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REVIEW

# Diaphragmatic ultrasonography as a predictor for mechanical ventilation weaning in adults: an integrative review

*Ultrassonografia diafragmática como preditivo para o desmame da ventilação mecânica em adultos: uma revisão integrativa*

*La ecografía diafragmática como predictora del destete de la ventilación mecánica en adultos: una revisión integradora*

**Enathanael Ribeiro Soares[1], Joel Freires de Alencar Arrais[2], Flávio Vinicius Fagundes Xavier[3], Adalberto Veronese da Costa[4] , Glêbia Alexa Cardoso[5] , Wildberg Alencar Lima[6]**

**ABSTRACT |** Diaphragmatic ultrasonography (US) has been used to evaluate several respiratory diseases. Due to portability, this examination can easily be performed at bedside, in wards, emergency rooms and especially in the intensive care unit To identify and analyze how diaphragmatic ultrasonography can support safe mechanical ventilation weaning based on scientific evidence. This is an integrative literature review. Bibliographic survey was conducted from September to November 2022 in the following electronic databases: SciELO, LILACS and PubMed. A total of eight articles were included and evaluated using the Newcastle-Ottawa and PEDro scales, showing intermediate to high methodological quality. In total, the studies included 482 adult volunteers, of both sexes, aged 58.09±8.03, who had undergone invasive mechanical ventilation for at least 24 hours and were under ventilation to continue invasive ventilation weaning. In the selected studies, we found three evaluative variables: diaphragmatic excursion (DE) (75%); diaphragmatic thickness (DT) (62.5%); and diaphragmatic thickening fraction (DTF) (100%). Incorporating DT, DE and DTF into protocols for mechanical ventilation weaning in critically ill patients seems to support decision-making on the ideal time for weaning, reducing extubation failure.
**Keywords |** Ultrasonography; Diaphragm; Ventilator Weaning.

**RESUMO |** A ultrassonografia diafragmática (US) tem sido usada na avaliação de diversas doenças respiratórias. Por conta da portabilidade, tal exame, pode, facilmente, ser realizado beira-leito, em enfermarias, pronto atendimentos e especialmente na UTI. O objetivo do artigo é reconhecer e analisar através de evidências cientificas de qual maneira a ultrassonografia diafragmática pode corroborar no desmame seguro da VMI. Trata-se de uma revisão integrativa da literatura. O levantamento bibliográfico ocorreu entre setembro e novembro de 2022. A pesquisa foi realizada nas bases de dados eletrônicas: SciELO, LILACS e PubMed. Foram inclusos oito artigos, sendo avaliados pelas escalas Newcastle-Ottawa e PEDro evidenciando qualidade metodológica intermediária a alta. No total os estudos contaram com 482 voluntários adultos, ambos os sexos, com idade 58,09 ± 8,03 submetidos a ventilação mecânica invasiva (VMI) por pelo menos 24 horas, e que

[1]Universidade Federal do Cariri – Barbalha (CE), Brazil. E-mail: enathanael.ribeiro@gmail.com. Orcid: 0009-0007-3234-8270
[2] Universidade do Estado do Rio Grande do Norte (UERN) – Mossoró (RN), Brazil. E-mail: joel.freires00@gmail.com. Orcid: 0000-0002-5127-5309
[3] Centro Universitário São Camilo – Juazeiro do Norte (CE), Brazil. E-mail: viniciusfagundesfisio@gmail.com. Orcid: 0000-0002-0193-5276
[4] Universidade do Estado do Rio Grande do Norte (UERN) – Mossoró (RN), Brazil. E-mail: adalbertoveronese@uern.br. Orcid: 0000-0001-6597-463X
[5] Universidade do Estado do Rio Grande do Norte (UERN) – Mossoró (RN), Brazil. E-mail: glebiacardoso@uern.br. Orcid: 0009-0003-3820-8771
[6] Universidade Federal de Pernambuco (UFPE) – Recife (PE), Brazil. E-mail: wildbergalencar@gmail.com. Orcid: 0000-0002-9584-3961

Corresponding address: Enathanael Ribeiro Soares – Rua Padre Cícero, 287, Centro – Missão Velha (CE) – Zip Code: 63200-000 – E-mail: enathanael.ribeiro@gmail.com –
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apresentavam condições ventiladores para prosseguir com desmame da VMI. Foram encontradas três variáveis avaliativas nos estudos selecionados: excursão diafragmática (ExD) (75%); espessura diafragmática (Tdi) (62,5%); e fração de espessamento diafragmática (FED) (100%). A incorporação das variáveis: Tdi, ExD e FED em protocolos de desmame de VMI em pacientes críticos parecem auxiliar positivamente na tomada de decisão sobre o momento ideal para o desmame, diminuído falhas de extubação.

**Descritores** | Ultrassonografia; Diafragma; Desmame do Respirador.

**RESUMEN |** La ecografía diafragmática (ED) se ha utilizado en la evaluación de varias enfermedades respiratorias. Debido a la portabilidad, este examen se puede realizar fácilmente en la cama, en salas de hospitalización, en urgencias y, especialmente, en la unidad de cuidados intensivos (UCI). El objetivo de este artículo es reconocer y analizar mediante evidencia científica cómo la ecografía diafragmática puede corroborar el destete seguro de la VMI. Esta es una revisión integradora de la literatura. Se realizó una búsqueda bibliográfica entre septiembre y noviembre de 2022. La búsqueda se llevó a cabo en las bases de datos electrónicas SciELO, LILACS y PubMed. Se incluyeron ocho artículos, que habían sido evaluados por las escalas Newcastle-Ottawa y PEDro, lo cual apunta a una calidad metodológica de intermedia a alta. En total, los estudios incluyeron a 482 voluntarios adultos, de ambos sexos, de 58,09 ± 8,03 años de edad, sometidos a ventilación mecánica invasiva (VMI) durante al menos 24 horas y que tenían condiciones ventilatorias para continuar con el destete de la VMI. En los estudios seleccionados se encontraron tres variables evaluativas: excursión diafragmática (ExD) (75%); grosor diafragmático (Tdi) (62,5%); y fracción de engrosamiento diafragmático (FED) (100%). La incorporación de las variables Tdi, ExD y FED en los protocolos de destete de VMI en pacientes críticos parece contribuir positivamente a la toma de decisiones sobre el momento ideal para el destete, lo cual reduce las fallas de extubación.

**Palabras clave |** Ultrasonografía; Diafragma; Desconexión del Ventilador.

## INTRODUCTION

In intensive care units (ICUs), about 40% of patients are subjected to invasive mechanical ventilation (IMV)[1]. These patients may require IMV for short periods; however, 15% to 25% of them have difficulties in ventilator weaning and transition to prolonged mechanical ventilation (PMV)[2,3]. When mechanical ventilation is used for 6 hours or longer per day, for 21 days or more, it is considered PMV[2].

IMV weaning is a gradual process, which encompasses the release of the patient from mechanical ventilation and removal of the endotracheal tube[4]. Weaning should be indicated when there is control or improvement of the acute disease, hemodynamic stability and absence of decompensated coronary insufficiency and arrhythmias with hemodynamic repercussions, improvement in oxygenation and ventilation parameters, neurological improvement and normalization of hydroelectrolytic disorders. However, three failures in the spontaneous breathing trial (SBT) or failures more than seven days after the first SBT constitute prolonged weaning[5,6].

Prolonged use of IMV poses a high risk of pulmonary complications, such as barotrauma, ventilator-associated pneumonia (VAP), tracheal ischemia, thromboembolism, peripheral muscle atrophy, respiratory muscle dysfunction, and oxygentoxicity[7-9]. In addition to increased mortality rate[10].

Weaning may represent up to 42% of the total IMV time[11]. However, numerous attempts to discontinue IMV should also be avoided, since extubation failure is related to an 8-fold increased probability of developing nosocomial pneumonia, in addition to a 6 to 12-fold increased risk of death[12].

About 60% of patients admitted to the ICU develop some diaphragmatic dysfunction as to reduced activity, characterizing weakness. Individuals may suffer from diaphragm bilateral or unilateral weakness, paradoxical movement, or even paralysis (abolished function). In addition, around 80% present diaphragmatic dysfunction in IMV[13]. This demonstrates the importance of discontinuing IMV as soon as possible.

Therefore, contractile inactivity of the diaphragm may be the origin of ventilator-induced diaphragmatic dysfunction (VIDD), considerably affecting diaphragmatic resistance, considered the ability to maintain contractile force in relation to a resistive inspiratory load[14,15].

From this perspective, there has been a growing interest in diaphragm imaging evaluation methods in

recent years. The most widely used, chest X-ray, may enable visualizing the diaphragmatic eventration, but it has poor sensitivity or specificity[16,17].

Diaphragmatic ultrasonography (US) is characterized as an effective technique to evaluate diaphragm function and anatomy, especially diaphragmatic thickness and excursion[18]. Due to portability, US can easily be performed at bedside, in wards, emergency rooms and especially in the ICU[19].

In addition, diaphragmatic US has been used in the evaluation of several respiratory disorders, including asthma, cystic fibrosis, chronic obstructive pulmonary disease (COPD) and interstitial lung disease. It is noted for having important advantages over other techniques for the analysis of diaphragmatic function, as it does not employ ionizing radiation[20].

Therefore, in consideration of such situational focus, this study aimed to recognize and analyze how diaphragmatic ultrasonography can support safe IMV weaning based on scientific evidence.

## METHODOLOGY

This is an integrative literature review and follows the instructions of the Joanna Briggs Institute (JBI)[21] manual for evidence synthesis and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (Prisma-ScR)[22], and it was carried out from September to November 2022. To ensure the impartiality and accuracy of the results, two independent, blinded evaluators selected and analyzed the studies included in three electronic databases: Latin American and Caribbean Health Sciences Literature (LILACS), Scientific Electronic Library Online (SciELO), and National Library of Medicine (PubMed).

Adopting the PICO framework for non-clinical research, the objective was to answer the following guiding question: is there clear and effective evidence on the inclusion/use of diaphragmatic ultrasonography to support decision-making on IMV weaning? What variables can be considered? To this end, in the formulation of the search strategy, the following descriptors were used: "Ultrasonography," "Diaphragm," and "Ventilator Weaning," adopting AND and OR as Boolean operators. All descriptors are indexed in the Descriptors in Health Sciences (DeCS) and Medical Subject Headings (MeSH) platforms (Chart 1).

Chart 1. Search strategies

| Databases | Boolean Operators | Search strategies |
|---|---|---|
| LILACS<br>SciELO<br>PubMed | AND | Ultrasonography AND Ventilator Weaning<br>Ultrasonography AND Diaphragm AND Ventilator Weaning |
| PubMed | AND/OR | ""Ultrasonography"" AND ""Ventilator Weaning/methods""<br>""Ultrasonography/methods"" AND ""Diaphragm/diagnosis"" OR ""Diaphragm/diagnostic imaging""<br>""Ultrasonography"" AND ""Diaphragm/diagnosis"" OR ""Diaphragm/diagnostic imaging"" AND ""Ventilator Weaning"" |

The following inclusion criteria were adopted: publications from, 2017 to 2022, in Portuguese, English or Spanish; comparative, experimental clinical studies and randomized trials; available in full and free of charge in the database. The following exclusion criteria were adopted: inconclusive studies and duplicates; those carried out in an animal model, neonatal population and pediatric population. Review and meta-analysis studies were also excluded.

The studies were selected by reading the titles of the studies found via the search strategy adopted, followed by reading abstracts to analyze the consistency with the theme, concluding with full reading of the studies considered relevant.

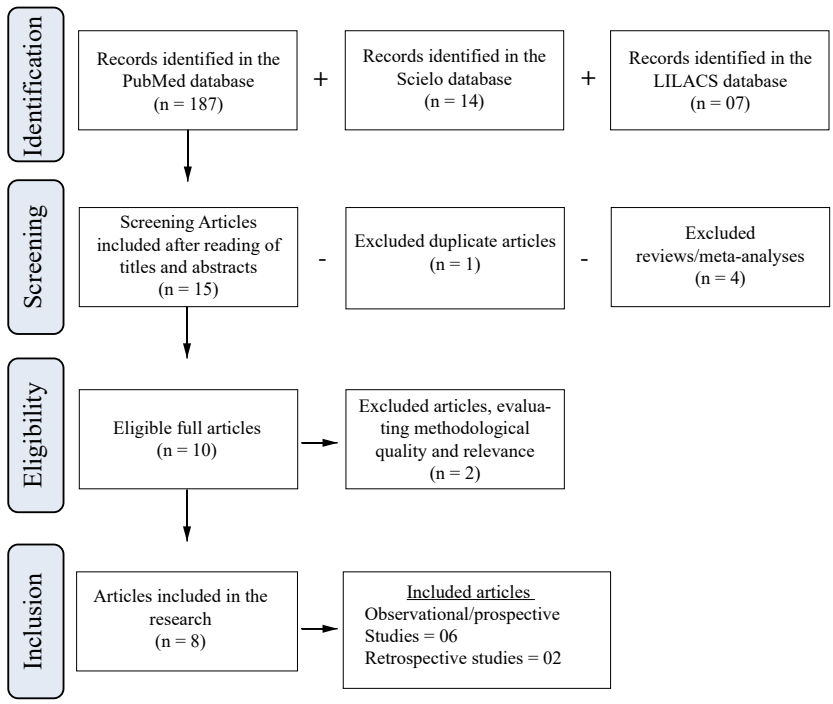
The Newcastle-Ottawa[23] scale was used to assess the quality of the observational studies included in this review. The Physiotherapy Evidence Database (PEDro)[24] scale was used to assess the methodological quality of specific clinical trials. It consists of 11 items that examine the internal validity and interpretation of results of a given study, and aims to trace high-quality studies that can inform evidence-based clinical practice.

The selected studies were distributed and organized into tables prepared using Microsoft® Word, 2019 version, with studies classified by author(s), year of publication, language, sample size, type of methodological intervention adopted, and main outcomes.

## RESULTS

We found 208 publications in the databases. After the publications were identified, they were screened according to the logistics proposed by the study method, by reading of titles and analysis of abstracts, which enabled initially evaluating the studies as to consistency with the research focus. At this stage, we selected approximately 7.21% (n=15) of the studies found. It was also at this stage that duplicates, reviews and meta-analyses were discarded. In the eligibility phase, about 4.8% (n=10) of the total publications were selected for full analysis. After observing the methodological accuracy and relevance, two studies were excluded. Finally, the sample included about 3.85% (n=8) of the studies found (Figure 1).

Figure 1. Sample selection strategy




A total of 482 individuals participated in the studies (Table 1). All studies address the inclusion and/or use of diaphragmatic ultrasonography as a complementary tool to support decision-making on discontinuing invasive mechanical ventilation, considering the best time and clinical correlation. IMV time was took in account, with the required time ranging from 24 hours[25] to 72 hours[26] in two studies. The other studies adopted the minimum time of 48 hours as eligibility criterion. Another similarity in the inclusion criteria is that all participants were able to perform the SBT (clinically and with minimum parameters in the IMV).

After full reading of the eight selected articles, their quality was evaluated according to the Newcastle-Ottawa[23] scale, with scores ranging from 0 to 9 for each study. Thus, six of them could be classified (Chart 2) and obtained satisfactory scores, which demonstrates good methodological quality.

Table 1. Study characterization

| Author | n<br>Mean age (years)<br>±<br>SD | Study design | Variables analyzed | Outcome |
|---|---|---|---|---|
| Dong et al.[27] | 80<br><br>61.74 ± 16.16 | Randomized controlled trial | DE; DTF | US is a convenient and useful tool for assessing diaphragmatic function in mechanically ventilated patients. |

Continues

Table 1. Continuation

| Author | n<br>Mean age (years)<br>±<br>SD | Study design | Variables analyzed | Outcome |
|---|---|---|---|---|
| Dubé et al.[28] | 112<br>62±* | Retrospective study | DT; DE; DTF | No significant relation was found between diaphragm thickness and contractile capacity. |
| Elshazly et al.[29] | 62<br>62.75±* | Observational study | DT; DE; DTF | Diaphragmatic ultrasonography has proven a promising tool for predicting the outcome of extubation in mechanically ventilated patients. |
| Eltrabili et al.[30] | 30<br>52.7±13.4 | Observational prospective study | DT; DE; DTF | Diaphragmatic ultrasonography indices (diaphragmatic thickening fraction and diaphragmatic excursion) may be useful parameters for evaluation of extubation in patients with abdominal sepsis. |
| Gok et al.[31] | 46<br>57.6±14.1 | Observational prospective study | DE; DTF | Ultrasonographic examinations followed by RSBI should be performed to increase the success of extubation. |
| Kundu et al.[32] | 60<br>42.7±16.98 | Observational prospective study | DTF | The use of an integrated US protocol may be useful in tracing patients who will probably have extubation failure. |
| McCool; Oyieng'O; Koo[33] | 32<br>55.8±14.8 | Prospective, randomized, controlled study | DTF; DT | Diaphragmatic ultrasound information enabled the physicians to identify the functioning of the diaphragm, improving the extubation process and time. |
| Yoo et al.[34] | 60<br>69.5±* | Retrospective study | DE; DTF; DT | US can be a valuable tool for assessing diaphragmatic dysfunction and predicting extubation success. |

*: data not reported in the study; n: sample; SD: standard deviation; DT: diaphragmatic thickness; DTF: diaphragmatic thickening fraction; DE: diaphragmatic excursion; US: ultrasonography; RSBI: rapid shallow breathing index; DD: diaphragmatic dysfunction.

Chart 2. Bias assessment according to Newcastle-Ottawa scale

| Study | Design | Assessed items | | | | | | | | Score |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Selection | | | | Comparability | Outcome | | | |
| | | 1 | 2 | 3 | 4 | 1 | 1 | 2 | 3 | |
| Dubé et al.[28] | Retrospective study | * | - | * | * | ** | * | * | * | 8/9 |
| Elshazly et al.[29] | Observational study | * | - | * | * | ** | * | * | * | 8/9 |
| Eltrabili et al.[30] | Observational prospective study | * | - | * | * | ** | * | * | * | 8/9 |
| Gok et al.[31] | Observational prospective study | * | - | * | * | ** | * | * | * | 8/9 |
| Kundu et al.[32] | Observational prospective study | * | - | * | * | ** | * | * | * | 8/9 |
| Yoo et al.[34] | Retrospective study | * | * | * | * | * | * | * | * | 8/9 |

The total score is expressed on a scale from 0 to 9, with the maximum score indicating that all criteria were met. The "*" symbol indicates the criterion was met. The "-" symbol indicates the criterion was not met. "**" indicates the criterion was met with an extra point of comparability.

Two of the selected articles were evaluated according to the PEDro[24] scale, with an intermediate score for both (Chart 3), which shows intermediate methodological quality.

Chart 3. Study evaluation by the PEDro scale

| Study | Assessed criteria | | | | | | | | | | | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| Dong et al.[27] | - | * | - | * | - | - | * | - | * | - | * | 5/10 |
| McCool; Oyieng'O; Koo[33] | - | * | - | * | * | * | * | - | - | - | * | 6/10 |

The PEDro scale has a total score ranging from 0 to 10, excluding item 1, which is not used in calculating the final score. The "*" symbol indicates the criterion was met – being understood as "yes" on the scale. The "-" symbol indicates the criterion was not met.

In the selected studies, we observed three evaluative variables: diaphragmatic excursion (DE), representing 75% (n=6) of the studies; diaphragmatic thickness (DT), 62.5% (n=5); and diaphragmatic thickening fraction (DTF), used in 100% (n=8) of the sample. Of the total, 25% (n=2) of the studies did not report the presence of comorbidities in the participants (Table 2).

The acute physiology and chronic health evaluation II (APACHE II) scale was used to classify 62.5% (n=5) of the studies; body mass index (BMI) was included in 25% (n=2) of the studies; and sequential organ failure assessment (SOFA) was in 25% (n=2) of the sample. All studies excluded subjects with diaphragmatic paralysis and/or severe nerve injury. There was no homogeneity of the underlying diseases nor reasons that led to orotracheal intubation (OTI). All subjects were over 18 years of age and there was no objection as to sex.

## DISCUSSION

The US-based diaphragmatic evaluation for diagnosis of diaphragmatic dysfunction (DD) requires measuring diaphragmatic thickness (DT) and diaphragmatic thickening fraction (DTF) to evaluate diaphragmatic contraction and atrophy[20].

One of the studies[25] observed that US can incorporate information on diaphragmatic function, enabling professionals to trace patients eligible for IMV discontinuation. In its study for individuals with DTF ≥ 30%, the time to extubation was significantly reduced in the intervention group when compared to the control group.

When critically ill, patients are more vulnerable to the development of DD due to exposure to various myotoxic factors[26], even if it is at the beginning of their ICU stay[35], especially in individuals who develop respiratory failure and need MV.

There is a significant relation between DTF and diaphragm contraction force, only when measured in pressure support ventilation (PSV). This hypothesis was justified by the presence of spontaneous respiratory effort in pressure support ventilation, when compared to controlled ventilation. Effectively, it is empirically easy to assume that, in the absence of active respiratory efforts, DTF is not expected to act as a dynamic physiological estimator of diaphragm function[25].

In the study with 62 patients submitted to SBT and followed for 48 hours post-extubation, low DTF and DT were negatively correlated with longer IMV time, with the mean DTF in successful participants being 32.65% and in those who failed extubation being 17.6%. A DT cutoff value of >1.25 cm was associated with successful extubation[29].

A relation is observed between adverse outcomes and DD, such as prolonged IMV, weaning failure, or even a higher mortality rate[30]. In the case of a study conducted with 60 patients at bedside submitted to SBT, these individuals were followed for 48 hours to verify the clinical outcome. In the group that successfully transitioned from extubation, the average DTF was 30.87%, while for those who returned to MV it was 27.88%. They concluded, then, that the use of an integrated ultrasonography protocol may be useful in tracing patients who probably failed extubation. The correlation with clinical analysis of heart and lung images is important to modify therapies and/or trace patients at high risk of extubation failure[32].

In this sense, a correlation was detected between extubation success and several parameters, such as the rapid shallow breathing index (RSBI) and all ultrasonographic parameters evaluated by them (DE and DTF). Cut-off values (in individuals who successfully progressed from extubation) were 64 for RSBI; 27.5% for DTF; 1.3 cm for DE. There was emphasis that ultrasonography examinations followed by RSBI should be performed to increase the success of extubation in critically ill patients[31].

In the study with 60 patients, in which 78.3% of these were successfully extubated, it was found that the mean degree of DE was higher in patients with successful extubation than in those with failed extubation (1.65 cm *versus* 0.8 cm). While in patients with successful extubation DTF was higher than in those with failed extubation (42.1% *vs.* 22.5%). This may improve the effectiveness of the use of diaphragmatic US for clinical decision-making in critically ill patients[34].

Tracing other clinical and therapeutic relation, correlating early rehabilitation with diaphragmatic assessment and IMV time, they observed that DE and DTF were significantly decreased in all patients after prolonged MV, even those submitted to early rehabilitation, which had lower DTF reduction compared to the control group. After the third day of IMV, the mean DTF was 15%, and 1.33 cm for DE in the intervention group; with DTF of 12%, and DE of 1.27 cm in the control group. This associates low DTF with longer IMV time[27].

In this line of reasoning, they report that subjects with sepsis of abdominal focus, with successful extubation, had significantly lower APACHE II and SOFA compared to those in the group with extubation failure. Based on this scenario, the ideal DTF cutoff value to predict release success was >30.7%, and the mean DE was 17 mm[30].

## CONCLUSION

Diaphragmatic ultrasonography proved a reliable, non-invasive and convenient technique to predict the success of IMV weaning. Incorporating DT, DE and DTF variables into protocols for IMV weaning in critically ill patients appears to support decision-making on the ideal time for weaning, reducing extubation failures. Correlation with other imaging exams of heart and lung, constant clinical evaluation and personalization of care are important. Diaphragmatic US examinations have also proven useful in IMV weaning in patients with abdominal sepsis. Early mobilization assists in maintaining diaphragmatic functionality in patients mechanically ventilated for long periods.

Therefore, the results presented in this study represent important and reliable findings, given the methodological rigor of the studies analyzed here. The search for new evidence is always fostered with the construction of other studies, consdering the pathological diversity and specificities of the populations that can benefit from the technique explained here.

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