Phoniatry

Post-thyroidectomy dysphonia in patients with bilateral resection of the superior laryngeal nerve: a comparative spectrographic study

Disfonia post-tiroidectomia nei pazienti con resezione bilaterale del nervo laringeo superiore: studio spettrografico comparativo

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SUMMARY

The most serious complications of total thyroidectomy, in cases of widespread and invasive diseases, are mainly hypoparathyroidism and laryngeal inferior nerve palsy. Lesions of the external branch of superior laryngeal nerve instead, although less obvious than the those caused by the recurrent laryngeal nerve lesions, have been taken less into consideration. The frequency of this lesion varies from 14% to 20% of cases, although in reality it is underestimated; in fact, on the one hand it is difficult to assess this, and on the other, post-thyroidectomy dysphonia is often considered inevitable. In the present retrospective research, 15 thyroidectomized patients (4 male, 11 female), have been subjected to qualitative and quantitative evaluation of the voice. Of these, 7 had a nerve lesion, while 8 did not. All the patients received a self-evaluation voice questionnaire (VHI). In all cases, a videolaryngostroboscopy has been carried out and the voice acoustic features examined through a spectrographic analysis. The results showed that removal of the thyroid, at the end of a 12-month post-surgery period, still causes an impact on the qualitative and quantitative aspects of the vocal function, whether the superior larynx nerve was injured or not. The majority of the patients, in both groups, reported that their voice had worsened in quality and durability. Hence, we have shown that the patients with upper larynx nerve lesion have an alteration of F0, show a lower energy level and a modified spectrographic quality compared to patients without injury. This low voice is often considered by patients as a normal consequence of thyroid surgery. The present research confirms that the attempt to identify and protect the superior laryngeal nerve is essential to prevent post-thyroidectomy dysphonia, but this is not sufficient to obtain the best results because of the existence of muscular and psychogenic factors that reduce the still voice capacity of the patient.

KEY WORDS: Dysphonia • Superior laryngeal nerve • Voice handicap index • Thyroidectomy

RIASSUNTO

Le complicanze più gravi della tiroidectomia totale sono sostanzialmente l'ipoparatiroidismo e la paralisi del nervo laringeo inferiore o ricorrente. Le lesioni del ramo esterno del nervo laringeo superiore, invece, clinicamente meno evidenti delle lesioni del nervo ricorrente, sono prese poco in considerazione. La frequenza di questa lesione varia dal 14% al 20% dei casi, anche se in realtà è sottostimata, sia perché difficile da dimostrare sia perché la disfonia post-tiroidectomia è spesso considerata inevitabile. Nella nostra indagine retrospettiva, sono stati sottoposti a valutazione qualitativa e quantitativa della voce 15 pazienti (4 uomini e 11 donne) sottoposti a tiroidectomia totale 12 mesi prima. Di questi, 7 avevano lesioni accertate del nervo laringeo superiore mentre 8 lo avevano sicuramente conservato. Tutti i pazienti hanno compilato un questionario di autovalutazione della voce (VHI). In tutti i casi abbiamo effettuato una videolaringostroboscopia e le caratteristiche acustiche della voce sono state esaminate attraverso l'analisi spettrografica. I risultati hanno mostrato che la rimozione della tiroide, al termine di un periodo di dodici mesi dopo l'intervento, causava ancora un impatto sugli aspetti qualitativi e quantitativi della funzione vocale, anche se il nervo laringeo superiore era stato risparmiato. La maggior parte dei pazienti, in entrambe i gruppi osservati infatti hanno riferito che la loro voce era peggiorata in termini di qualità e durata. I pazienti con lesione del nervo laringeo superiore mostrano, infatti, una alterazione della F0, un livello di energia minore e una qualità spettrografica modificata rispetto ai pazienti senza lesione. Questa ridotta capacità vocale viene spesso considerata dai pazienti come una normale conseguenza della chirurgia tiroidea. La nostra ricerca conferma che il tentativo di identificare e proteggere il nervo laringeo superiore è fondamentale per evitare una disfonia post-tiroidectomia, ma che questo non è sufficiente per ottenere i migliori risultati a causa della sussistenza di elementi muscolari e psicogeni che riducono comunque le capacità vocali del paziente.

PAROLE CHIAVE: *Disfonia • Nervo laringeo superiore • Voice Handicap Index • Tiroidectomia*

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Introduction

The thyroid gland is often affected by pathological processes which can be treated by partial or total surgery.
An analysis of the literature has shown that the most common complications in thyroid surgery more often depend upon the traumatic nature of the operation as well as technical mistakes, especially in the case of extended exeresis due to particular physical factors, such as a large or intra-thoracic goitre or extensive malignancy. In these cases, the dimensions of the gland and the invasiveness of the pathological process increase the possibilities of post-surgery complications [1-3].
The most important complications are the lesions of the recurrent laryngeal nerve palsy and hypothyroidism [3-5]. Less attention is focused on the external branch of superior laryngeal nerve (SLN) paralysis, the repercussions of which are less serious than those provoked by the recurrent laryngeal nerve lesions. This nerve has been referred to as "the nerve of Amelita Galli Curci" because of the disastrous termination of this world class opera singer's career as a result of her injury after thyroidectomy for a benign disease performed during the 1930s [2].
The frequency of this lesion, although difficult to assess, varies from 14% [6] to 20% [7] of the cases, which encourage the preservation of the superior laryngeal nerve. If the lesion of the SLN may often remain uncertain, in other circumstances, it can have disabling outcomes, especially in singers. This is because the nerve injury induces paralysis of the cricothyroid muscle, the function of which is to stretch the vocal cords during phonation and even more during singing. Interruption of the external branch of the superior laryngeal nerve causes vocal fatigue: a voice which is easily tired, with reduced tonality and volume, with modified pitch range and hoarseness [8 9]. These conclusions have been reached by testing patients who have suffered from a lesion of the exterior part of the superior laryngeal nerve, following removal of the thyroid.
In this study, 12 months after total thyroidectomy (TT), a comparison was made between two groups of patients: the first with the SLN preserved and the second with SLN damaged bilaterally.
Comparing the two groups, we studied the differences in the acoustic and perceptual voice quality, recordable injuries of the bilateral lesion of the SLN produces and its consequences on the quality of life in non-professional voice workers.

Material and methods

A retrospective observational analysis has been performed. During the one-year period from January 1, 2007 to December 31, 2007, the Endocrine Surgery Unit provided us with data related to the 350 patients operated upon for TT, who were submitted to a scrupulous post-operative follow-up.
The only cases selected were those where the surgeon had described having directly observed the SLN. Among these we recruited, one year after surgery, there were 15 patients (11 female 4 male), between 30 and 55 years old, 7 cases with bilateral lesion of the SLN and 8 with the nerve intact.
Excluded from the study were patients over 65 years old, subjects with a history of voice problems, cases in which the SLN was sectioned on only one side, anxious patients and professions related to voice, such as speakers, teachers or singers.
All patients were subjected to:

- *Voice Handicap Index (VHI),* self assessment questionnaire where the patients report the changes perceived in their own voice and the psychosocial handicap aspects of voice disorders.
- *Videolaryngostroboscopy (VLS):* To ensure a detailed observation of the minute alterations of the cordal mobility and for an analysis of the physiological and pathological characteristics of the glottis vibration, an atmos videostroboscope was used. The morphology and the appearance of the vocal cords are also observed: colour, volume, vascularization, integrity and lesions. In our analysis, we considered the two main vibratory cordal cycle phases, split into the opening and closing of the vocal cords and attention was focused on the following parameters: symmetry, periodicity, glottal closure, largeness and progression of the mucous wave.
- *The spectrogram* was performed using a Speech Audio Lab (SAL) with a frequency rank of 22050 Hz and recording quality of 8 bits connected to a Sonagraph. Collection of the vocal material was made in a silent and sound proof environment, where the patient was asked to pronounce, speaking into a microphone connected to a Sonagraph, 20 cm away from their mouth, the Italian word "aiuole" by extending the pronunciation of the vowel /aaaa/eeee/iiii/oooo/uuuu/. The top recording time was 2.4 seconds. The recorded and treated signals were transferred onto the z-axis, where time was reported on the x-axis and the harmonic frequency measured in Hz on the y-axis. The spectrum-acoustic level of the dysphonia has been classified, according to Yanagihara [10], into 4 categories, in relation to the spectrum increasing noise. Two analyses have been carried out on the results obtained in each patient:
  - *Long-term analysis:* where an oscillogramme shows the air variation during sound emission and the modifications that the sounds undergo, whilst crossing the "vocal tract";
  - *Short-term analysis* which describes, for each vowel represented on the oscillogramme, the matching data in a set interval, measured in msec, in order to determine voice acoustic parameters through *Linear Predictive Coding* (*LPC*) and *Fast Fourier Transformation* (*FFT*).

Table I. Patients with abnormal videolaryngostroboscopy in both groups.

Videolaryngostroboscopy	SLN-	SLN+
Symmetry	7	0
Periodicity	7	0
Glottal closure	7	0
Largeness	7	0
Progression of the mucous wave	7	0

Once the recording was obtained, the following parameters of voice production were recorded on a graph and measured:

- *Speaking fundamental frequency* (F0) and its variation, the quantitative indicator of vocal cord vibration. Normal values are: males 70-200 Hz, females 150-300 Hz.

Formant F2, created in the pharynx area and dependent upon the tongue position. Normal values are between 600 and 2500 Hz.

- Patients were then evaluated by an experienced speech therapist for assessment of the voice with the Voice Handicap Index.
- For statistical analysis, a Student t-test was used and the statistical significance was defined as $p < 0.05$.

Results

During the one-year period, 350 patients were observed who underwent TT in the operating unit of Endocrine Surgery. No complications occurred during the operation or in the post-operative period and, in all cases, the inferior laryngeal nerve was preserved. In 252 cases (72%), the surgeon described having directly observed the SLN.

Of these 12 patients over 65 years of age (4.8%), 51 subjects who had a history of voice problems (20.2%), 30 cases in which the SLN was sectioned only on one side (11.9%), 62 anxious patients (24.6%) and 82 professionals of voice (32.5%) were excluded from the study.

We recruited, one year after surgery, the remaining 15 patients (11 females, 4 males), aged between 30 and 55 years. In 7 cases (SNL- group), the SLN was involuntarily sectioned bilaterally during surgery, in the remaining 8 cases, the surgeon could manage to leave it untouched (SLN+ group).

All the chosen patients had reported having a normal vocal function before TT and none of the 15 patients presented organic lesions on their vocal cords during VLS.

The functional aspect in VLS however, was normal in the SLN+ group, but severely altered in all patients belonging to group SLN- who showed cord hypotonia, incomplete glottal closure, mucosal wave asymmetry and wavy freeboard of the real vocal cords (Table I).

All patients reduced the F0 on average of 17.7% in the SLN- group and 10.7% in SLN+ subjects. The statistical analysis of the F0 showed statistically significant differences between pre- and post-operative values in the SLN- group ($p = 0.003$) whereas in the SLN+ group these differences were not statistically significant ($p = 0.006$) (Table II). Comparing the individual differences of F0, it can be seen that 4 subjects SLN- (57.1%) and 2 SLN+ patients (25%) presented a significant reduction between the pre- and post-operative period.

The comparison between the two groups of F2 formant of the vowels / e / and / i / (Fig. 1) showed a significant increase in the first, and non significant in the second (Table III).

The 2nd, 3rd and 4th harmonic texture increased in all SLN- patients (Fig. 2). The same values remained stable in all SLN+ patients. All SLN- patients presented an

Table II. Values of F0 in patients subjected to TT; the average rate is reduced in the SLN- group compared to the SLN+ group.

F0					
SLN-			SLN+		
Hz		Sex	Hz		Sex
Pre	Post		Pre	Post	
176	128	M	118	112	M
180	125	F	247	162	F
163	124	M	146	140	M
205	168	F	229	225	F
220	211	F	231	224	F
197	157	F	250	188	F
203	196	F	204	200	F
			213	205	F
Average		p	Average		p
192	158	0.04	204	182	0.3

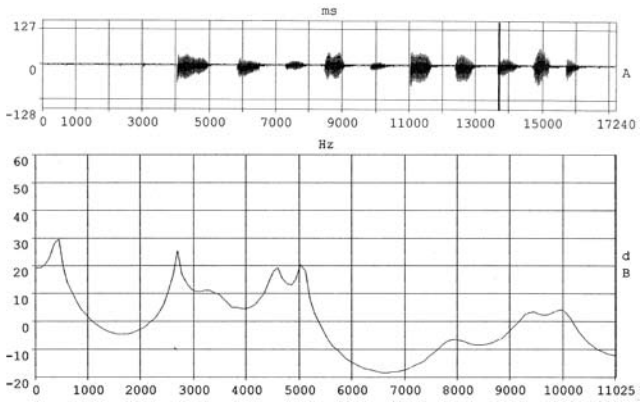

Fig. 1. Acoustic parameter of the voice with LPC method in SLN- patients. Components F2 of vowels /e/ and /i/ have increased.

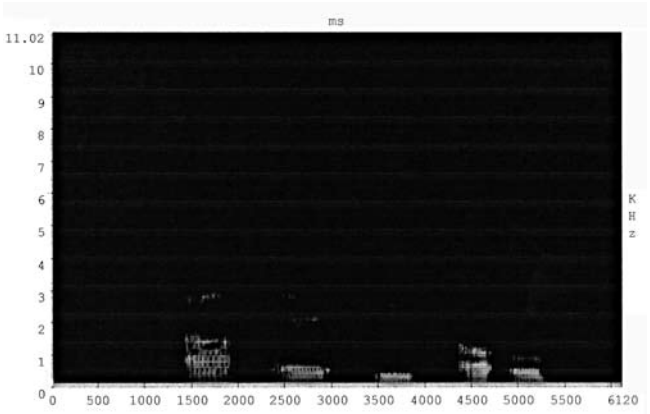

Fig. 2. Spectrographic picture of Type 3: the noise spectrum replaces F2 in all the vocal sounds in SLN- patients.

energy deficit. Energy was normal in 7 SLN+ patients and only one subject reported a slightly decreased energy level.

The spectrographic test, carried out on the vowels and the word "aiuole", was normal in only one of the 7 patients with injury (14.2%). In three of the six remaining patients (42.8%), the main damage was Type 2 of the Yanagihara list, shown both in vowels and the "aiuole" word test (Fig. 2). The 3 remaining patients showed a spectrographic test with a variable noise component. Only one patient (12.5%) in the SLN+ group showed a changed spectrographic test with the type 2 noise spectrum (Table IV).

The psychosocial handicapping aspects of the voice disorder was based on the Voice handicap Index: in 3 of the 7 patients SLN (42.8%), the VHI did not reveal any change in self-perception of the voice characteristics. In the remaining 4 patients (57.2%), this was perceived as the voice deteriorated. Of the 8 patients SLN+, 3 (37.5%) reported changes in the voice. The remaining 5 patients (62.5%) did not report any modification. In all patients with voice problems, after thyroidectomy, the difficulty was generally represented by phonastenia, slight hoarseness, difficulty modulating frequency of the voice, especially during the sharp tone and pronunciation of vowels. The psychological impact of dysphonia on daily activities was well tolerated.

The quality of voice, evaluated by a speech therapist, expert in voice alterations and their treatment, showed in all SLN-cases a failure in the tension of the vocal cords and in larynx muscular activity, resulting in a weak voice and blown whereas patients SLN+ showed no alterations in voice quality.

Table III. F2 evaluation of /e/ and /i/ by means of LPC function in both groups.

Patients	F2			
	/ e /		/ i /	
	SLN- (Hz)	SLN+ (Hz)	SLN- (Hz)	SLN+ (Hz)
1	2862	1798	2548	1993
2	1993	1600	2624	2339
3	2542	1810	2900	2481
4	2664	2379	2685	2603
5	2500	2243	2500	2687
6	2685	2359	3112	2644
7	2518	2025	2705	2484
8		2500		2685
Mean value	2537.7143	2089.2500	2724.8571	2489.5000
Standard Dev.	271.2150	328.4978	213.9115	233.9853
p	0.0135		0.0643	

Discussion

Voice changes after thyroidectomy may be caused by damage to any of the intrinsic structures involved in the complex mechanism of phonation.

The external laryngeal nerve moves the cricothyroid muscles which make the vocal cords tense. It comes into play at frequencies above 150 Hz and it is primarily involved in the production of high tones in the female voice range [11].

In addition, a degree of fine tuning of the voice is achieved by contraction of the vocalist muscle (the medial fibres of the thyroarytenoid), which is supplied by the recurrent laryngeal nerve.

Table IV. Patients with altered spectrogram classified according to Yanagihara [10].

Spectrogram	SLN-		SLN+	
	Vowels	"Aiuola"	Vowels	"Aiuola"
Normal	1	1	7	7
Type 1	2	1	/	/
Type 2	3	3	1	1
Type 3	/	2	/	/
Type 4	1	/	/	/

Damage to the external laryngeal nerve causes paralysis of the cricothyroid muscle. Moosman and DeWeese showed that the external branch usually lies adjacent to the inferior constrictor outside the surgical capsule of the thyroid gland [12]. The surgical method to preserve the SLN is based on developing a plane within the surgical capsule, that would ordinarily separate the vessels from the nerve. In 5.2% of cases, the nerve is either adherent to, or entwined around, branches of the superior thyroid artery within the thyroid capsule. Therefore, the massive ligature of the supra-polar vessels can certainly trap the nerve in one in five of in all cases. Others have noted the proximity of the nerve to the artery in an even higher proportion of cases [13-15]. The external branch of the nerve, may finally disappear into the belly of the inferior constrictor muscle well above the upper pole in 6-15% of cases [16].

In these cases, the nerve, safely out of reach, cannot usually be identified; this might offer an explanation in the cases in which the nerve could not be found. All these anatomical variations would help to better understand the surgical difficulty encountered to preserve the SLN.

In the present study, 7 thyroidectomized patients with a certain SLN lesion were selected and compared with 8 patients in whom the SLN had been identified and preserved in the operating room. As expected, the VLS showed that all the above-mentioned parameters had decreased in the SLN- patients, typical behaviour of the upper larynx lesions, and normal in SLN+ patients. However, in our opinion, the diagnosis of SLN injury cannot be made only with the VLS because it is a subjective test that depends on the ability of the examiner, collects mainly qualitative rather than quantitative information data regarding the cordal movement, the lamp has a limited response to high frequency voice, finally, it is difficult to perform in patients with a dull or aphonic voice. Moreover, a direct link does not always exist between the extension or nature of organic lesions and influence of the cordal vibrations. Due to all the above-mentioned reasons, we have, therefore, adopted the Audio Speech, and the Spectrographic tests, electro-acoustic exams which objectively showed the results obtained at phonatory level.

Our study shows that, regardless of the sex of the patients, as expected, all patients showed a reduction in the F0 on average of 17.7% in the SLN- group and 10.7% in SLN+ patients. Comparing the individual differences between the values before and after thyroidectomy, it can be seen that 4 SLN- subjects (57.1%) and 2 SLN+ patients (25%) presented significant differences between the 2 conditions (Table II).

It is evident that in SLN lesions, the larynx can also compensate by using some unknown mechanism which allows good cordal vibration, even with the functional deficit of the cricothyroid muscle as documented in the VLS (Table I). However, even the alterations found in patients SLN+, indicate that the external nerve is not the only anatomical structure that must be preserved, but, as noted by Painter [17], there are other structures involved in the production of a normal F0. Confirmed by electromyography, Aluffi et al. [18] reported that, even with no injury of the external branch of the superior laryngeal nerve, the acoustic analysis was altered in some patients after thyroidectomy. Hong and Kim [19] reported that phonation time and fundamental frequency were not changed after surgery, but the speaking fundamental frequency, range of speaking fundamental frequency, and vocal range were decreased.

The spectrographic exam, classified according to Yanagihara [10], provides an objective representation of the vocal tone and its variations, as well as defining the degree of dysphonia. The comparative spectrography results on vowels, shown in Table IV, as expected, showed the great importance of the SLN in the production of voice, in all cases, except for the normality result of the SLN- patient which also shows pathological changes of the F2 in / i /. As this last parameter measures the dynamic changes due to the link between pharynx and tongue, it is possible to assume that the patient has compensated the contraction deficit of the cricothyroid muscle with a pharynx hypertone. An even better result can be achieved by raising the tongue which offers the possibility to stretch the larynx upwards and obtain better cordal tension.

The VHI has been obtained, in collaboration with a speech therapist who was an expert in the field of voice alteration treatments, from medical history targeted to identify the patient's disorder and distinguish between the voice alterations (timbre, intensity, stability) and the vocal decreasing capabilities (extension of the communication).

Questions have been asked in order to better understand the patient's difficulties in interacting with others and the psychological impact due to their vocal disorder. The self evaluation is a way to understand how the patient perceives his own voice and how he faces his vocal problem. It also offers the possibility to compare the information gathered by the examiner with the patient's own evaluation.

For this reason, the patient completed a VHI, self evaluation form compared to the pre-treatment situation.

In the VHI, 3 out of 7 patients SLN- did not report any change in the perception of the vocal features. In the remaining 4 patients, the voice perception had changed. In 3 cases, within the group of the 8 SLN+ patients, changes in the vocal features were shown. The remaining 5 patients did not report any variation. In all patients, the impact of vocal issues on daily activities and the psychological impact were well tolerated.

Therefore, in our experience, there is no conformity between the objective and subjective results.

The SLN+ group, in fact, whose overall picture was normal, the male patients reported a post-surgery change in their voice, on their self-evaluation report, while 43% of the SLN- group did not report any phonetic problems, despite showing alterations in the objective tests. A non-

conformity has been found also between the results given by the speech therapist and the self assessment reports, on the one hand, compared to the stroboscopic results, on the other.

Many patients present a reduction in voice range after thyroidectomy [20]. Although it is possible to prevent voice changes after surgery, by preserving the laryngeal nerve, it seems, however, to be inevitable for half of the patients to feel slight changes in their voice after this operation. This shows once again that the perception of your own voice depends on several variables, such as profession, singing habits, psychological underestimation of the vocal functions, which can prevent or accentuate the functional damage of the SLN lesion.

The SLN lesion certainly modifies the vocal function, which is also noticeable and measurable in an objective manner. Those alterations, however, do not show, in all the SLN- patients, probably because of a number of compensating mechanisms, or due to unknown variables which allow good vocal cord vibrations.

SLN preservation, however, is not a sufficient element to prevent changes in vocal function. We have, indeed, discovered that also in patients with SLN presenting normal function after thyroidectomy, the voice was perceived as altered. The impression that the voice is abnormal is possible leading to the permanent alterations of the extrinsic laryngeal muscles that somehow interfere with the phonation [8]. As we all know, indeed, the strap muscles, sternohyoid, and sternothyroid muscles, may be damaged by the lateral retraction or cutting of these muscles during thyroid surgery or by wound contracture with surrounding structures after surgery. These play a role, indirectly or directly, in the functioning of the larynx, but their phonatory function is less well defined. Sonninen [21] reported that the function of the extrinsic laryngeal muscles, the so-called external frame function, is considered to lengthen or shorten the vocal folds and regulate pitch by changing the relation of the thyroid to the cricoid cartilage. On the other hand, many authors have proposed that the sterno-thyroid muscle could serve as a pitch raiser. They speculated that the thyroid cartilage rotates downward around the cricothyroid joint, or the frontal part of the cricoid's ring comes closer to the thyroid cartilage and the arytenoid's cartilage. This results in higher tension of the vocal folds [22].

Others also reported that the contraction of the sternohyoid and sternothyroid muscles caused the laryngo-tracheal downward pull, caused high air volume in the subglottic air space, and corresponded to increases in subglottic pressure. This downward pull resulted in shortening of the cricothyroid distance, and anterior downward bending caused shortening of the anterior cricothyroid distance, resulting in lengthening of the vocal folds and increase in the frequency [23]. Finally, removal of the thyroid gland modifies the vascular supply and venous drainage of the larynx and it cannot be excluded that, in SLN+ patients, surgical manipulation and disturbed vascularization could cause a discreet dysfunction of the SLN nerves.

It is possible that all these factors may work synergistically, making the relative importance of each difficult to assess. For this reason, therefore, it is essential to preserve the SLN. Additionally, it is also fundamental to study the psychological profile of the patient, because he/she could consider this limitation as an irreversible post-operative damage that severely limits quality of life, and to evaluate the impact of dysphonia on professional abilities. The impact of post-thyroidectomy dysphonia on the ability, for example, to work as a singer rather than a librarian is quite different. Finally, the patient should be informed about the possibility of post-surgery dysphonia, even in the absence of a SLN lesion, to avoid the risk of legal dispute.

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