with a suitable microphone by a professional; non-clinical ones are of lower quality; They are taken without a microphone and can be taken by the patient himself; In turn, they can be valid or invalid samples (Figure 2).

In relation to biodynamic modeling, we start from the concept that the histological classification of free edges has biodynamic properties; hence its biodynamic classification: the roof is the area that has the greatest mobility; and the body the least mobile area; and an intermediate mobility zone or transition zone (Figure 3).

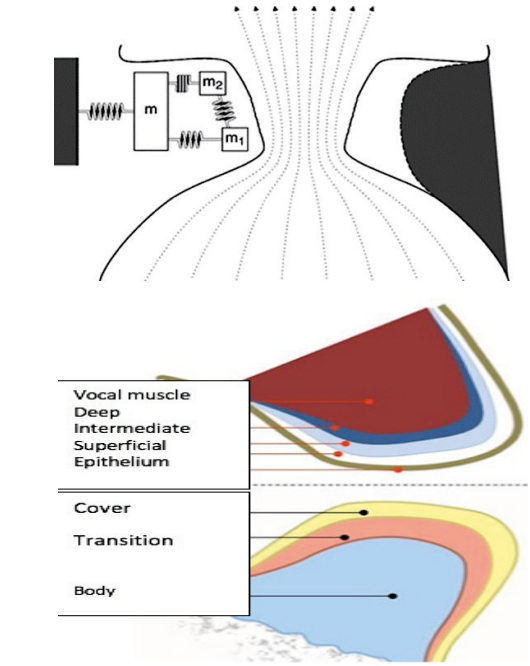

Figure 3: Representation of the histological and biodynamic classification of the free edges of a vocal fold. Taken from Voice Expert Course 2023 The Voice Clinical System.

The biomechanics developed by the free edges are a consequence of functional and structural factors dependent on their histology; there is a degree of relationship such that their histological structure is decisive for their biomechanics. A biomechanical alteration can lead to a structural imbalance and vice versa.

Regarding the modeling of free edges; extrapolating this biodynamic classification of free edges, and applying a mass model in different planes; The ABM allows us to approximate and quantify the biodynamics of the free edges in both the vertical (caudal-cranial) and horizontal (anteroposterior) planes.

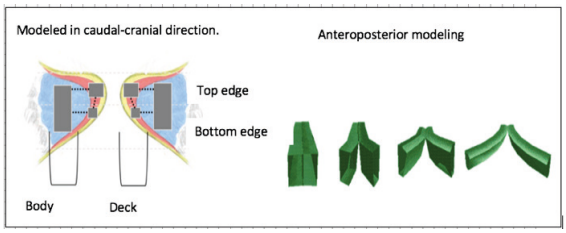

Figure 4: representation of the free edge modeling performed by the ABM. Taken from Voice Expert Course 2023 The Voice Clinical System.

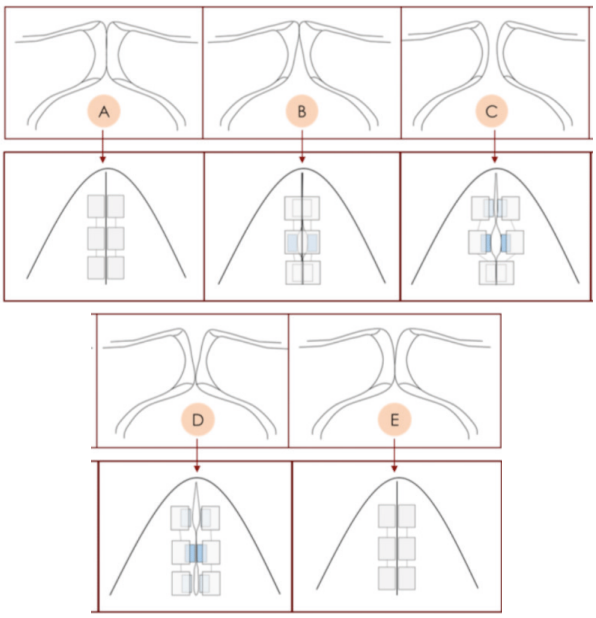

Figure 5: Representation of the final ABM modeling that encompasses the ondamucosa effect developed at the free edges. Taken from Voice Expert Course 2023 The Voice Clinical System.

The final modeling is based on encompassing the mucosal wave effect and its characteristics in both its vertical plane (caudal

cranial) and horizontal anteroposterior plane (Figure 5).

The results provide us with several types of age- and sex-specific parameters with their reference ranges of the control subjects.

The tool offers us the possibility of choosing 3 types of reports: Each one provides a different type of information, which requires a different level of specialization and is used for a specific task (Figure 6-7).

The R1 report offers the percentage of functional and organic alteration; It is a basic report. It is intended for the detection of voice pathology without attempting its diagnosis or characterization; for example, in singing centers, schools, preventive medicine, primary care centers, etc. The R2 report provides Essential Biomechanical Parameters; for patient monitoring during the development of a treatment. The R3-Complete Biomechanical report is a type of analysis designed for voice specialist professionals. It requires maximum knowledge of the dynamics of the voice and specific training is necessary to be able to extract all the information and clinical correlates included in it. The report contains a dynamic profile indicating the highlighted pathological profiles; illustrates the phases of the cycle with the approximation attempts of the free edges; the gap; the vocal cycle; and a list of all quantified parameters such as fundamental frequency, symmetry, cycle phases, force and tension, GAP, closure quality, muscle control, mucosal wave state, mass effect, among others (Figure 6-7)[13-15].

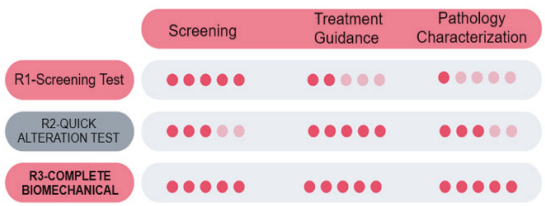

Figure 7: Specific uses according to the type of report obtained. Taken from Voice Expert Course 2023 The Voice Clinical System.

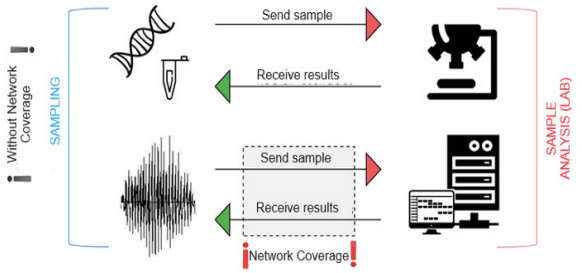

Figure 8: The ABM tool requires a connection to an Internet network. Taken from Voice Expert Course 2023 The Voice Clinical System.

For example, it is very similar to when a blood test is requested; the blood sample is taken; is sent to the laboratory; It processes it, analyzes it and sends the results. In the same way if it is extrapolated to ABM; the sample is sent to a virtual laboratory; that requires internet network coverage; he processes and analyzes it and sends the results (Figure 8).

SCREENING FOR VOICE PATHOLOGY WITH ABM

With the R1 report (Figure 9) screening for voice pathology can be performed; This report offers important points: the percentage of functional/organic alteration delimiting whether it exists is within normal or altered ranges; It also indicates the GAP, which refers to the space that exists between the free edges of the vocal cords during phonation. Under normal conditions, there is a certain degree during phonation; but when the GAP is increased to a moderate or severe degree; that is, the free edges do not contact each other; can give rise to altered dynamics of the free edges, leading to errors in interpretation [15].

GAP MANAGEMENT

The GAP can behave differently in the face of pathology, whether organic or functional, also in the absence of pathology; for example, in the presence of a pathology of the free edges such as vocal nodules, Reinke's edema,

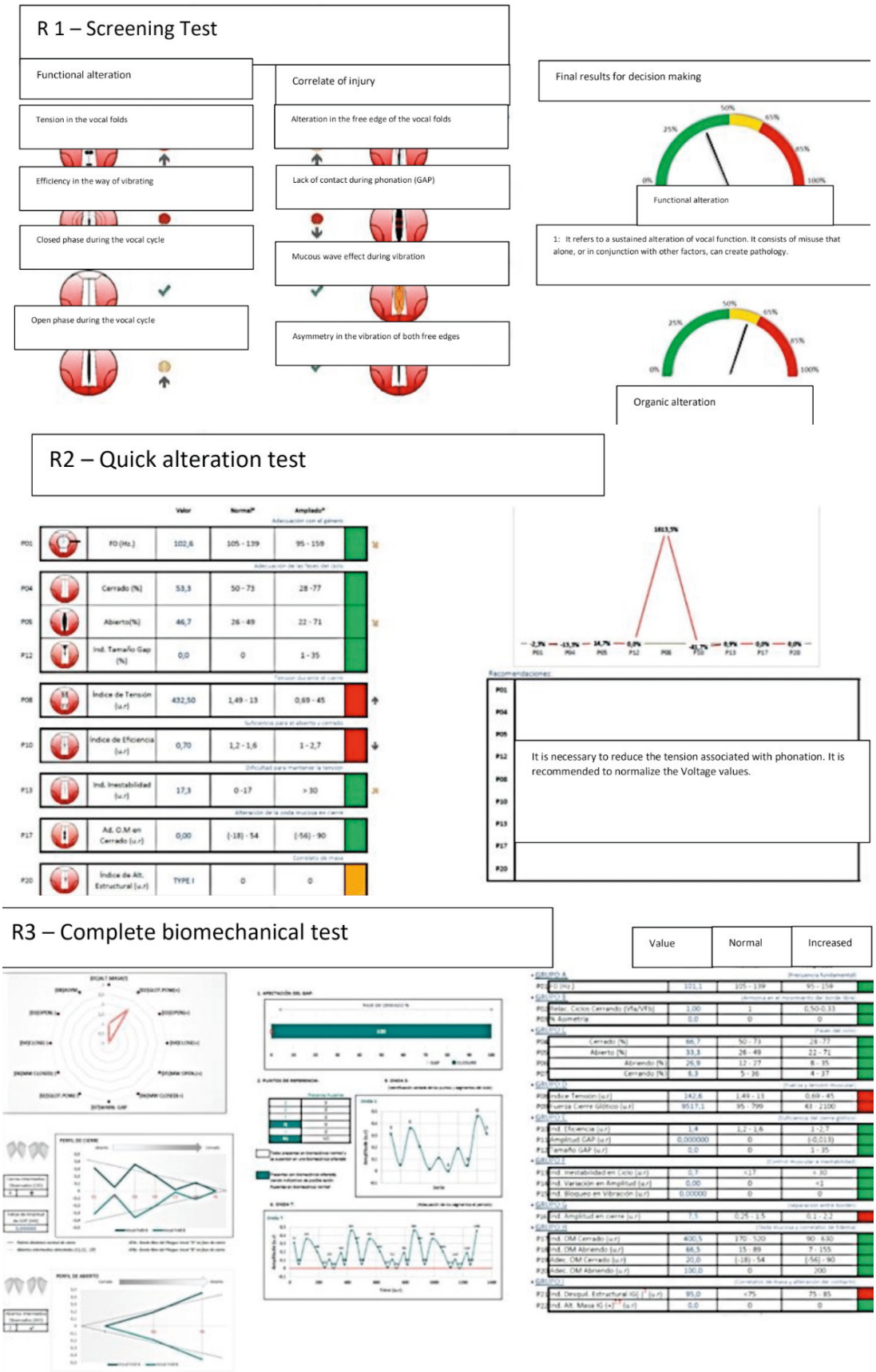

Figure 6: Types of reports that can be obtained with ABM

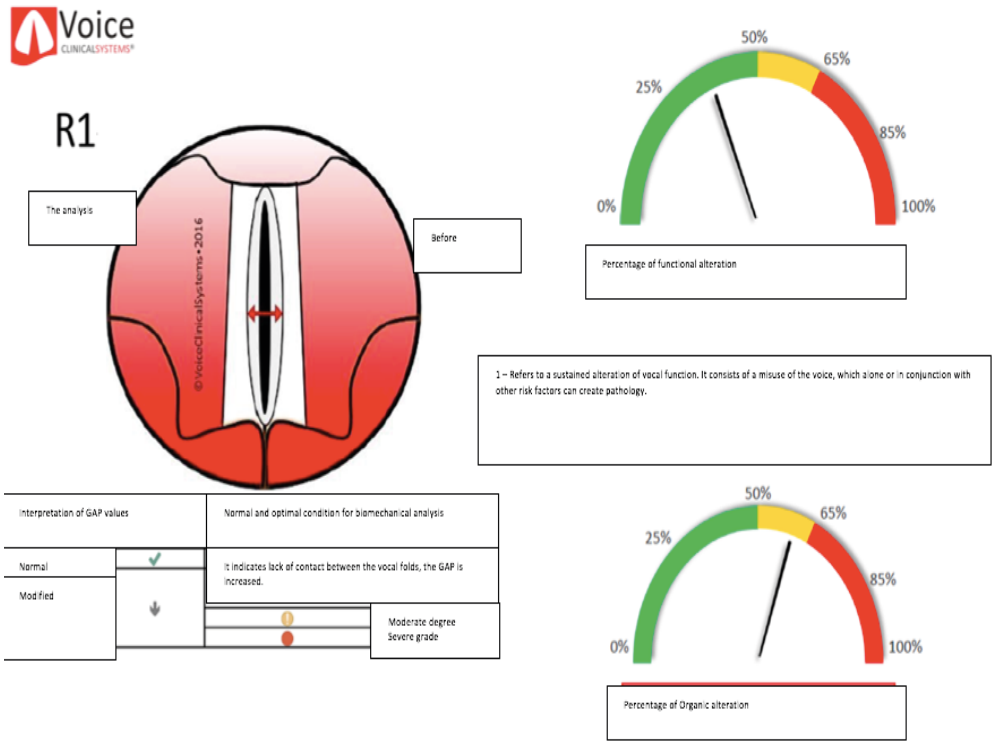

Figure 9: Example of report R1. Taken from Voice Expert Course 2023 The Voice Clinical System.

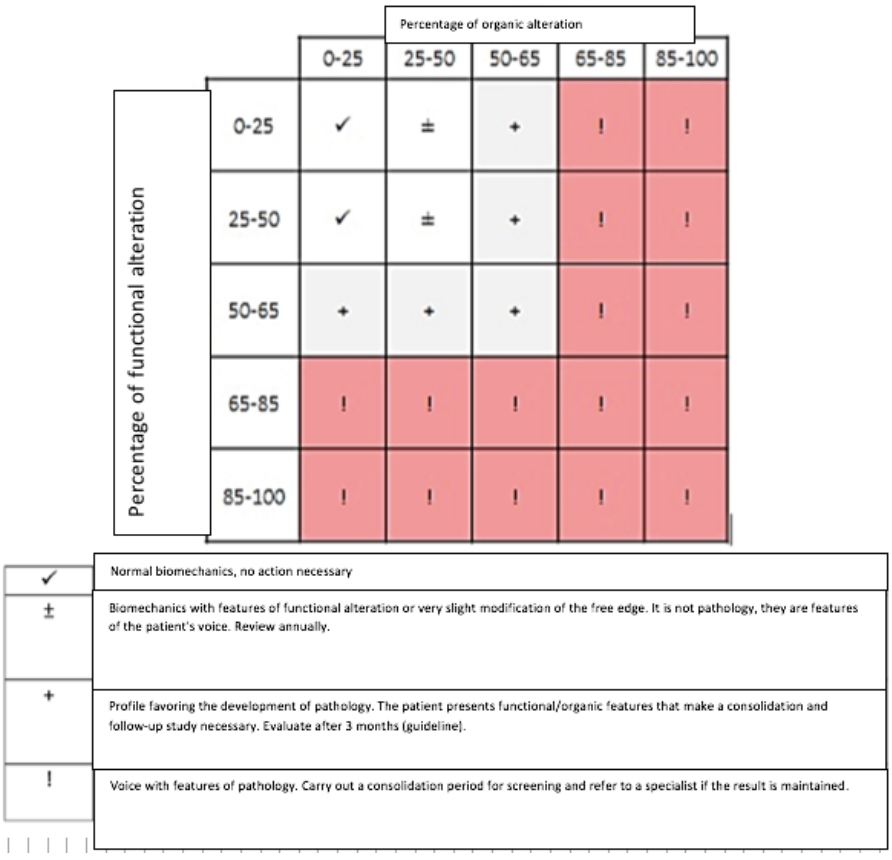

Figure 13: Interpretation of the results of the r1-test biomechanical screening report

submucous cyst; The lack of contact between the free edges, that is, the GAP, can overlap the existing pathology (Figure 10). In free edges without pathologies, the GAP can cause the tool to interpret a pathology pattern when there is none.

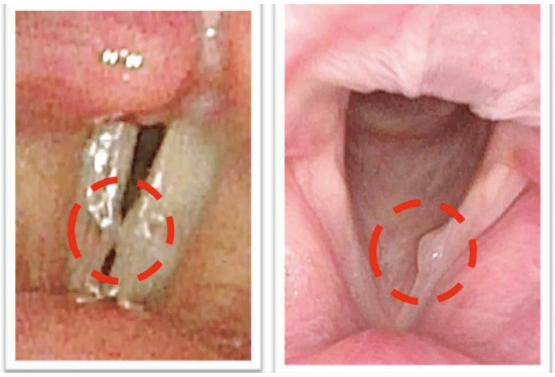

Figure 10: Examples of lesions in the free edges captured by flexible fibrolaryngoscopy; In the graph on the left, two vocal nodules located bilaterally between the middle and anterior third of both vocal cords are evident, indicated between the red lines between cuts; The image on the right shows a polyp on the left vocal cord in its middle third.

As indicated above, during the screening process for voice pathology using the ABM tool, the presence of GAP requires special attention; That is why there is an order of action when it is present.

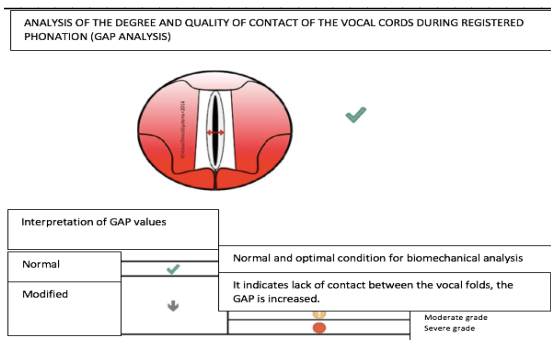

Figure 11: Report R1 section GAP; The tool indicates whether this parameter is within normal ranges, or altered to a moderate or severe degree.

The objective is to rule out the GAP phenomenon associated with non-pathological features such as soft or weak phonation. An example of a normal GAP range identified by the ABM is shown in Figure 11; When an altered GAP is identified in a first voice sample, whether moderate or severe, a new voice sample must be obtained. This time the subject must be asked to make phonation somewhat stronger and more sustained, since when the GAP does not It is pathological, it is usually associated with weak and soft phonations (Table 1 A).

Management of GAP in training	
A	If it appears in the first record. Repeat the recording asking the patient for speech with a little more intensity. The GAP, when it is not pathological, is associated with weak and soft speech.
B	If in the second recording, GAP continues to appear, despite increasing the intensity. The GAP will be considered to be a characteristic of the patient's alteration and this sample will be considered good.

Table 1: The management of GAP in the samples obtained is described.

However, if the GAP persists despite making these changes in phonation; The GAP is considered to be a pathological trait specific to the patient and that sample will be considered suitable (Table 1 B). Algorithm for decision making in screening for voice pathology with ABM

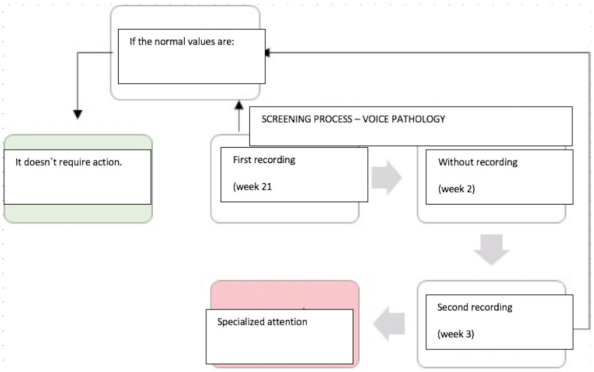

Figure 12: Algorithm for decision making; the consolidation period of screening and referral to specialized care. Taken from Voice Expert Course 2023 The Voice Clinical System.

Explaining the decision-making algorithm in Figure 12; If a patient consults for dysphonia (for example due to a viral infection of the upper respiratory tract), and we want to screen for voice pathology, we will perform the ABM, requesting the R1 report; once the GAP is adequately addressed, if the percentage of functional and organic alteration indicates pathological data; A new voice sample would have to be taken in 3 weeks; If the results are normalized, no further actions are required; On the contrary, if pathological values persist, it is advisable to refer to a specialist.

Figure 13 describes how to interpret the results of the R1 report. Once the GAP has been adequately addressed, the percentage of organic and functional alteration must be taken into account, and the indications in Figure 13 must be applied.

As Figure 13 describes; If the functional alteration is within 50% alone or accompanied by organic alteration (up to 25% organic alteration) it is within the normal range; or presents slight modification of its edges that give rise to its own organic/functional features (if the organic alteration reaches up to 50%), in the latter case an annual evaluation could be recommended.

When the percentage of organic and functional alteration exceeds 50%, it is more likely that there is a relationship with pathology in the free edges, especially when this exceeds 65%, so it is advisable to apply the screening consolidation period; and if it is persistent, refer it to a specialist for evaluation.

If the organic/functional alteration is between 50-65%, this indicates that the patient has features that favor functional/ organic pathology; Therefore, a consolidation study and follow-up after 3 months can be recommended.

DISCUSSION

Evidence has shown that screening through biomechanical analysis is a tool with high sensitivity and specificity; in the study that had 131 subjects – 34 subjects without pathology; 36 with a diagnosis of functional dysphonia and 61 with a diagnosis of organic dysphonia. After establishing the diagnosis through video laryngoscopy and the VHI-10 test, the R1 voice screening test was performed through biomechanical analysis with the tool, which showed that with an alteration threshold of 50%, it presented sensitivity (S) and specificity (E) indices in the screening. of very suitable voice pathologies: Control group vs. Organic dysphonia, E: 1, S: 0.80; Control group vs. Functional dysphonia, E: 1, S: 0.67; Functional dysphonia vs. Organic dysphonia, E: 0.98; S: 0.67; Dysphonia Group (Organic Dysphonia + Functional Dysphonia) vs. Normal Group, E: 1; S: 0.81. Demonstrating that the R1 biomechanical analysis with a 50% threshold is a tool with high sensitivity and specificity for the screening of voice pathology [8,13,14]. (Figure 14).

Currently, with the high demand for health care needs that exceeds the supply of the service; It is very important to have methods that allow identifying, organizing and prioritizing the specific attention required; or direct it appropriately to the different corresponding specialties and on time. It is well known that in the study of the voice and its pathology, several approaches are required for its complete understanding; The voice professional needs objective tools that provide us with information to be able to carry out screening, diagnosis and treatment tasks.

Cardoso I.13 establishes the validity of biomechanical analysis as a tool for evaluating the dynamics of the vocal cycle; identifies the variation in vocal behavior patterns in relation to the type of phonation and the presence of pathology through its parameters;

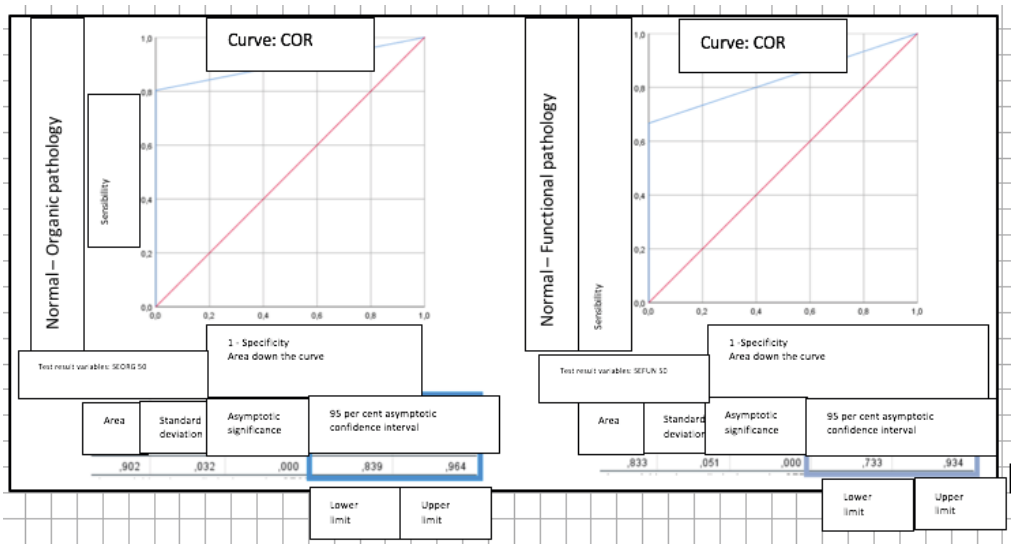

Figure 14: Graph that illustrates the sensitivity and specificity of screening using biomechanical tests using ROC curves. Cardoso I. (2021). Sensitivity of biomechanical analysis as a new tool for dysphonia screening

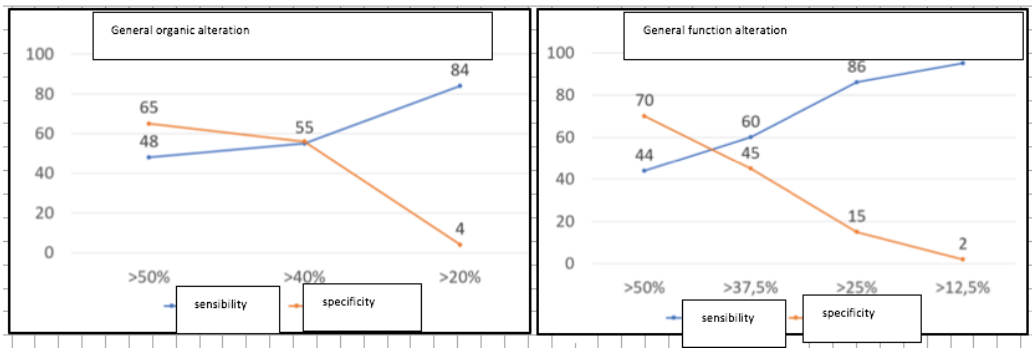

Figure 15: Graph that illustrates the sensitivity and specificity of the ABM in the detection of organic and functional alteration at different sections in the study population.

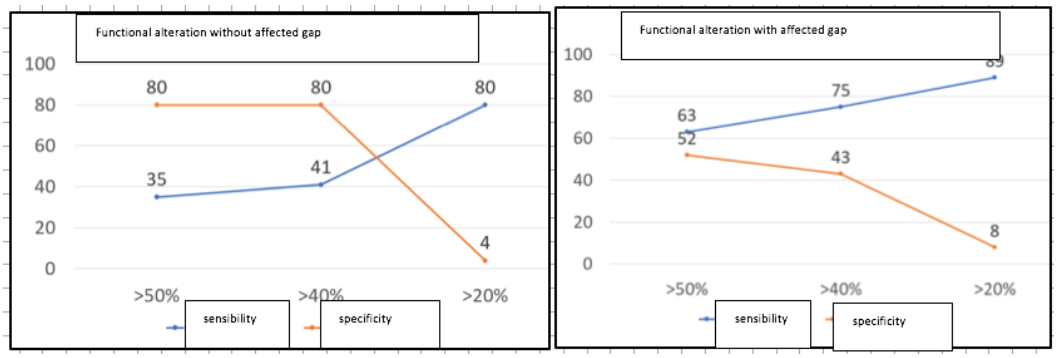

Figure 16: Graph that illustrates the sensitivity and specificity of the ABM in the detection of organic alteration with and without GAP involvement at different cuts in the study population.

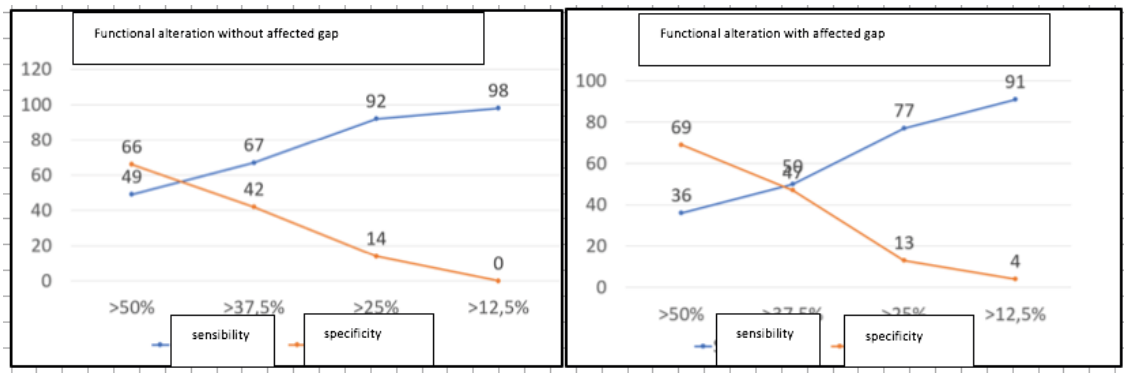

Figure 17: Graph that illustrates the sensitivity and specificity of the ABM in the detection of functional alteration with and without GAP involvement at different cuts in the study population.

it even provides a more complete and accurate description of free edge dynamics than the electroglottogram; Furthermore, it has been shown to constitute a valid tool for screening voice pathology, even to discriminate functional pathology due to its high sensitivity and specificity14.

In a study sample of patients who attended the Voice Pathology Unit of the Vithas Arturo Soria University Hospital in Madrid in Spain carried out between September 2021 and April 2023, 137 subjects were included, including men and women between 18 and 55 years old. Of those, 93 had a pathological examination of their vocal cords; We value the ability to detect sick and healthy patients with this tool; at different cuts of the percentage of organic alteration. R1 has been requested and analyzed the behavior of the results.

In the study sample it is evident that the specificity is high (65-70% respectively) when the cut-off of both organic and functional alteration (Figure 15) is at a cut-off equal to or greater than 50%; and as the cut-off decreases (40, 20%) the specificity falls. Regarding sensitivity, it is between (44-48% respectively) when the cut-off of both organic and functional alteration is at a cut-off equal to or greater than 50%; and presents an increase as the cut-off range of organic or functional alteration decreases.

When the specificity of the ABM is analyzed in the detection of organic alteration with and without involvement of the GAP at different sections; in the group that has an unaltered GAP (Figure 16), the specificity increases; That is to say, in the group in which the GAP is not affected, the tool is capable of better identifying healthy subjects. Regarding the group where the GAP is affected, the opposite occurs, where the tool is capable of better identifying the patients. The sensitivity remains unchanged.

There are no important variations in the sensitivity and specificity levels of the ABM in the detection of functional alteration with and without GAP involvement at different slices in the study population (Figure 17).

CONCLUSIONS

1. In previous research; The validity as a tool to evaluate the dynamics of the vocal cycle has already been established; identifies the variation in vocal behavior patterns in relation to the type of phonation and the presence of pathology; even to discriminate functional pathology. It constitutes a valid tool for the detection of voice pathology.
2. With the application of the action algorithm for screening, it allows the pathology to be identified, the evolution and response to treatments to be monitored, and is an effective aid in decision-making that leads to referring the patient to

specialized care.

3. Adequate applied knowledge of the use of the tool is important, so specific basic training is required to obtain adequate performance.

CONFLICTS OF INTERESTS

The researchers declare that they have no conflict of interest.

REFERENCES

1. Roy N, Merrill RM, Gray SD, Smith EM. (2005). Voice disorders in the general population: prevalence, risk factors, and occupational impact. *Laryngoscope*. 2005;115(11):1988-1995. doi:10.1097/01.mlg.0000179174.32345.41

2. Lyberg Åhlander V, Rydel, R, Fredlund P, Magnusson C, Wilén S. (2018). Prevalence of Voice Disorders in the General Population, based on the Stockholm Public Health Cohort. 10.13140/RG.2.2.35192.08963.

3. Elhendi H Wasim, Caravaca G Antonio, Santos P Sofía. (2012). Medición de la discapacidad vocal en los pacientes con disfonías funcionales. Rev.

4. Verdolini, Katherine & Ramig, Lorraine. (2001). Review: Occupational risks for voice problems. Logopedics, phoniatrics, vocology. 26. 37-46. 10.1080/140154301300109125.

5. Ceballo Pedraja, JM. Disfonía: proceso asistencial integrado. (2002). Consejería de Salud. Sevilla.

6. Instituto Nacional de Seguridad, Salud y Bienestar en el Trabajo (INSSBT), O.A., M.P. (2017). Guía clínica para el abordaje de la disfonía crónica en Medicina Primaria y Medicina del Trabajo. INSSBT. Madrid.

7. Kenny C. Dysphonia and Vocal Tract Discomfort While Working From Home During COVID-19 [published online ahead of print, 2020 Oct 16]. *J Voice*. 2020;S0892-1997(20)30384-2. doi:10.1016/j.jvoice.2020.10.010.

8. Cardoso I, Fernande-Baillo R, Tenesaca W, (2022). Validación del análisis biomecánico para el cribado de patología de la voz. International Journal of Health Science; v. 2, n. 30, 2022. doi 10.22533/at.ed.1592302215063.

9. Al-Nasheri A, Muhammad G, Alsulaiman M, Ali Z. Investigation of Voice Pathology Detection and Classification on Different Frequency Regions Using Correlation Functions. *J Voice*. 2017;31(1):3-15. doi:10.1016/j.jvoice.2016.01.014.

10. Fernández-Baillo, R., Ramírez Calvo, R., Ruíz Galea, JI (2017). Biomechanical Analysis of Voice. Voice Clinical Systems. 1ª Ed. Madrid. 978-84- 8198-975-5. e-book: www.voicecs.com.

11. Gomez P, Fernandez-Baillo R, Nieto A;Diaz F, Fernandez Camacho F.J, Rodellar V, Alvarez A, Martinez R. (2007). Evaluation Of Voice Pathology Based On The Estimation Of Vocal Fold Biomechanical Parameters. The Journal Of Voice. 21. 450-76. Elsevier. 0892-1997

12. Gomez P, Fernandez-Baillo R, Rodellar V, Nieto V, Alvarez A, Mazaira L. M, Martinez, R, Godino J.I. (2009). Glottal Source Biometrical Signature For Voice Pathology Detection. Speech Communication. 51. 759-81. Elsevier. 2009. 0167-6393.

13. Cardoso López, I (2021). Análisis Biomecánico de la Voz en el Estudio del Ciclo de Vibración de los Pliegues Vocales y su Patología (tesis doctoral, Universidad Europea, Madrid Spain.

14. Cardoso I. (2021). Sensibilidad del análisis biomecánico como nueva herramienta para el cribado de la disfonía. *Rev Asoc Esp Espec Med Trab*, 30, 1, 81-89

15. Expert Online Course on Pathology of the Voice" Voice Clinical. Systems. 2021. www.ifmec.com.

16. Zhang Z. Mechanics of human voice production and control. J Acoust Soc Am. 2016;140(4):2614. doi:10.1121/1.4964509.