Vocal Outcome After Arytenoid Adduction and Ansa Cervicalis Transfer

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Objective: To evaluate the long-term efficacy of arytenoid adduction (AA) combined with ansa cervicalis–recurrent laryngeal nerve anastomosis (ACN-RLN) in the treatment of unilateral vocal fold paralysis.

Design: Retrospective review of clinical records.

Setting: Institutional practice.

Patients: Nine patients with severe paralytic dysphonia with large glottal gap were included. Voice outcome was followed up over 24 months postoperatively. One patient did not attend the 24-month evaluation.

Interventions: All patients underwent AA + ACN-RLN. The ansa cervicalis nerve to the sternohyoid muscle was used as the donor nerve.

Main Outcome Measures: Maximum phonation time (MPT), pitch range, harmonics-to-noise ratio (HNR), and perceptual voice quality were evaluated preoperatively and postoperatively at 1 to 3 months, 6 to 8 months, 12 to 14 months, and 24 months.

Results: All parameters improved significantly after surgery and continued to improve over the 24-month period. The MPT continued to improve over time (P = .01, P = .006, and P = .001 when comparing the 1- to 3-month evaluation with the 6- to 8-month, 12- to 14-month, and 24-month evaluations, respectively). Also, pitch range and HNR showed significant, steady improvement over the 24-month duration of the study. Perceptual voice quality markedly improved at 24 months compared with the 1- to 3-month, 6- to 8-month, and 12- to 14-month follow-ups (P = .004, P = .005, and P = .02, respectively, for grade overall, and P = .004, P = .008, and P = .02, respectively, for breathiness grade).

Conclusions: Treatment with AA + ACN-RLN provides near-normal vocal function in the 24-month follow-up. Therefore, this method could be a successful surgical treatment for severe paralytic dysphonia.


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VOCAL FOLD (VF) INJECTION, thyroplasty type I, and arytenoid adduction (AA) are common treatments for breathy dysphonia due to unilateral VF paralysis (UVFP). However, some patients do not recover their normal voices following these procedures. Normal voice production requires optimal closure of the glottis with median location of the VFs, symmetrical VF tension and mass, and supple mucosa. Conventional surgical procedures provide static adjustment for some of these features. However, the thyroarytenoid (TA) muscle does not work as the body of the immobile VF, resulting in little contribution in tuning tension and stiffness of the immobile VF as a vibrating structure. Theoretically, reinnervation of the TA muscle is the ideal treatment for UVFP when the immobile VF is located at the median position. Thyroarytenoid contraction provides tension of the VF and a medial bulge of the lower surface of the VF. Accordingly, TA contraction gives rise to shifting of the mucosal upheaval toward the tracheal side, resulting in expansion of the VF vibrating surface, which in turn enables the occurrence of normal mucosal traveling wave. Therefore, reinnervation of TA muscle tone by reinnervation is necessary for retrieval of normal voice production.

A number of reinnervation techniques have been attempted for the treatment of paralytic dysphonia, including nerve-muscle pedicle transfer (NMP),6 direct implantation of a donor nerve,7 and anastomosis of various donor nerves (the ansa cervicalis nerve [ACN]8 and hypoglossal nerve9) to the recurrent laryngeal nerve (RLN). Crumley and Izdebski8 reported voice improvement following reinnervation of the VFs in 2 cases using ACN-RLN. The hypoglossal nerve has been tried successfully for anastomosis to the RLN with acceptable donor site morbidity.9 Tucker8 reported good voice results with some degree of spontaneous return of adduction following NMP flap raised from the omohyoid muscle and implanted onto the TA muscle. Another adductor, the lateral cricoarytenoid (LCA) muscle, was an area for researches. May and Beery13 reported improvement of voice...
quality following omohyoid NMP flap implantation into the LCA muscle. They attributed this improvement to the reestablishment and maintenance of VF tone and mass following the procedure.\textsuperscript{11} Direct implantation of ACN into the TA muscle was tried as an alternative to the anastomosis with the RLN when the latter could not be located because of neck scarring, with improved phonatory quality in 80% of cases.\textsuperscript{7} Among these, ACN-RLN was the most frequently reported and demonstrated improvement of vocal function.\textsuperscript{12} However, reports regarding ACN-RLN anastomosis lacked time-dependent systematic data of postoperative vocal function.\textsuperscript{8,13-17} The study by Lorenz et al\textsuperscript{18} was the only one that followed patients' voices over long periods, at 6, 12, and 18 months after the procedure.\textsuperscript{18} They reported significant improvement of voice quality in comparison with preoperative voice. However, they failed to compare postoperative voice with normal voice quality. Chhetri et al\textsuperscript{19} combined AA and ACN-RLN anastomosis and reported significant decrease of perceived severity of hoarseness. However, the rating of postoperative voice (a mean rating of 2.9 based on a 7-point scale, where 1 indicates normal quality and 7 indicates severely abnormal quality)\textsuperscript{16} is still far from indicating normal voice quality. One reason of this unsatisfactory result seemed to come from varying follow-up periods ranging from 3 to 36 months.

In the present study, we combined AA and ACN-RLN for treating severe breathy dysphonia due to UVFP. Vocal function was followed up for 24 months to evaluate the short- and long-term efficacy of this combined procedure.

This study was conducted in 9 adult patients (5 men and 4 women) among those presenting with breathy dysphonia due to UVFP in the period from October 2001 to November 2008. Their mean (SD) age was 53 (14.5) years. The etiology of their UVFP was as follows: 1 patient had surgery for basilar meningioma; 1 had surgery for right vertebral artery aneurysm, 1 had surgery for a neck tumor, 1 had surgery for vagal schwannoma, 2 had surgery for aortic aneurysm, 1 had idiopathic etiology, 1 had left bulbar palsy (Wallenberg syndrome), and 1 had a mediastinal tumor. The diagnosis was established by history, fiberoptic nasopharyngolaryngoscopy, and videostroboscopy. The inclusion criterion was paralytic dysphonia with a moderate to large glottal gap. The time from the onset of paralysis to surgery ranged from 6 to 41 months (mean [SD], 17.0 [12.5] months). During this period, 2 patients experienced trials of voice therapy for 7 and 8 months without improvement. In this group, only 1 patient had a history of laryngeal surgery in the form of thyroplasty type 1 performed at a different hospital 2 years before our treatment, but it failed to improve his voice. Four patients had comorbidities: diabetes mellitus with associated left X, XI, and XII nerve paralysis; hypertension; palatal paralysis; and associated left IX, X, and XII nerve paralysis). None of the patients had a history of irradiation prior to surgery. In our technique, AA was combined with ACN-RLN (AA + ACN-RLN) to close the posterior glottal gap and to restore the TA muscle bulk and tone at the same time. The ACN branch to the sternohyoid muscle was used as the donor nerve for anastomosis with the RLN in combination with AA. The inferior root of the ACN was preserved. We modified the method of Ishikawa et al\textsuperscript{20} method to perform AA; first, the connective tissue on the posterior cricoid lamina was preserved between the cricothyroid and cricoarytenoid (CA) joints, where the adductor branch of the RLN passes, and, second, the CA joint was not opened. Subjective and objective voice parameters were evaluated 5 times: preoperatively and postoperatively at 1 to 3 months, 6 to 8 months, 12 to 14 months, and 24 months. These parameters are maximum phonation time (MPT), pitch range, harmonics-to-noise ratio (HNR), grade overall (G), and breathiness grade (B) of the grade overall-roughness-breathiness-asthenia-strain scale (GRBAS). This study was approved by the institutional review board, Kumamoto University Hospital, Kumamoto, Japan.

Surgical Technique

The surgical technique is as follows: first, preliminary direct laryngoscopy is performed on the operating table to confirm passive arytenoid cartilage mobility. General anesthesia using a small endotracheal tube is administered to the patient. A horizontal neck incision is made extending from the midline to anterior border of the sternocleidomastoid (SCM) muscle on the paralyzed side at the level of the lower one-fourth of the thyroid cartilage. The skin flap, including the platysma, is elevated to the upper margin of the thyroid cartilage (TC) and to the lower margin of the cricoid cartilage.

Next, the space anterior to the SCM muscle is opened, exposing the internal jugular vein and the AC nerve and its branch to the OH muscle. The OH muscle is cut, and the AC nerve is followed inferiorly until its entrance to the SH muscle. The major branch to the SH muscle was identified via nerve stimulation, transected, and freed cranially so that it could be mobilized for anastomosis. The RLN can be identified in the tracheoesophageal groove after elevation of the posterior border of the ipsilateral thyroid lobe.

Next, in the approach to arytenoid cartilage and creating the anastomosis, hydrocortisone sodium succinate, 500 mg, is administered intravenously over 40 to 60 minutes. The strap muscles are cut, and the whole thyroid ala is exposed. Then, the attachment of the superior cornu to the thyrohyoid (TH) ligament is severed. The thyropharyngeal muscle is cut and detached from the thyroid ala. The inferior cornu is exposed, and the cricothyroid (CT) joint is severed. Subsequently, the thyroid ala is pulled and rotated to the contralateral side to open the ipsilateral paraglottic space. Palpation along the surface of the posterior cricoid lamina toward the cranial direction is helpful at this stage to identify the muscular process of the arytenoid cartilage. The CA joint is located as a depression between the cricoid and arytenoid cartilages, and the muscular process of the arytenoid cartilage is identified as a small protrusion just above the CA joint. The muscular process is grasped with a pair of Adson forceps, and its mobility is confirmed. Two nylon threads (3-0) are passed through the muscular process without opening the CA joint and tied as 2 knots for later use (Figure 1A). Great attention is paid to avoid injury of the pyriform sinus mucosa and the anterior division of the RLN at the surface of the posterior cricoid lamina where it is vulnerable. The proximal end of the already prepared ACN is anastomosed to the distal stump of the RLN with 3 or 4 stitches using 9-0 nylon thread under the surgical microscope (Figure 1B).

Finally, fixation of the muscular process of the arytenoid cartilage to the anterior surface of thyroid ala is performed: 2 small adjacent holes are made in the thyroid ala. The posterior hole is placed just anterior to the inferior tubercle, and the anterior hole is located 3 mm apart. Nylon threads are now introduced to the anterior surface of the thyroid ala through these holes. For each knot, one end of the thread is passed through

\section*{METHODS}

\begin{figure}[h]
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\includegraphics[width=\textwidth]{figure1.png}
\caption{Figure 1.}
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\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Figure 2.}
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\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Figure 3.}
\end{figure}
a thyroid hole, and the other passed through the CT membrane. Then, the threads were tied into 2 adjacent knots over 2 small pieces of silicon after applying suitable traction (Figure 1B). Finally, the strap muscles are sutured, 2 drains were left in the wound, and the skin is closed.

**AERODYNAMIC MEASUREMENT**

Each patient was instructed to produce sustained phonation of the vowel /a/ as long as possible at a comfortable pitch and loudness. The MPT was measured twice using a stopwatch, and the higher value was recorded.

**PITCH RANGE**

Each patient was instructed to produce the vowel /a/ into the mouthpiece repeatedly in ascending pitches up to the highest pitch, and, then, in descending pitches down to the lowest pitch. Pitch range was measured from the phonetogram using the PS-77E phonatory function analyzer (Nagashima, Tokyo, Japan) and expressed in a semitone scale.

**VOICE RECORDING**

Voice recording was carried out in a sound proof room using a Marantz Solid State Recorder (model PMD 670; Sagamihara, Japan) connected to a microphone (model WM-421; Panasonic, Osaka, Japan). The microphone was held at a distance of 20 cm from the mouth during recording. Recorded samples included name, date, standard text, and sustained phonation for the vowel /a/ at a comfortable pitch and loudness. The voice was digitized at 43 kHz through an anti-aliasing filter and stored in pulse-code modulation format. The vowel segments were used for acoustic analysis, and the speech segments of the records were used for auditory perceptual assessment.

**ACOUSTIC ANALYSIS**

The noise to harmonics ratio (NHR) was measured using the Multi-Dimensional Voice Program (MDVP) (model 5103, version 3.1.7; Kay Elemetrics, Lincoln Park, New Jersey) and was converted to HNR. The vowel segment was cut from the complete voice sample, and then 3 different seconds from this segment were trimmed and analyzed. The mean value of HNR was calculated for each patient from the 3 obtained results.

**AUDITORY PERCEPTUAL ASSESSMENT**

Speech segments were treated by cutting the names before they were subjected to auditory perceptual assessment by GRBAS to prevent any possible bias. The assessment was conducted by 3 different listeners (2 trained otolaryngologists [M.M.H. and E.Y.] and 1 speech pathologist [N.K.]) in a random order of the different evaluations. Finally, the mean values of G and B were calculated and recorded for each patient.

**STATISTICS**

Before collection of data, we predicted the difference in means between preoperative and postoperative measurements and among the different postoperative measurements over time if any should go in 1 direction for a parameter. These differences must be tested to determine whether they are statistically significant. Nonetheless, if there was any significant difference in the unpredicted direction for a parameter, we attributed that to a mere chance and considered it to be not statistically significant. Therefore, 1-tailed paired t test was used to compare among the repeated measurements of each voice parameter. Values of voice parameters at 24 months are not matched with the rest of the evaluations because 1 patient missed the evaluation at 24 months. Therefore, unpaired t test (1-tailed) was used for the unmatched comparisons. Also, Tukey multiple comparison test was used to adjust the P values obtained by t test.

**RESULTS**

All patients were evaluated 5 times, except for 1 who missed the 24-month evaluation. The 5 voice parameters improved significantly after surgery relative to the preoperative evaluation. In addition, voice parameters continued to improve over time, as is evident across the postoperative evaluation periods (Table 1). For reference, Table 2 shows the ranges obtained from healthy Japanese men and women ages 50 to 59 years for MPT, MFR, and pitch range. The normal ranges for jitter (<1.04%), shimmer (<3.81%), and HNR (>7.21 dB) were listed ac-
The MPT continued to improve over time with linear trend. Further voice improvements were evident when 1- to 3-month evaluations were compared with 6- to 8-month, 12- to 14-month, and 24-month evaluations (P = .01, P = .006, and P = .001, respectively) (Figure 2). The mean MPT improved steadily, reaching normal range in the final measurement.

INCREASED PITCH RANGE

Pitch range also continued to increase over time with linear trend. Further improvements of pitch range were evident when comparing the 1- to 3-month evaluations with the 6- to 8-month and 12- to 14-month evaluations (P = .009 and P = .002, respectively) (Figure 3), although the mean pitch range remained just below the normal range at the 24-month evaluation.

ACOUSTIC REANALYSIS

The HNR showed 2 significant improvements among the postoperative evaluations when comparing the 1- to 3-month evaluations with the 6- to 8-month and 24-month evaluations (P = .04 and P = .03, respectively) (Figure 4). The mean value of HNR reached normal range in the final measurement at the 24-month evaluation.

AUDITORY PERCEPTUAL REASSESSMENT

Auditory perceptual assessment (G and B) continued to improve over time with linear trend following AA + ACN-RLN. This was evident when results at 24 months were compared with results at 1 to 3 months, 6 to 8 months, and 12

Table 1. Results of Paired t Test and Tukey Multiple Comparison Test in the Comparison Among Repeated Measurements of the Different Voice Parameter After AA + Ansa Cervicalis–RLN Anastomosis

<table>
<thead>
<tr>
<th>Point of Comparison</th>
<th>MPT</th>
<th>Pitch Range</th>
<th>HNR</th>
<th>GRBAS G</th>
<th>GRBAS B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preop vs 3 mo</td>
<td>≤.05/.05</td>
<td>≤.001/.001</td>
<td>≤.05/.05</td>
<td>≤.01/.01</td>
<td>≤.01/.001</td>
</tr>
<tr>
<td>Preop vs 6 mo</td>
<td>≤.01/.01</td>
<td>≤.001/.001</td>
<td>≤.01/.01</td>
<td>≤.01/.01</td>
<td>≤.01/.001</td>
</tr>
<tr>
<td>Preop vs 12 mo</td>
<td>≤.001/.001</td>
<td>≤.001/.001</td>
<td>≤.001/.01</td>
<td>≤.001/.001</td>
<td>≤.001/.001</td>
</tr>
<tr>
<td>Preop vs 24 mo</td>
<td>≤.001/.001</td>
<td>≤.001/.001</td>
<td>≤.001/.001</td>
<td>≤.001/.001</td>
<td>≤.001/.001</td>
</tr>
<tr>
<td>3 mo vs 24 mo</td>
<td>≤.01/.01</td>
<td>≤.05/.05</td>
<td>≤.01/.05</td>
<td>≤.01/.001</td>
<td>≤.01/.001</td>
</tr>
</tbody>
</table>

Abbreviations: AA, arytenoid adduction; B, breathiness grade; G, grade overall; GRBAS, grade-roughness-breathiness-asthenia-strain scale; HNR, harmonics-to-noise ratio; MPT, maximum phonation time; preop, preoperative; RLN, recurrent laryngeal nerve anastomosis.

a Unpaired t test.

Table 2. Ranges for MPT, MFR, and Pitch Range Obtained From Healthy Japanese Men and Women Ages 50 to 59 Years

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPT, seconds</td>
<td>12.5-30.4</td>
<td>14.2-19.3</td>
</tr>
<tr>
<td>MFR, mL/s</td>
<td>113-262</td>
<td>99-173</td>
</tr>
<tr>
<td>Pitch range, semitone</td>
<td>18.2-28.6</td>
<td>18.7-30.4</td>
</tr>
</tbody>
</table>

Abbreviations: HNR, harmonics-to-noise ratio; MFR, mean airflow rate; MPT, maximum phonation time; NHR, noise to harmonics ratio.

*See Lee et al.17 The percentage range for jitter is less than 1.04%; for shimmer, less than 3.81%; and for HNR (in decibels), greater than 7.21 dB [HNR (dB) = 10log(1/NHR)].
to 14 months (P=.004, P=.005, and P=.02, respectively, for G; and P=.004, P=.008, and P=.02, respectively, for B) (Figure 5). Voice quality showed excellent improvement to normal voice (G, 0; B, 0) in 6 of 8 patients at 24 months. The remaining 2 patients had near-normal voice quality at the same evaluation period (the mean score of the 3 listeners were G, 0.3; B, 0.3; and G, 0.3; B, 0.6).

Treatment with ACN-RLN restores the bulk and tension of the immobile VF as a vibrator. In the present series, AA was added to locate the immobile VF at the midline for closure of the moderate to large glottal gap. Theoretically, a combination of AA and reinnervation would be expected to further improve vocal function over AA, type I thyroplasty, intrafold injection, and any combination of these procedures. Chhetri et al.16 conducted a comparative study between AA + ACN-RLN (10 patients) and AA alone (9 patients). Evidence of reinnervation were reported in 1 of their patients in the combined group. In that case, postoperative EMG and magnetic stimulation studies performed 15 months after surgery showed not only that the VF was reinnervated but also that the activation pattern was normal in its timing, indicating that the TA muscle was activated correctly during voice production. Another patient who had failed treatment with a type I thyroplasty after resection of vagal schwannoma underwent AA + ACN-RLN. Complete glottal closure was achieved, and perceptual voice improvement was excellent 15 months after surgery.18 However, the overall results of that study did not show any significant differences in the videostroboscopic parameters, aerodynamic measures, and perceptual ratings between the 2 groups. Although Chhetri et al.16 speculated that the results were due to the small number of patients in the study, we inferred that the most probable reason was the variability of their follow-up periods, which ranged from 3 to 36 months. Four of 10 patients in the combined group were examined within 8 months. Voice outcome after reinnervation procedure usually begins to improve 4 to 6 months after the procedure22 and is expected to improve over at least 1 year postoperatively. Therefore, their report lacks the time-dependent follow-up.

To our knowledge, all studies reporting voice outcomes following AA and type I thyroplasty,1,2,21-23 combined procedures,16,22 concentrated mainly on comparing preoperative evaluation with only 1 postoperative evaluation without conducting repeated voice measurements at different time points after surgery. Lack of such repeated measurements makes it difficult to formulate a clear concept about the pattern of vocal function over time. Lorenz et al.18 compared preoperative videostroboscopic and perceptual measurements with those followed for the evaluation. Results of the present study agreed with those obtained in other studies listed herein that voice improved significantly after reinnervation.

The present study revealed a continuous voice improvement for 24 months after AA + ACN-RLN. Perceptual voice quality showed linear-trend improvement over time, with the best voice improvement 24 months after surgery. The voice improved to normal or near-normal quality in most cases at 24 months, with 6 of 8 patients having scores of 0 for G and B. In addition, there was a trend toward continuous improvement in perceptual voice quality even in the absence of any significant difference among 1- to 3-month, 6- to 8-month, and 12- to 14-month evaluations, which is mostly due to the limited number of patients. This steady voice improvement most probably reflects the continuously added effect of the reinnervation process achieved by ACN-RLN over the 24-month follow-up period.

Objectively, all voice parameters in the present study showed further significant improvements after the initial evaluation as illustrated in Figures 2, 3, and 4. The MPT clearly showed continuous improvement with steady increase over the 24-month follow-up period. In addition, pitch range continued to improve over time. Apart from the insignificant decline of the mean (SD) pitch range

Figure 4. Harmonics-to-noise ratio (HNR). Results of comparisons among the different postoperative evaluations of the 9 patients in the study. Results of comparisons to preoperative evaluation are not plotted. One patient did not attend the 24-month follow-up. Preop, preoperative. *P≤.05.

Figure 5. Grade-roughness-breathiness-asthenia-strain scale (GRBAS). Results of comparisons among the different postoperative evaluations of the 9 patients in the study. Results of comparisons to preoperative evaluation are not plotted. One patient did not attend the 24-month follow-up. B, breathiness grade; G, grade overall; preop, preoperative. *P≤.05. †P≤.01.
at 24 months (18.0 [4.0]) relative to 12 months (19.3 [6.0]), the overall outcomes of pitch range showed continuous increase over time with a linear trend pattern (Figure 3). The HNR also improved continuously after surgery in a linear trend with 2 further significant improvements during the postoperative evaluation periods. Our findings might support the assumption of Chhetri et al26 that AA combined with laryngeal reinnervation provides theoretical advantages over AA alone in the treatment of UVFP. However, a comparative study should be performed to confirm that AA + ACN-RLN results in better postoperative vocal function than AA alone.

The pattern of voice outcome in the present study can be explained by the glottal closure achieved by AA and the bulk and tension enhanced by contraction of the TA muscle, which is restored over time by ACN-RLN. However, the exact time span required for the beginning of TA reinnervation could not be determined. Maronian et al26 reported EMG findings in 8 patients who underwent either NMP flap transfer or ACN-RLN. They found return of voicing in 6 weeks to 7 months and maximum voice improvement 5 to 12 months postoperatively.26 In a review for reinnervation techniques in which ACN-RLN was most frequently applied, the mean time to the first sign of reinnervation was 4 months.21 In the present study, MPT, pitch range, and HNR significantly increased at 6 to 8 months compared with the measurements taken at 1 to 3 months. Thus, our results agreed with those of previous reports. However, future studies including EMG examination are needed to determine the time span required for beginning and fully establishing reinnervation following ACN-RLN.

In conclusion, AA + ACN-RLN provides near-normal vocal function by the 24-month follow-up in patients with UVFP having a moderate to large posterior glottal gap. Therefore, this method can be considered successful surgical treatment for severe paralytic dysphonia.

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Author Contributions: Dr Hassan had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Yumoto. Acquisition of data: Hassan, Kumai, and Kodama. Analysis and interpretation of data: Hassan, Yumoto, and Sanuki. Drafting of the manuscript: Hassan, Kumai, and Sanuki. Critical revision of the manuscript for important intellectual content: Yumoto and Kodama. Statistical analysis: Hassan. Administrative, technical, and material support: Kodama. Study supervision: Yumoto.

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