Incidence and Outcomes of Revision Bronchoscopies Following Bronchoscopic Lung Volume Reduction (BLVR)

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Background: Bronchoscopic lung volume reduction (BLVR) is a minimally invasive procedure used to reduce shortness of breath and improve functionality in some patients with emphysema. While BLVR is often effective for improving dyspnea by causing target lobe atelectasis, the treatment effect can sometimes be lost. This study reviews the incidence of revision bronchoscopies in patients who lost or never achieved target lobe atelectasis following BLVR.

Methods: This retrospective, single-center analysis reviewed patients who underwent BLVR over a 5-year period. All patients were determined to be collateral ventilation negative by an intraprocedural Chartis system assessment. Treatment success was defined as radiographic target lobe atelectasis. For patients who underwent revision bronchoscopies, the EMR was used to review procedure notes, radiographic imaging, post-BLVR analyses, and outpatient clinic notes to collect data on the indication for revision bronchoscopy, intraprocedural observations accounting for loss of treatment effect, revision interventions performed, and outcomes of revision bronchoscopies. After a minimum of 10 postoperative days, at the discretion of the treating physician, an EBV revision bronchoscopy could be performed if target lobe atelectasis was lost or never developed after initial treatment.

Results: Forty-three total valve revision procedures were performed, based on first, second, and third bronchoscopies combined. The most common cause for revision bronchoscopy based on the intraoperative assessment was air leaking around one or more valves from either incorrect sizing of previous valves or airway stretching in 18 revision procedures (42%). Thirty-four revision procedures (79%) were performed for loss of previous atelectasis, and 24 (70%) resulted in the redevelopment of target lobe atelectasis. Nine revision procedures (21%) were performed for lack of initial target lobe atelectasis. Two of the 9 revision procedures (22%) performed for failure to achieve initial atelectasis resulted in new target lobe atelectasis.

Conclusion: Post-BLVR revision bronchoscopies are necessary in ~20% of patients for either loss of target lobe atelectasis or failure to achieve atelectasis after the initial BLVR procedure. In many cases, especially when atelectasis is lost, revision bronchoscopies can reestablish post-BLVR atelectasis.

Key Words: bronchoscopic lung volume reduction, revision bronchoscopy

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Bronchoscopic lung volume reduction (BLVR) is a minimally invasive procedure used to reduce shortness of breath and improve functionality in select patients with emphysema.[1–3] Small, removable endobronchial valves (EBV) are placed into the airways of diseased and hyperinflated lobes of the lung to reduce lung volume and improve diaphragmatic motion. Patients without interlobar collateral ventilation have the greatest degree of lung volume reduction and more significant clinical improvements due to target lobe atelectasis.[4,5] BLVR aims to emulate the benefits of lung volume reduction surgery (LVRS) without the degree of observed morbidity and mortality seen in the National Emphysema Treatment Trial (NETT).[6]

While BLVR is often effective for improving dyspnea, the treatment effect can sometimes be lost.[7] When target lobe atelectasis is lost or never achieved, patients may require repeat bronchoscopies to revise one or more EBVs.[8–10] A variety of etiologies can account for the loss of atelectasis, the most common being loss of paravalvular airway seal around the EBV, granulation tissue formation, or failure of EBV function. Positive treatment effect can be determined by the radiographic presence of post-BLVR atelectasis.

This study describes the incidence of revision bronchoscopies in patients who lost or never achieved target lobe atelectasis following BLVR. BLVR success was defined as achievement of target lobe atelectasis. Multiple data points were assessed during this study, including the incidence of revision, the number of revisions, the lobe requiring EBV revision, and the intraprocedural reason for revision. This analysis will provide both patients and physicians with data relating to indications and outcomes for patients requiring additional bronchoscopic procedures following BLVR.

METHOD

This retrospective, single-center analysis assesses patients who underwent BLVR over a 5-year period. Patients were treated with EBVs (Zephyr, PulmonX

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Studies involving human subjects (including research on identifiable human material and data) must have been performed with the appropriate participants' informed consent in compliance with the Helsinki Declaration. As this was a quality improvement study, the local regulatory body at Inova Fairfax Hospital did not require ethical standard approval. This study protocol was reviewed and the need for approval was waived by the Inova Health System Institutional Review Board. Despite the lack of need, all ethical standards were followed in this study.
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Corporation, Redwood City, CA) for the purpose of BLVR. All patients who underwent BLVR for emphysema were selected based on pulmonary function testing (PFT) with volume assessments using a body box, 6-minute walk distance (6MWD), absence of significant pulmonary hypertension, and quantitative computer tomography analysis using Stratx Lung Analysis Report (Supplied by PulmonX, Redwood City, CA). The inclusion criteria used in the LIBERATE study was used to guide BLVR appropriateness. Every patient underwent bronchoscopic Chartis system (Supplied by PulmonX Corporation, Redwood City, CA) assessment and were absent of collateral ventilation before valve insertion. Following BLVR, all patients were admitted to the inpatient unit for 72 hours. During that period, daily chest x-rays were performed to assess for pneumothorax and to confirm or deny the presence of target lobe atelectasis. A majority of patients underwent chest computer tomography (CT) before discharge if obvious atelectasis was not seen on chest x-rays. Procedural success was determined by the presence of atelectasis in the target lobe post-BLVR. Improvement in symptoms observed for all patients undergoing BLVR at the institution shows an increase in forced expiratory volume in 1 second (FEV1) of 28% and an SGRQ reduction score of −9, compared with an FEV1 increase of 17.16% and an SGRQ reduction score of −7.55 seen in the LIBERATE trial.[1]

Loss of treatment effect was defined as loss of target lobe atelectasis. If complete target lobe atelectasis was not present post-BLVR, failure to achieve greater than a 50% reduction in total lung volume reduction (TLVR) was also an indication for revision.[11] Reduction in TLVR of > 50% was determined by post-Stratx analysis. A post-Stratx analysis is a test based on a prerevision high-resolution CT scan. Trained radiologists reviewed the prerevision CT scans to identify malpositioned valves or signs of paravalvular air leakage. In addition, lobar volumes can be quantified on these analyses to determine volumetric changes in TLVR. In most patients, post-BLVR PFTs, 6MWD, St. George's Respiratory Questionnaire (SGRQ), and body mass index, obstruction, dyspnea, and exercise capacity (BODE) index were followed at 3, 6, and 12 months to assess recurrence of hyperinflation or worsening of dyspnea. Worsening in shortness of breath and PFTs were utilized as indicators to assess for loss of post-BLVR atelectasis. Dislodgement or expectoration of valves was not included in this analysis as a need for revision. Instead, dislodgement or expectoration was considered an indication for repeat EBV insertion.

For patients who underwent revision bronchoscopies, the EMR was used to review procedure notes, radiographic imaging, post-BLVR analyses, and outpatient clinic notes to collect data on the indication for revision bronchoscopy, intraprocedural observations accounting for loss of treatment effect, revision interventions performed, and outcomes of revision bronchoscopies. After a minimum of 10 postoperative days, at the discretion of the treating physician, an EBV revision bronchoscopy could be performed if atelectasis was lost or if atelectasis never occurred. In most cases, the treating physician used a post-Stratx analysis to help identify EBVs needing revision. The treating physician had the ability to remove valves and wait until a later date to reinsert them if excessive granulation tissue or swelling was present in the airways. New valves could be placed in the same location as previous or more distally at the discretion of the treating physicians.

TABLE 1. Demographic Data

No. patients	30
Age (mean)	67 ± 6 y
Male: female	15:15
Forced expiratory volume at 1 second (FEV1) (mean)	31 ± 11%
Residual volume (RV) (mean)	205 ± 49%
Six-minute walk distance (6MWD) (mean)	263 ± 92 m
St. George's Respiratory Questionnaire	58 ± 17

TABLE 2. Reason for EBV Revision

Cause	No. patients (%)
Paravalvular leak	17 (38%)
Granulation tissue	6 (14%)
Malfunctioning valve	2 (5%)
Unable to determine the cause	18 (42%)

RESULTS

Over the 5-year period between August 2019 and March 2024, 148 patients underwent BLVR for emphysema. Thirty of the 148 patients (20%) required at least one revision bronchoscopy. Demographic data is listed in Table 1. Twenty patients (66%) required 1 revision, 11 patients required 2 revisions (37%), and 2 patients (6%) required 3 revisions. The median number of days to the first revision was 361.5 (interquartile range of 155 to 533). The median number of days between the first and second revision was 316 (interquartile range: 184 to 372). There were only 2 incidences of third revisions, with median days from the second to the third revision of 204 at days 176 and days 232. Fifteen of the 30 patients (50%) who underwent revision bronchoscopy required the procedure in the first year after initial valve placement. The right upper and right middle lobe treatment combination was the most common target for valve revision (30%). The most common indication for EBV revision was loss of target lobe atelectasis in 29 cases (67%). Failure to achieve initial BLVR target lobe atelectasis accounted for 12 revision procedures (28%).

Forty-three total valve revision procedures were performed, based on first, second, and third bronchoscopies together combined. In this cohort, all valve replacements during revision procedures occurred during the same bronchoscopy. The most common cause for revision bronchoscopy based on the intraoperative assessment was air leaking around one or more valves from either incorrect sizing of previous valves or airway stretching in 17 revision procedures (38%). The development of granulation tissue around or on one or more valves accounted for 6 revision procedures (14%), and the presence of malfunctioning valves (failure of the duckbill to close) accounted for 2 revision procedures (5%). The cause for loss of atelectasis was not

TABLE 3. Lobe Requiring Revision

Lobe	No. (%)
Right upper lobe	2 (7)
Right upper lobe/right middle lobe	9 (30)
Right lower lobe	4 (13)
Left upper lobe	7 (23)
Left lower lobe	8 (27)

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able to be determined intraoperatively in 18 revision procedures (42%) (Table 2). The lobe requiring revision was the right upper lobe in 2 patients (7%), the right upper lobe/right middle lobe in 9 patients (30%), the right lower lobe in 4 patients (13%), the left upper lobe in 7 patients (23%), and the left lower lobe in 8 patients (27%) (Table 3). Of the 34 revision procedures performed for loss of previous atelectasis, 24 (70%) resulted in the redevelopment of target lobe atelectasis. Two of the 9 revision procedures (22%) performed for failure to achieve initial BLVR atelectasis resulted in new target lobe atelectasis (Fig. 1). Incidence of pneumothorax during initial bronchoscopy occurred in 4 patients (13%). No pneumothoraces developed following revision bronchoscopies. Two patients (7%) suffered a chronic obstructive lung disease (COPD) exacerbation following initial bronchoscopy, defined as having an increased oxygen requirement requiring a steroid course. One patient (3%) suffered from a COPD exacerbation requiring a steroid course after revision bronchoscopy.

Post-BLVR analyses were obtained before 41 of the 43 revision procedures (95%). The suggested reason for the loss of treatment effect on post-BLVR analysis matched the bronchoscopic assessment for the cause of treatment effect loss in 21 revision procedures (51%).

DISCUSSION

The 20% revision rate in our cohort is significantly lower than the previously published 41% by Roodenburg and colleagues. Furthermore, to our knowledge, this represents the lowest revision rate published to date. The most common indication for revision bronchoscopy was paravalvular leakage around EBVs. While individual physicians may have different indications for performing a revision bronchoscopy, expert panel recommendations endorse repeat EBV evaluation for patients with no volume reduction ~6 weeks after treatment, sudden loss of treatment benefit and/or loss of volume reduction, persistent cough, persistent hemoptysis, or obstructive pneumonia.[12] The higher revision rate observed by Roodenburg and colleagues may be related to the inclusion of patients with hemoptysis, persistent cough, valve expectoration, hypoxemia, or obstructive pneumonia. These symptoms and clinical findings are indications for valve evaluation but may not be an indication for actual revision.

The 20% revision rate is based solely on loss of target lobe atelectasis or failure to achieve initial post-BLVR atelectasis. This remains lower than the 31% revision rate for matched indications seen in the Roodenburg and colleagues cohort. Procedural success was defined as the achievement of target lobe atelectasis in our study. This radiographic outcome was an important endpoint in the LIBERATE trial.[1] While improvement in SGRQ and other symptomatic indicators was important in the LIBERATE Trial, these values are subject to bias from other comorbid medical conditions that could cause subjective dyspnea, such as cardiac disease and deconditioning. Our goal with revision bronchoscopy was to reestablish treatment effect or determine if valve placement or function was responsible for the lack of initial post-BLVR atelectasis.

Revision success in our cohort was significantly influenced by the presence or absence of initial post-BLVR atelectasis. Patients who had initial target lobe atelectasis were observed to reestablish atelectasis with target lobe atelectasis again in 70% of cases after valve revision bronchoscopy. Conversely, if no initial post-BLVR atelectasis was observed, revision bronchoscopy only resulted in new atelectasis in 22% of patients (Fig. 2). The 7 patients who failed to achieve atelectasis despite revision bronchoscopy did not have valves removed in our cohort. Follow-up data was available for 5 of these patients and showed that this group had a significant improvement in 6MWD or SGRQ. These benefits allowed for improvements in quality

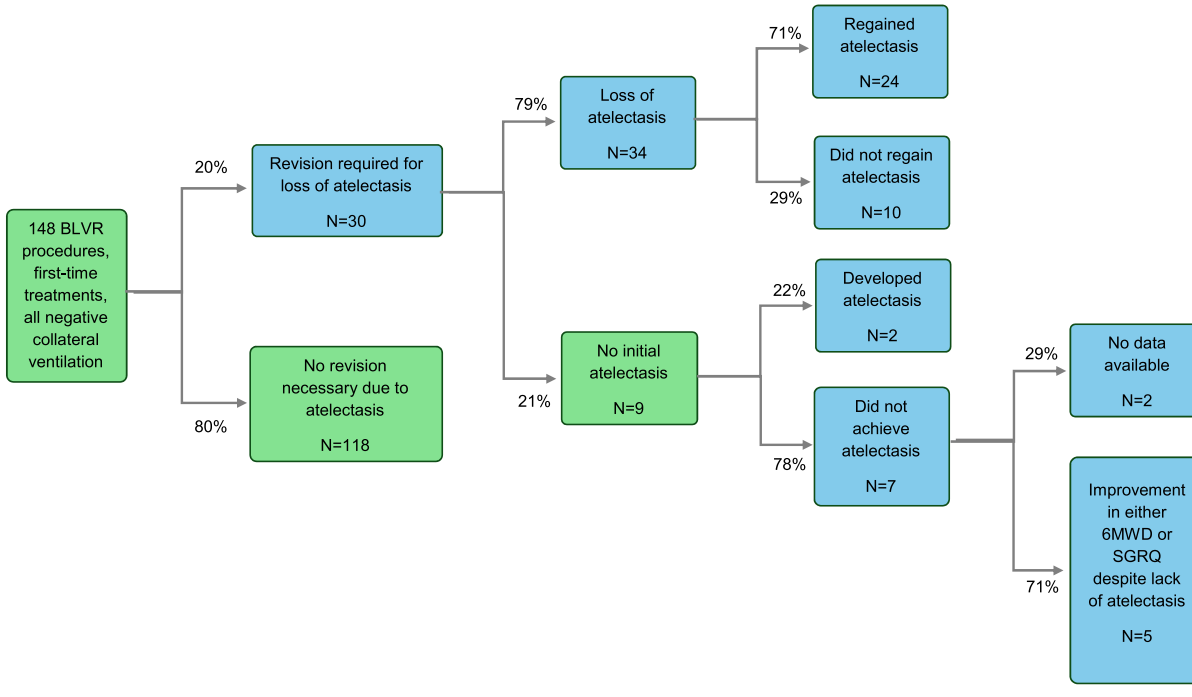

FIGURE 1. Revision incidence and presentation.

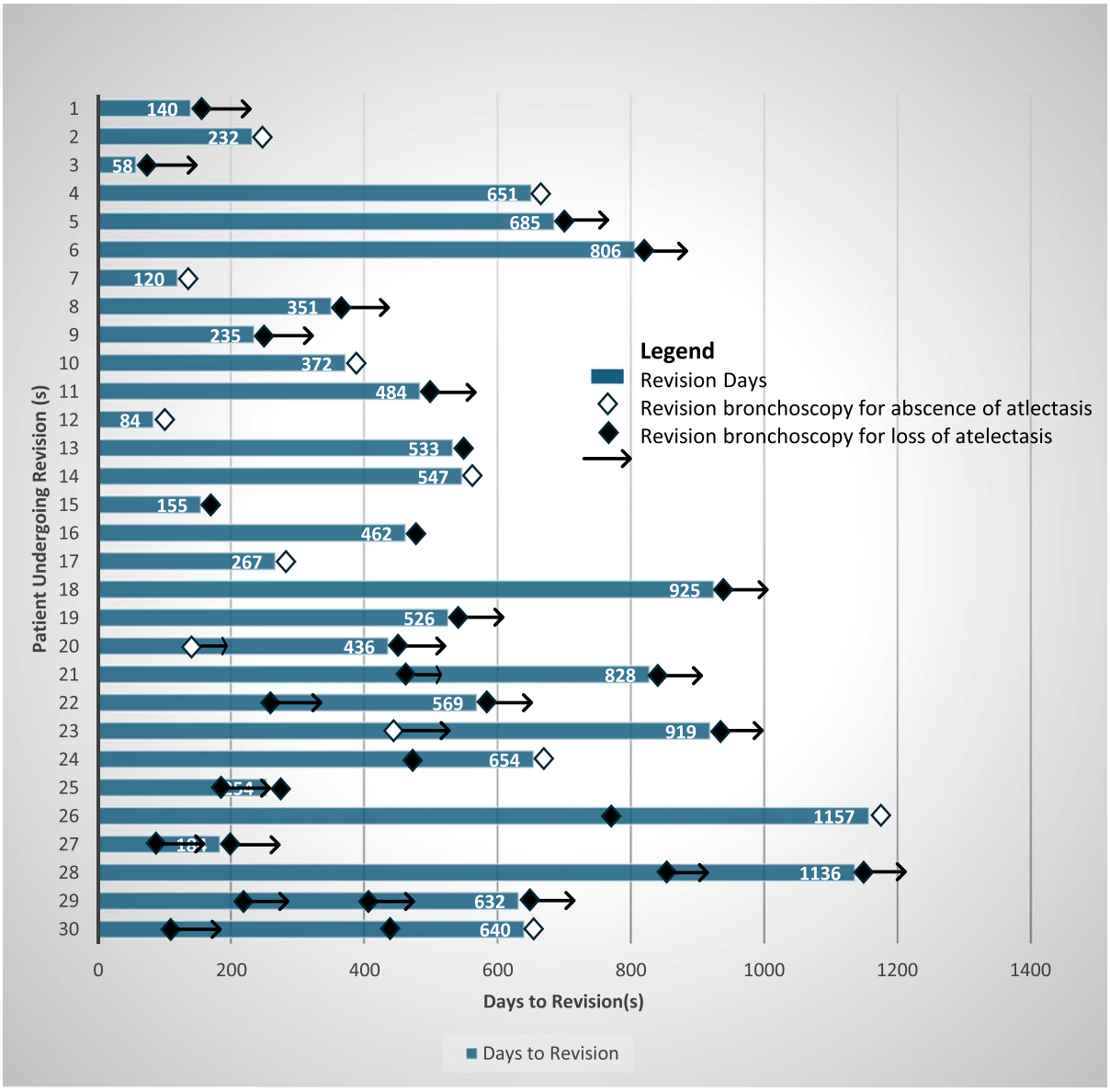

FIGURE 2. Swimmer plot of revisions and outcomes.

of life that deemed the procedure a success for those patients without desire for further revision procedures, despite the lack of target lobe atelectasis. Such outcomes were also seen in the EMPROVE study utilizing the Spiration Valve System (Olympus Corporation, Redmond, WA), where meaningful improvements in quality-of-life measures were seen despite only a 40% incidence in target lobe atelectasis.[2]

Failure to achieve initial BLVR atelectasis may result from a variety of etiologies.[13] First, airway anatomy may not have been favorable for valve placement, or post-BLVR airway changes could have resulted in an ineffective airway-to-valve seal. This would result in significant paravalvular air leak and lack of treatment effect atelectasis. Secondly, changes in pulmonary parenchymal microanatomy may result in the conversion of previously collateral ventilation-negative patients to collateral ventilation positivity. While there is no published data to support this theory, the ability to convert from collateral ventilation negative to collateral ventilation positive has been described. Finally, in patients who failed to achieve initial post-BLVR atelectasis, despite initial Chartis system assessment showing the patient to be negative collateral ventilation, inaccurate Chartis system assessment may have resulted in a false-negative result. This presence of collateral ventilation, despite a negative Chartis system assessment, could account for the 83% failure to achieve target lobe atelectasis following single or multiple revisions in patients who failed to achieve initial post-BLVR target lobe atelectasis. Future studies should focus on repeat Chartis system assessments in patients requiring valve revision procedures in those with and without initial post-BLVR target lobe atelectasis.

The most common cause for loss of treatment effect observed intraoperatively was lack of airway-to-valve seal in the target lobe resulting in paravalvular air leak in 38% of

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cases. As a result, the one-way effect of the valve was lost, resulting in inflation of the target lobe. This was related to inappropriate airway sizing, poor seating of one or more valves within the airway, or stretching of airways. The most common lobe requiring valve revision was the right middle lobe and right upper lobe combination. This could be related to airway anatomy and the potential for shorter segments in this lobe, making valve seating more difficult, especially in the posterior and apical segments of the right upper lobe. Revision of these valves typically involves valve removal and insertion of larger valves or a valve of a more appropriate length. Forty-three percent of revision cases did not show any sign of valve issues despite the loss of treatment effect. This was typically verified by visual inspection and saline flush testing to assess for air leaking around the valves. In these cases, all valves were typically removed and replaced. While Roodenburg and colleagues described the most common indication for valve revision to be granulation tissue, our cohort only required valve revision due to granulation tissue formation 24% of the time.

The use of post-Stratx analysis is aimed to assist physicians in determining the presence or absence of a poorly positioned valve, a leak around EBVs, or failure to achieve initial post-BLVR atelectasis. The identification of a valve-related issue could direct a physician to focus on a specific site for revision. Unfortunately, the correlation between the post-BLVR analysis and the perceived intraoperative cause for loss of atelectasis was poor. While 95% of revision bronchoscopies were accompanied by a preprocedure post-BLVR analysis, only 55% of these analyses matched what was perceived as the cause by the proceduralist. The sensitivity for the post-BLVR analysis was 65% and the specificity was 36%. Unfortunately, based on poor sensitivity and specificity of the post-BLVR analysis, post-BLVR analyses may serve limited use.

There are limitations to our study. This was a retrospective analysis that may not be adequately powered to determine appropriate revision rates. Furthermore, the lack of previous studies related to BLVR revisions makes comparison to standard practice difficult. During this study, we did not repeat the Chartis system assessment post-treatment failure. In future studies, repeating the Chartis system assessment could determine if the initial assessment was flawed or help determine if new collateral ventilation can develop after valve placement.

Patients with emphysema can benefit from BLVR to improve shortness of breath and functionality. Based on our study, post-BLVR revision bronchoscopies are necessary in ~20% of patients for either loss of target lobe atelectasis or failure to achieve atelectasis after the initial BLVR procedure. In many cases, especially when radiographic target lobe atelectasis is lost, revision bronchoscopies can reestablish post-BLVR atelectasis. Understanding the incidence of revision bronchoscopies is important for physicians and patients to have appropriate long-term expectations following BLVR.

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