Interventional ultrasonography of the chest: Techniques and indications

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KEYWORDS

Ultrasonography;
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Abstract Thoracic ultrasonography can be used for diagnostic purposes as well as a guide for diagnostic and therapeutic interventions.

When the lesion or fluid collection has been located and the patient properly positioned, the angle of the needle is identified with respect to the transducer. The insertion tract should transgress the smallest possible area of aerated parenchyma. The needle can be introduced with a free-hand technique or with the aid of a needle guide. Correct planning of the procedure reduces intervention time and decreases the risk of complications.

The main indications are superficial masses that require biopsy, pleural and parenchymal lesions formerly biopsied with CT or fluoroscopic guidance, and fluid collections that need to be drained.

Ultrasound, thanks to its widespread use, simple execution, and low costs, represents a safe, manageable guide for thoracic interventions.

Sommario L'impiego dell'ecografia in ambito toracico, oltre all'utilità diagnostica, è quello di guida e supporto alle tecniche interventistiche, sia diagnostiche, sia terapeutiche.

Individuata la lesione o la raccolta e l'idonea posizione del paziente, si pianifica la procedura, impostando l'angolo d'inclinazione dell'ago rispetto alla superficie del trasduttore, cercando di risparmiare il maggior parenchima aerato possibile. L'introduzione dell'ago può essere condotta sia a mano libera, sia mediante opportune guide. Una corretta pianificazione dell'intervento riduce i tempi di esecuzione e l'entità delle complicanze.

Le principali indicazioni sono rappresentate dal prelievo biotico di lesioni espansive superficiali cui si associano quelle in ambito pleurico e parenchimale già campo d'azione di metodiche quali la TC e precedentemente la fluoroscopia, oltre al drenaggio delle raccolte.

Per l'ampia diffusione, la semplicità di esecuzione ed i bassi costi l'ecografia si pone come uno strumento sicuro e maneggevole nella guida delle procedure interventistiche in ambito toracico.

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Introduction

Thanks to its advantages-absence of adverse effects, wide-scale availability, low costs, simple, well-defined semeiotics-ultrasonography is being used with increasing frequency to explore diseases involving the chest. It now has a well-established role in the investigation of pleuroparenchymal lung changes and disease involving the chest wall. Specific findings have been well-defined for several diseases [1,2], and in many settings (e.g., critical care units and emergency rooms), ultrasound represents a valid adjunct to clinical assessment, radiography, and computed tomography [3].

Thoracic ultrasound is easy to perform and provides accurate, real-time results. In addition to its diagnostic uses, these features make it a very useful guide for interventional procedures, including those with diagnostic aims (collection of biological samples for chemicophysical, microbiological, cytological, or histological analysis) as well as those that are therapeutic (fluid drainage).

The aim of this article to evaluate thoracic ultrasound-guided interventions-including indications, contraindications, complications, and precautions-with emphasis on practical measures for rendering these procedures simple and safe.

Precautions and contraindications

As a guide for invasive procedures, ultrasound offers indisputable advantages over CT or fluoroscopy, including the absence of exposure to ionizing radiation, low costs, and simple execution. However, it is important to follow well-defined protocols that specify contraindications to the procedures and precautions that must be adopted [4].

First of all, the patient needs to be hospitalized so that he/she can be adequately monitored after the procedure.

The patient should be interviewed and the recent medical history evaluated to identify the indications for the procedure, the presence of any relevant comorbidities, and any drugs being used by the patient.

The patient should also sign an informed consent form, which provides a simple but accurate description of the indications for the procedure, the steps involved, and any complications that might occur.

Safe execution of an interventional procedure requires aseptic conditions and an assessment of the patient's coagulation profile. For pleuroparenchymal procedures, it is also important to evaluate the patient's pulmonary function (particularly the functional residual capacity) in the event of postprocedural complications.

Asepsis involves careful cleansing and disinfection of the skin at the access point, sterile draping, use of sterile gloves by the operator (after thorough disinfection of his/her hands), and use of masks by the operator and patient (Fig. 1).

The ultrasound transducer can be covered with sterile plastic wrap. If contact between the transducer and the needle is not expected, the surfaces of the transducer can simply be disinfected with appropriate products. The gel used must be absolutely sterile.

The main contraindications to interventional procedures (regardless of the site involved) are related to coagulation problems. The procedure should not be performed if the patient has any of the following: an INR above 1.3, a platelet

Fig. 1 Aspiration of a fluid collection: Access is prepared and the area disinfected. The operator, wearing sterile gloves and mask, proceeds with drainage.

count under 70,000, and/or prothrombin time less than 50%. These parameters should be checked no more than 3 weeks before the scheduled date of the procedure.

Particular attention should be given to the medications being used by the patient, especially those drugs that affect platelet aggregation or the coagulation cascade and those that can interfere with hemostasis (NSAIDs, antidepressants, etc.) For a patient who is on platelet inhibitors or anticoagulant therapy, it is important to consider the risk/benefit ratio, that is the specific risk related to the procedure (for example, minor coagulopathies are a relative contraindication for needle aspiration of superficial lesions). The patient's physician should be consulted to evaluate the possibility of suspending therapy or replacing it with another drug.

Work-up of the patient should include evaluation of conditions specifically involving the respiratory tract. History of contralateral pneumonectomy, severe respiratory failure, uncontrollable coughing, inability to hold one's breath, emphysema, and suspected echinococcal disease are specific contraindications. In this case as well, the risks and potential complications of the procedure can be minimized by careful evaluation of the patient history and consultation of the patient's physician.

The preliminary phase, which includes a complete history, close collaboration with the clinician, and application of specific norms, is essential for avoiding complications, particularly those that are infectious in nature.

Technique

Ultrasound examinations of thoracic structures are done with linear, convex, and sectorial transducers with frequencies ranging from 3 to 10 MHz. The choice depends on the depth of the structure being examined. Superficial structures—subcutaneous soft tissues, muscle tissues, and bones—are examined with high-frequency linear transducers; pleural disease and consolidation and focal lesions of the lung parenchyma can be studied with linear or convex transducers and frequencies that range from high to low depending on the depth of the examination [5].

Transverse and longitudinal scans are used with intercostal, subcostal, supra- and parasternal, or paravertebral accesses. The patient can be examined in the supine, prone, lateral or seated position, depending on the area being examined, operator maneuverability, and patient comfort [1]. The main objective in all cases finds an acoustic window that allows adequate visualization of the lesion.

Before the procedure

The initial phase of the procedure involves centering of the lesion. The operator identifies the pathway along which the needle will be advanced. To reduce the risk of complications, vascular structures should be avoided and the route should include the smallest possible area of aerated lung parenchyma.

Color Doppler can be very helpful for detecting vascular structures during both the diagnostic and interventional phases of the procedure.

The equipment needed for the examination should be prepared in advance: material needed to prepare a sterile field, disinfect the skin, and maintain operator sterility; needles; glass slides and sterile containers, fixing agents for tissue samples, drainage catheters, sterile gauze and tape for postprocedure dressings (Fig. 2). Careful planning shortens procedure time and reduces complications.

During the procedure

When the lesion has been identified and the patient positioned, the procedure begins with the administration of a local anesthetic, which can be given subcutaneously or injected into the pleura [6].

Depending on its caliber, the needle itself can be inserted with a free-hand technique or with the aid of a needle guide. Some transducers have guides that are incorporated in a lateral or central position. Alternatively, an external guide can be attached to the transducer [7] (Fig. 3).

Some scanners are equipped with software that allows the operator to set the angle of the needle with respect to the skin and visualize the resulting trajectory on the monitor.

Fig. 2 Preparation of a sterile field where material for the intervention will be arranged.

Further discussions of technique will be divided into those used for diagnostic and therapeutic interventions.

Specimen collection for diagnostic purposes

The objective of diagnostic interventions is to collect an adequate amount of material for microbiological, biochemical, cytological and histological analyses.

The first step is to select the type of needle that will be used to collect the material.

Needles differ from one another in several respects, including length, gauge, and tip features, which reflect in part the collection method. For practical purposes, it is useful to distinguish needles used to collect cytology specimens from those used to obtain material for microhistological studies.

Fine-needle aspiration biopsy (FNAB) is performed with a 20–23 gauge Chiba or spinal needle (Fig. 4A and Fig. 7A) with a beveled tip with variable inclination [8]. Coaxial or single needles may be used. The former consist of an outer needle and a flexible internal needle, which is removed to allow aspiration. Single needles consist of a single component [9].

Once the needle has been advanced into the lesion and connected to a syringe (5cc, 10cc, or 50cc), aspiration begins.

Microhistology specimens (CNB) can be collected with an 18 to 21-gauge needle with a cutting tip (Tru-cut) or a cutting lateral border (Menghini). Tru-cut-type needles are the ones most commonly used. They consist of an outer cannula and an inner stylet with a notched distal segment: during insertion, the stylet remains inside the outer cannula. When the tip reaches the edge of the lesion, the cannula is arrested, and the stylet advanced into the lesion. The distal specimen notch fills with tissue, and at this point, the cannula is advanced over the stylet, shearing the tissue (Fig. 4B and Fig. 7B).

Cope or Abrams needles can also be used for pleural biopsies. These needles were previously used for biopsies done without imaging guidance in patients with relatively large volume effusions, but they are now used for ultrasound-guided collection of microhistology specimens even when there is only a small amount of intracavitary fluid. The site is prepared and the needle is inserted through a surgical incision. The tissue is collected by traction: a terminal notch is used to anchor the needle to the pleura while it is being pulled out.

The needle type and sampling method (collection of material for cytology or microhistology) depends on the indication for the biopsy, the type of injury, and the condition of the patient.

Comparative studies [10,11] show that cytology and histology play complementary roles, and their combined use is associated with diagnostic accuracy as high as 89%. However, for neoplastic lesions of the lung parenchyma, needle aspiration alone is highly reliable in differentiating small-cell and non-small-cell carcinomas of the lung and is associated with a lower incidence of complications. Fine needle aspiration cytology is less reliable in cases of non-epithelial neoplasms, such as lymphoproliferative tumors or those derived from mesenchymal tissues, and for diagnosis of benign lesions.

Fig. 3 Types of transducers and needle guides. Transducer with a built-in central needle guide and a needle in the guide; the sonographic image shows a hypoechoic strip running longitudinally that corresponds to the position of the guide (A). Transducer with an external device attached, which allows placement and needle guidance according to a predefined angle. On the sonographic image, the tip of the needle lies within a hypoechoic abscess (B). Electronic trajectory projection on the monitor (C).

In a study by Yang et al., ultrasound-guided biopsies were performed in 149 patients with mediastinal and lung tumors. CNB and FNAB were associated with diagnostic accuracies of 97% and 59% for malignant lesions and 85% versus 33% for those that were benign [12].

Containers, slides, and solutions for fixing and preserving the specimen must be prepared in advance. Close collaboration with the pathologist is also fundamental: depending on the indications for the biopsy, supplementary preservation procedures may be necessary (Fig. 5).

Specimens for cytology should be streaked onto clean slides immediately after collection. The slides should be fixed with 95% alcohol solutions or appropriate fixatives or simply air-dried, depending on the pathologist's instructions. Tissue cores for microhistology should be placed in formalin-filled containers.

Therapeutic procedures

Ultrasound can be used as a guide during thoracentesis procedures or for the placement of chest tubes in patients with pleural effusions (inflammatory, infectious, neoplastic)

or inflammatory infiltrates involving the lung parenchyma or chest wall.

Thoracentesis is performed for therapeutic or diagnostic purposes. It is generally done at the bedside using needles of different caliber and length, three-way stopcocks (for connecting the syringe used for aspiration device), and a collection system.

The fluid collection should be evaluated to determine where the maximum volume is and to identify the presence of septa and/or loculation.

Small-caliber (7-8 French) pigtail catheters are generally used to drain pleural fluid.

The patient is placed in the lateral decubitus or semi-seated position on the unaffected side, or if possible, in a full seated position. The access point is identified, and the needle is inserted along the upper border of the rib to avoid damaging the neurovascular bundles located at the lower border of the ribs.

Once the operative field has been prepared and the location of the maximum volume of fluid pinpointed, the skin is disinfected, local anesthetic is administered, and a scalpel incision is made for insertion of the catheter.

Fig. 4 Coaxial Chiba needle for collection of cytological specimens with an external guide needle and central stylet (A). Tru-cut needle with an external cannula and central stylet with the specimen notch used to capture microhistological samples (B).

The technique used depends on the type of drainage tube being inserted, but in clinical practice small-caliber (8–14 F) pigtail drainage catheters are generally inserted with the Seldinger technique. Pigtail catheters are packaged in a special kit. The distal tip is curved into a loop (like a pig's tail) and has multiple lateral holes for drainage of liquid or air. First, an 18-gauge needle is inserted into the pleural space and a guidewire passed through its lumen. The needle is removed, and progressively large-caliber dilators are passed over the guidewire until the pathway is large enough to receive the pigtail catheter (the diameter of which is selected on the basis of necessity and the dilatation achieved) (Fig. 6). The catheter is anchored to the skin of the chest with an adhesive disk or a suture. The

Fig. 5 Preparation of material and supplies needed for collection and preservation of cytological and histological specimens.

Fig. 6 Using the Seldinger technique, a pig tail catheter has been inserted through a right intercostal access to drain a pleural effusion.

contents of the pleural space can then be drained. It is important to recall that no more than 1.5 L of fluid should be removed at one sitting; otherwise, rapid re-expansion of the lung can lead to pulmonary edema.

The proximal end of the drainage tube is connected to a collection system by means of a valve, which allows the passage of liquid and air during expiration and prevents air from entering the cavity during inspiration. In the Bulau drainage system, the valve consists in an underwater seal with the collection bottle positioned below the level of the chest. The Heimlich system, which includes a one-way rubber valve, is a practical, easy-to-manage system that can be used with Bulau bottles or connected to a drainage bag like that used for urine. The patient should be instructed to keep the collection system below the level of the chest, particularly when the water-seal method is being used. If the collection bag or bottle has to be raised above this level, the chest tube has to be clamped to avoid the reentry of air or liquid into the pleural cavity.

After the procedure

After any interventional procedure involving the chest, a standard radiograph should be obtained (ideally with the patient in an upright position) to check for complications. After placement of a drainage tube (particularly when large quantities of fluid have been removed), the position of the tube should be verified on the radiograph. In over 30% of all cases, it also reveals a small residual pneumothorax, which is parapsychological and resolves rapidly.

Standard radiography is also indicated after trans-thoracic biopsies. It should be done at the end of the procedure and repeated 1–2 h later to exclude short-term complications. Ultrasonography is an effective alternative

Fig. 7 Biopsy of a metastatic chest-wall lesion in a patient with adenocarcinoma of the pancreas. The panoramic sonographic image shows an expansive chest-wall mass surrounding the costal arch. The lesion appears inhomogeneous with a hypoechoic center. On the pleural aspect, it juts out with an interface that is hyperechoic with respect to the discontinuous lung parenchyma. On the parietal side, the mass has obliterated the superficial fat cleavage plane and infiltrated the muscle plane. In the center of the lesion is a strongly hyperechoic spot that corresponds to the tip of a Chiba needle used for aspiration cytology (A). The sonographic image shows the oblique trajectory of the Tru-Cut biopsy needle. The tip is oriented toward the solid component of the lesion (B). TC MPR

to the plain film. It displays superior diagnostic accuracy in detecting pneumothoraces or hydro-pneumothoraces after thoracentesis or pleuroparenchymal biopsies [2].

Indications

Interventional ultrasonography of the chest can involve various structures: the chest wall, the pleural membranes and pleural cavity, the lung parenchyma, and mediastinal structures.

Imaging-guided interventions involving the chest wall are mainly diagnostic. Benign and malignant tumors and superficial infections are often difficult to characterize by means of imaging studies alone, and biopsy is needed to make an accurate diagnosis. Ultrasonography can be used to collect samples of expanding bone lesions of the ribs, which are a frequent site of distant metastases and involvement from disease arising in other contiguous structures [7] (Fig. 7).

The visceral and parietal pleurae can be identified with high-frequency linear transducers, which depict them as thin hyperechoic lines. Minimal amounts of fluid may also be identified between the two layers. Its presence is reflected by the “fluid color sign” on color Doppler.

Regardless of whether or not there is a pleural effusion, areas of diffuse and focal thickening of the pleurae and solid lesions can be sampled with FNAB or CNB. The choice depends to some extent on the characteristics of the lesion itself. However, histological examination of an adequate sample of tissue is usually the most sensitive method [13] (Fig. 8).

Biopsy may be indicated in the presence of a unilateral pleural effusion associated with pleural thickening whose cause has not been identified by cytological, biochemical, and microbiological analyses of specimens obtained via thoracentesis. However, the probability of successful diagnosis is significantly increased by combined use of thoracentesis and biopsy (Fig. 9).

There are valid CT criteria for differentiating benign and malignant forms of pleural thickening (diffuse and focal). Biopsy is indicated for differentiating primary mesotheliomas and pleural metastases; it is also used to diagnose granulomatous pleurisy (tubercular or other forms). In comparative studies, ultrasound-guided biopsy with a Tru-Cut needle was associated with 86% sensitivity in the diagnosis of tubercular pleurisy and 70% sensitivity for diagnosing neoplastic disease. These figures are superior to those for blind biopsy with an Abrams needle, reflecting the advantage of direct visualization, which allows collection of tissue from the area of maximal thickening [14].

Ultrasound can also be used as a guide for collecting samples of pleural fluid for chemico-physical, microbiological, and cytological analyses or for evacuation thoracentesis.

reconstruction in the coronal plane reveals a parietal lesion on the right midaxillary line; representation of the relations between the pulmonary parenchymal and superficial musculoadipose planes, as well as involvement of the costal arch with structural remodeling of the bone associated with a periosteal reaction caused by neoplastic infiltration (C).

Fig. 8 Biopsy of a metastatic pleural lesion in a patient with a history a squamous-cell carcinoma (A). The ultrasound image shows an expanding lesion on the pleural side composed primarily of hypoechoic fluid with evidence of colliquative necrosis. The tip of the biopsy needle can be seen within the lesion. An axial CT image confirms the presence of a pleural tumor with large areas of necrosis and surrounded by pleural fluid (B).

Fig. 9 Drainage of a pleural mesothelioma. The ultrasound image shows focal thickening of the pleura with solid and cystic components associated with a large pleural effusion. The drain is visualized within the fluid collection, which is adjacent to focal areas of solid thickening of the pleura representing neoplastic involvement.

Fig. 10 Multiloculated pleural effusion with thick septa enclosing circumscribed areas of fluid.

Recurrent/complicated neoplastic and infectious effusions that do not respond to a single thoracentesis session may require the insertion of one or more drainage tubes. This allows re-expansion of the lung parenchyma, reduces the severity of symptoms and the duration of hospitalization, and may lead to resolution of the disease.

Effusions related to primary or metastatic disease that do not improve with chemotherapy can be treated with drainage followed by pleurodesis, which involves the introduction of sclerosing agents under ultrasound guidance; the use of small-bore catheters allows patients of this type to be managed on an outpatient basis [15]. Pleurodesis with sclerosing agents such as talc, antibiotics, or anti-neoplastic drugs is performed when chest tube drainage has dropped below 10 ml/24 h and the chest radiograph is negative [16].

In the treatment of circumscribed multiloculated effusions or pleural empyema, ultrasound provides accurate information on the presence of septation and loculation, which is important for aspiration and effective placement of drainage tubes; whether or not this information is predictive of the outcome of drainage is still a matter of debate. Some investigators have reported successful drainage rates of 80% in patients with non-septated effusions [17], and they maintain that ultrasound findings can predict the success of drainage in patients with empyema or complicated effusions; in other studies, ultrasound findings of loculation or septa and internal echo characteristics showed no statistically significant correlation with the success or failure of the procedure [18] (Figs. 10 and 11).

For complicated, antibiotic-resistant effusions, ultrasound can also be used as a guide for intracavitary administration of fibrinolytic agents, which lyse adhesions and septa, improving the chances for effective drainage [18].

For disease of the lung parenchyma, interventional ultrasound is especially useful for small peripheral lesions, located in the lower lung fields (for better visualization), and for necrotic lesions (to avoid biopsy of necrotic areas) [19].

The presence of a pleural effusion or perilesional consolidation or atelectasis provides an acoustic window that can be exploited to collect samples of peripheral lung lesions for cytology or microhistology, which are associated with diagnostic accuracy as high as 99% [1].

Ultrasound-guided biopsy is indicated for Pancoast tumors, whose pleural and extrapleural extension can be evaluated in part by sonography. Color Doppler can be used

Fig. 11 Drainage of pleural empyema. The ultrasound image shows a large collection of pleural fluid with fine internal echoes reflecting its corpuscular nature; in the upper right portion is a hyperechoic image representing the cross-section of the drainage tube (A). Axial CT scan shows fluid distributed in a declivous position. A correctly positioned pigtail drainage catheter can be seen within the fluid collection (B).

to visualize the blood vessels located in the areas where these tumors arise [20].

Ultrasound-guided biopsy is also indicated for non-neoplastic lesions, such as parenchymal consolidations of unknown origin in an immunodepressed patient, where isolation of the causative pathogen has clear prognostic value. It can also be used to collect microbiological samples in cases of lung abscess.

As with lesions of the lung parenchyma, ultrasonographic assessment of mediastinal lesions requires an adequate acoustic window. It is limited to the upper, anterior regions of the mediastinum, which can be visualized with a supra-sternal or parasternal approach. The patient is placed in a supine position with a pillow under the shoulders and the neck hyperextended to maximize the field of vision. This approach allows visualization of the pretracheal, retro-sternal region all the way to the aortopulmonary window and the supraaortic region.

The use of color Doppler is fundamental for evaluating the vessels of this region.

Mediastinal masses require cytological or (better) histological diagnosis because the nature of these lesions varies widely and each requires specific therapy [21,22].

Despite its numerous limitations and restricted fields of visualization, ultrasound guidance can be used to perform FNAB and CNB with a low rate of complications, thanks to

real-time visualization of the needle, which allows one to avoid damaging vascular structures and lung parenchyma [22]. However, there are discordant opinions in the literature on the efficacy of ultrasound for differential diagnosis of mediastinal lesions.

Complications

The complications commonly associated with interventional procedures involving the chest, regardless of the type of guidance used, are pneumo- and hemothorax, hemoptysis, vasovagal reactions, and if a malignant lesion is being biopsied, neoplastic seeding along the needle tract.

When interventional procedures are performed under ultrasound guidance, the rate of complications is around 1% [7], which is lower than the rates reported for CT-guided procedures [19]. The use of ultrasound guidance has reduced the rate of post-thoracentesis pneumothorax to less than 3% [23]; in most cases the pneumothorax is quite small and resolves spontaneously.

Risk factors for pneumothorax include lung disease (e.g., chronic obstructive pulmonary disease or emphysema, uncontrollable coughing, lesion characteristics such as depth, size, cavitation, procedure characteristics such as the diameter of the needle, duration of the procedure, number of pleural punctures) [24]. Ultrasound guidance can shorten procedure times and facilitate the identification of a needle insertion pathway that transgresses the smallest amount of aerated parenchyma; its main limitation is the need for an effective acoustic window.

To maximize safety, it is important to visualize the needle and its tip as well as the intralesional and extralesional vascular structures with the use of color Doppler [6,7].

Neoplastic cell seeding of the biopsy needle tract occurs more frequently when there is pleural involvement, in particular in patients with mesothelioma. A recent study compared the incidence of this complication with surgical and imaging-guided biopsy procedures and found a rate of 5% with the latter [25].

Conclusions

Ultrasound is a safe, easy-to-use guide for interventional chest procedures, including those performed to biopsy superficial masses as well as pleural and parenchymal procedures formerly performed under CT or fluoroscopic guidance.

Use of interventional ultrasound requires sound knowledge of the sonographic features of pleural and parenchymal lesions, the techniques used for biopsy and drainage, and the instruments available for use in these procedures. These prerequisites allow correct execution of the procedure. Fundamental steps include preparation of the necessary equipment and supplies, documentation of the patient history, rigorous observation of hygienic norms, and consultation of the pathologist to ensure that the specimen is properly handled.

Although its use is limited to cases in which an acceptable acoustic window is available, ultrasound guidance offers the

advantages of real-time visualization, which allows collection of biopsy specimens and aspirates for microbiological analysis with a low rate of complications.

Conflict of interest statement

The authors have no conflict of interest.

Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.jus.2011.01.00](https://doi.org/10.1016/j.jus.2011.01.00).

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