

Imaging of pleural and chest wall tumors

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The visceral and parietal pleural lining of the thorax is a serosal membrane arising from mesoderm. Together these membranes invest the lungs, interlobar fissures, ribs, diaphragm, and mediastinum. Pleural tumors comprise multiple histologic forms of benign and malignant types. Approximately 90% of pleural tumors arise from metastatic deposits, whereas only 10% are truly primary pleural neoplasms. Histologic types of primary pleural tumors include malignant mesothelioma, fibrous pleural tumors, lymphoma, pleural liposarcoma, and other less common types (Box 1) [1–3].

The response of the pleura by an infiltrating disease process is manifested radiologically by effusion, thickening, or calcification. Several imaging modalities can be used to evaluate pleural masses, and the most common noninvasive methods include chest radiograph, CT, and MRI. Because of the inability of plain radiographs to provide detailed information regarding tissue specificity, CT and MRI are usually used as adjunctive studies.

Malignant mesothelioma

Malignant pleural mesothelioma (MPM) is an uncommon, highly lethal tumor with an incidence of 2000 to 3000 cases and 1500 deaths per year in the United States [4,5]. This tumor is thought to be of mesodermal origin and has a strong relation to previous asbestos exposure. There is no effective medi-

cal treatment, and the only long-term survivors are those who have undergone surgical resection by extrapleural pneumonectomy or pleurectomy/decortication. Evaluation for resectability is a challenging process involving multiple imaging modalities including chest radiograph, CT, MRI, and, more recently, 18-flouro-deoxyglucose (FDG-PET) scanning. It is important to attempt to rule out the presence of advanced disease because of the high morbidity and mortality associated with surgical resection. The radiographic criteria for resectability are listed in Box 2.

The most frequent radiologic abnormality found initially is a pleural irregularity and unilateral pleural effusion on plain chest radiograph (Fig. 1; Table 1) [3]. Other findings occasionally found on chest radiograph include osseous destruction, periosteal reaction, or calcification [1,5]. Isolated pleural masses without effusion are uncommon and occur in less than 25% of patients in the initial radiograph [1].

CT provides greater detail in imaging and clinical staging of MPM compared with chest radiography. The most common CT finding of MPM is pleural thickening, which usually involves the parietal and visceral pleurae (Fig. 2) [6].

A large effusion without mediastinal shift is also a common finding. The lack of mediastinal shift is caused by the restrictive nature of the tumor peel. MRI, which has also been used to evaluate MPM and determine its resectability, has the characteristic finding of increased signal intensity on T2-weighted images compared with adjacent tissue, the sensitivity of which approaches 100% [1]. MRI also allows the visualization of diffuse and nodular pleural thickening and fissural involvement, which often occurs in MPM. CT and MRI have been compared side-by-side in two studies regarding staging and resectability. Heelan et al [7] reported the results of 65 patients

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Box 1. Classification of pleural and chest wall tumors

Pleural tumors

Malignant pleural mesothelioma
Solitary fibrous tumor
Pleural liposarcoma
Pleural metastasis

Chest wall tumors

Soft tissue sarcomas
Cartilaginous tumors
Primary bone tumors
Metastatic lesions
Tumors invading from contiguous organs

who underwent CT, MRI, and attempt at surgical resection in an effort to determine the accuracy of CT and MRI with specific correlation to staging. The accuracy of CT and MRI was relatively poor in most areas. Their accuracy, respectively, to assess visceral pleural involvement was 67% versus 58%; diffuse chest wall involvement 65% versus 52%; invasion of diaphragm 55% versus 82%; and invasion of lung parenchyma 46% versus 69%. The ability to detect

Box 2. Imaging criteria for resectability in malignant pleural mesothelioma

Resectable tumors

Preserved extrapleural fat planes
Normal CT attenuation values and MR signal intensity of adjacent structures
Absence of extrapleural soft tissue masses
Smooth inferior diaphragmatic surface

Unresectable tumors

Tumor encasement of the diaphragm
Invasion of extrapleural soft tissue
Infiltration or displacement of ribs by tumor
Invasion of essential mediastinal structures



Fig. 1. Plain radiograph demonstrating left side pleural effusion in a patient who had MPM.

nodal involvement is even worse: 49% for CT versus 51% for MRI. The authors attribute these low accuracy rates to the diffuse nature of the tumor. MRI was found to be slightly better in revealing solitary foci of chest wall invasion, endothoracic fascia involvement, and diaphragmatic muscle invasion. These findings did not affect surgical decision-making, and the authors advocate the routine use of CT, not MRI, because of the increased cost of MRI. Patz et al [4] performed a study comparing CT and MRI in 41 patients to determine the resectability of MPM. The unresectability rate of patients undergoing thoracotomy was 30%. There was no significant difference in the predictive values of these modalities,

Table 1
Most common CT findings of malignant pleural mesothelioma

Finding	% Cases
Pleural thickening	92
Thickening of interlobar fissures	86
Pleural effusion	74
Loss of volume of involved hemithorax	42
Pleural calcification	20
Invasion of chest wall	18

Data from Refs. [2,6,18].

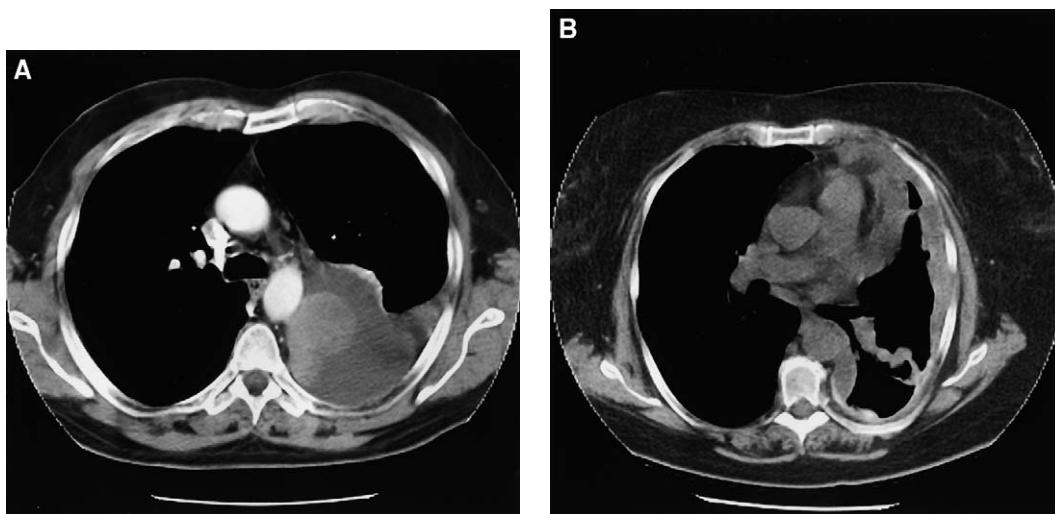


Fig. 2. (A) CT imaging demonstrating medial pleural mass and small pleural effusion in a patient who had MPM. (B) CT image demonstrating diffuse pleural thickening in a patient who had MPM.

leading the authors to recommend CT as the preferred imaging choice for determining resectability.

Recently, the use of imaging with FDG-PET has been applied to several tumor types, including thoracic malignancies (Fig. 3) [5]. MPM is reported to have increased uptake on FDG-PET compared with

benign pleural lesions in the majority of cases [8,9]. It has also been reported to have increased the detection of nodal metastasis compared with CT [9]. The authors reported their experience in 63 patients who had MPM who also underwent FDG-PET during a 4-year period [10]. Increased uptake was seen in all

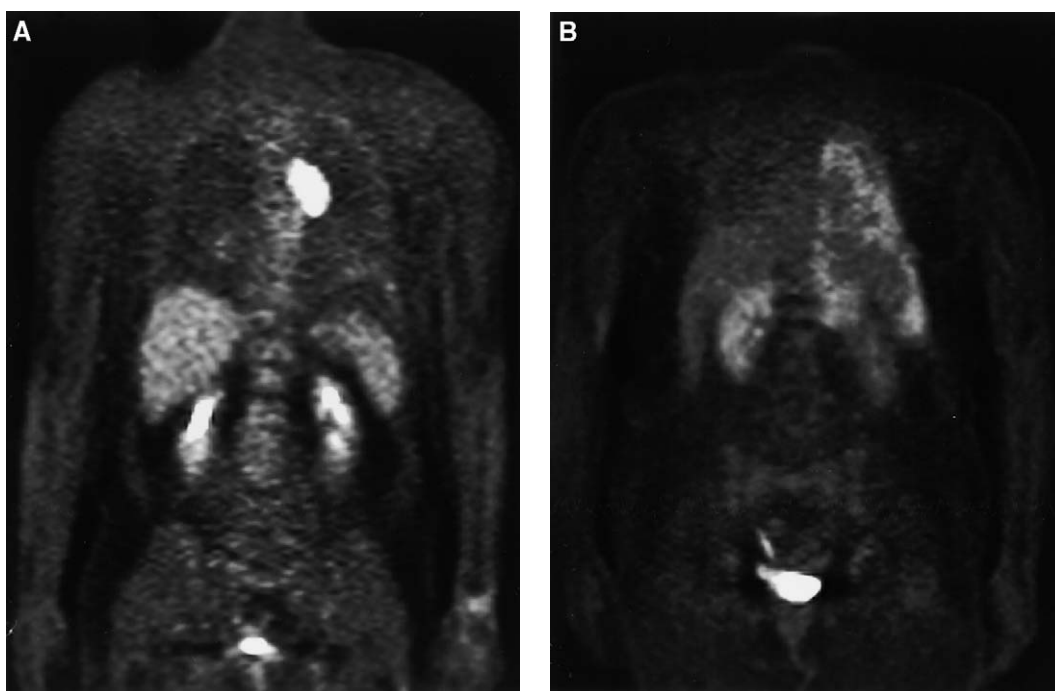


Fig. 3. FDG-PET uptake in patients who had solitary focus (A) and diffuse (B) pleural involvement in patients who had MPM.

but one tumor. PET findings yielded sensitivities of only 19% and 11% in determining tumor (T) and node (N) status, respectively. A high standard uptake value (SUV) did, however, correlate with the presence of N2 disease. The authors' results demonstrated that although FDG-PET is a poor predictor of stage, it identified occult stage IV disease that was otherwise undetected by CT scan alone in 10% of patients.

In addition to the benefit of identifying patients who have stage IV disease, PET scans might have prognostic significance. The authors evaluated their now-larger cohort of 85 patients who underwent PET scanning with the diagnosis of malignant pleural mesothelioma and found that there was a linear relationship between increasing SUV and poor median survival time. In addition, the relative risk of death in patients who had an SUV of greater than four when compared with an SUV of less than four was 3.3 ($P = 0.03$), which is a clinically significant finding that is equivalent to impact of histology on survival. The relative risk of death for nonepithelial histology compared with epithelial histology was 3.2 ($P = 0.03$). These findings suggest that PET can be used to stratify patients for treatment [11].

Pleural plaques

Pleural plaques, which are usually a result of asbestos exposure, can present as diffuse thickening of the visceral and parietal pleural layers. These lesions can vary from diffuse, nodular lesions on the pleural surface to lesions as wide as 6 cm. The coalescence of pleural surfaces and the propensity for the lower hemithorax can cause these lesions to be clinically mistaken for diffuse MPM. These plaques are thought to be formed by lymphatic transport of asbestos fibers from the visceral to the parietal pleura, with the fibers undergoing phagocytosis by macrophages that secrete substances stimulating submesothelial fibro-

blasts [12]. The physician should remember that it is not uncommon for mesothelioma and pleural plaques to be present simultaneously.

The distinction between benign pleural plaques and mesothelioma can generally be recognized easily by CT scan. Calcifications are usually present in patients who have a history of asbestos exposure, and extensive calcification usually indicates benign pleural pathology [13]. In certain cases PET scans have been useful in distinguishing between benign and malignant pleural pathology [14]; however, when a significant question arises, the gold standard in distinguishing a benign from a malignant pleural process is surgical biopsy, preferably by way of the video assisted thoracic surgery (VATS) technique.

Solitary fibrous tumor

Solitary fibrous tumors are thought to arise from submesothelial mesenchymal cells. They comprise only 10% of primary pleural tumors [15]. The incidence of these tumors is highest in patients older than 50 years of age [1]. Approximately 50% of benign fibrous tumors of the pleura are asymptomatic and are found incidentally on routine chest radiographs. Symptomatic patients might present with chest pain, cough, dyspnea, and fever. Pierre-Marie-Bamberg syndrome (pulmonary osteoarthropathy and clubbing) has been described in approximately 15% of cases from the tumor production of hyaluronic acid [16]. Doege-Potter Syndrome (refractory hypoglycemia) has been described in approximately 5% of cases; these lesions might secrete an insulin-like substance [17].

The typical radiographic appearance is a rounded or oval, frequently lobulated mass abutting the pleural surface. Calcification might be present in approximately 5% of cases. The location might be in the fissure (30%), adjoining the mediastinal pleura

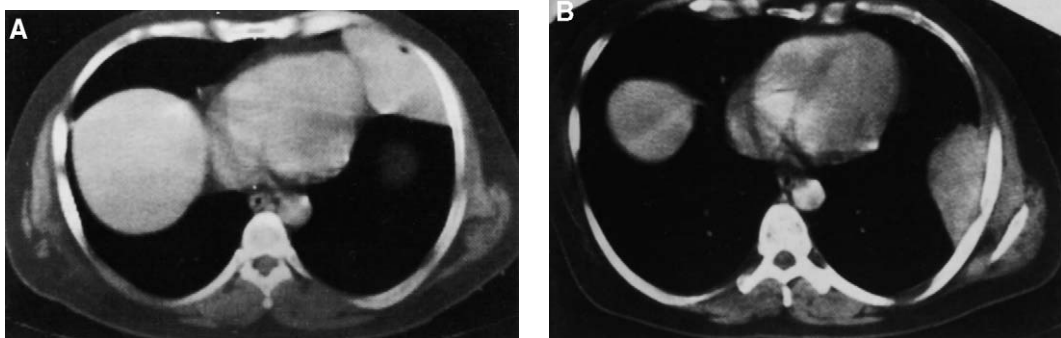


Fig. 4. (A, B) Solitary fibrous tumor attached to stalk. Note change in position with respiration.

(18%), thoracic pleura (46%), or diaphragm (6%). These lesions are reported to be benign in 63% of patients and malignant in 37% of patients [15]. CT imaging provides no pathognomonic findings to evaluate the malignant potential of such lesions except in cases in which a lesion is identified with a stalk (it is more likely to be benign). Variation in location during respiration on CT scan might also indicate the presence of a lesion attached by a stalk (Fig. 4A, B).

Pleural metastasis

Pleural metastases account for a large majority of pleural-based tumors. The most common primary tumors responsible for producing these lesions are bronchogenic carcinoma (36%), breast cancer (25%), lymphoma (10%), and ovarian and gastric carcinoma ($\leq 5\%$; Fig. 5). The most common radiologic finding of pleural metastasis is pleural effusion. Effusions are thought to be produced by tumor blockage of lymph ducts, thereby causing an exudative process. Leung et al [18] reported on the CT findings of pleural lesions, and the most common radiologic findings in patients who had pleural metastasis were effusion in 88%, lung base involvement in 88%, and nodularity in 50%. Other less common findings included pleural thickening and plaque formation in metastatic disease. Pleural lymphoma can produce pleural involvement by extension from mediastinal lymph nodes or, less commonly, by primary involvement. Invasive thymoma can also produce pleural thickening by direct extension from the mediastinum, resulting in pleural thickening or plaques.



Fig. 5. CT image of choriocarcinoma metastatic to the pleura.

Pleural liposarcoma

Pleural liposarcoma is a rare primary pleural tumor. Only 100 cases have been reported in the literature. These lesions present as well-defined pleural masses [19]. The pathognomonic CT and MRI findings are a heterogeneous mixture of fat and soft tissue densities. The surgeon should be able to differentiate pleural liposarcoma from a lipoma, which has a homogeneous tissue density consistent with fat.

Chest wall tumors

Tumors of the chest wall can be benign or malignant and can arise from any of its components, including muscle, bone, adipose tissue, nerves, blood, or lymphatic tissue. The majority of malignant chest wall tumors are metastatic lesions from other organs or they are the result of direct invasion of a tumor from the lung parenchyma. Primary chest wall neoplasms represent only 5% of all thoracic neoplasms, with approximately half of all primary chest wall tumors being benign lesions [20].

Surgical excision is the modality of choice to treat most chest wall tumors. There are few medical options for therapy. Advances in plastic and reconstructive surgery have provided physicians with the ability to reconstruct even the largest of chest wall defects; however, accurate radiologic evaluation of these tumors is essential in determining resectability and planning reconstruction. Radiographic tools for imaging these lesions consist mainly of plain radiographs, CT, and MRI.

Metastatic lesions

Metastatic tumors are the most common chest wall malignancy. The most common sources are lung, breast, kidney, and prostate carcinomas. The most common radiologic manifestation of these tumors is a lytic lesion of one of the ribs [21]. Other tumors such as metastatic thyroid carcinoma might produce expansile, or “blown-out,” lesions in the ribs [22].

Lung cancer with chest wall invasion

Direct extension of lung tumors occurs in up to 8% of cases and accounts for a significant proportion of chest wall malignancies (Fig. 6) [21]. CT is superior to plain radiographs in evaluating the extent of chest wall invasion in these lesions because of the large amount of bone destruction required for the



Fig. 6. T3 lung cancer demonstrating invasion of chest wall on CT imaging.

lesion to become visible on plain radiographs [21]. MRI has also been studied to evaluate the extent of chest wall invasion. Padovani et al [23] evaluated 34 patients who had bronchogenic carcinoma and reported a sensitivity of 90% by MRI for evaluating chest wall invasion. Webb et al [24] performed a study comparing the accuracy of CT and MRI in evaluating tumor classification and found that there was no difference in the ability of MRI versus CT in delineating chest wall invasion; however, they did find that MRI might be superior in identifying mediastinal invasion. Identifying lung cancers that invade into the chest wall is essential to the preoperative planning and the clinical staging of these patients, particularly since these tumors became classified as T3.

Pancoast tumors

Bronchogenic carcinomas that develop in the apex of the lung and invade the superior pulmonary sulcus were described in 1932 by Pancoast, who noted their association to the clinical findings of Horner's syndrome, unilateral arm pain, and wasting [25]. This type of tumor represents less than 5% of all lung cancers, and the survival rate is reported to range from 15% to 56% (Fig. 7) [26,27]. Vital structures such as the subclavian artery and vein, brachial plexus, and vertebral bodies can be invaded early in the course of growth of superior sulcus tumors. Surgical resection is an important predictor of cure. Accurate radiologic assessment of these tumors is essential to ensure appropriate selection of patients

as candidates for resection to avoid the morbidity associated with surgery.

These cancers are most often found on plain radiograph, but more detailed studies are required to delineate the extent of tumor invasion. CT and MRI are used extensively, and crucial therapeutic decisions are made based on these initial imaging studies. The critical anatomic areas to be addressed include (1) the apical layer of fat between the pleura and the subclavian artery and vein, (2) tumor invasion into the supraclavicular area, (3) invasion into the subclavian vein and artery, (4) brachial plexus invasion, and (5) involvement of adjacent ribs or vertebral bodies [28]. The decision to offer preoperative chemotherapy or radiation therapy is based on determining invasion into these specific areas.

Heelan et al [29] reported experience with 31 patients who had superior sulcus tumors at Memorial Sloan Kettering Cancer Center, comparing CT and MRI in all patients. MRI was superior to CT, with an accuracy of 94% compared with 63% in determining invasion extending beyond the apex of the lung. This increased accuracy is believed to be caused by MRI's ability to image in different planes, particularly the coronal and sagittal planes. Laissy et al [30] reported experience and efficacy with MR angiography to determine the presence of vessel involvement. Other authors reported that there might be an advantage to CT in delineating vertebral body and rib destruction [28]. The authors find that most patients initially obtain a CT because of its convenience and availa-

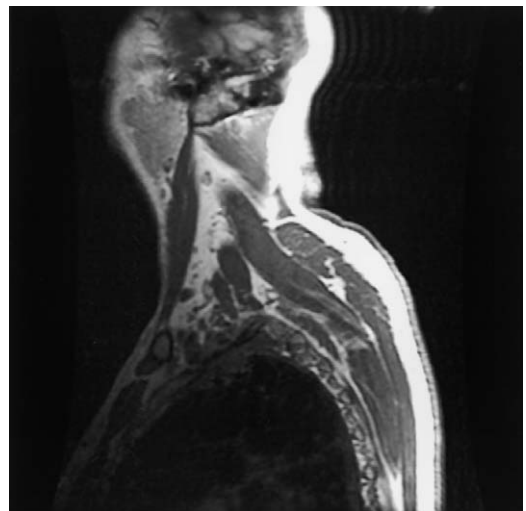


Fig. 7. Pancoast MRI demonstrating invasion of lower trunk of brachial plexus.

bility. MRI has been demonstrated to be superior in many aspects when compared with CT and should be employed in this group of patients.

Primary osseous and cartilaginous lesions

Fibrous dysplasia is the most common benign tumor arising from bone. These tumors account for approximately 30% of benign tumors of the chest wall [21,22]. These fibrous tumors are slow-growing and are usually seen in the lateral or posterior aspect of one of the ribs. The tumor progresses by filling in the medullary cavity with fibrous tissue, which can be demonstrated on CT or MRI [21]. The usual radiologic finding is an expanding lytic lesion in one of the ribs with a ground-glass appearance [22]. Osteochondroma and chondromas together comprise another 30% to 40% of benign chest wall tumors and usually arise at the sternocostal junction.

Chondrosarcoma is the most common malignant lesion arising from the bone, most frequently from the anterior portion of the ribs and less frequently from the sternum, scapula, or clavicle (Fig. 8) [20]. Chondrosarcomas frequently appear as a large, lobulated mass arising from a rib with scattered calcifications consistent with a bony matrix [22]. These lesions might be similar radiographically with their benign counterparts, enchondromas, osteochondromas, and osteblastomas, therefore necessitating tissue biopsy for diagnosis. The size of the lesion can be used as a predictor of malignancy; lesions larger than

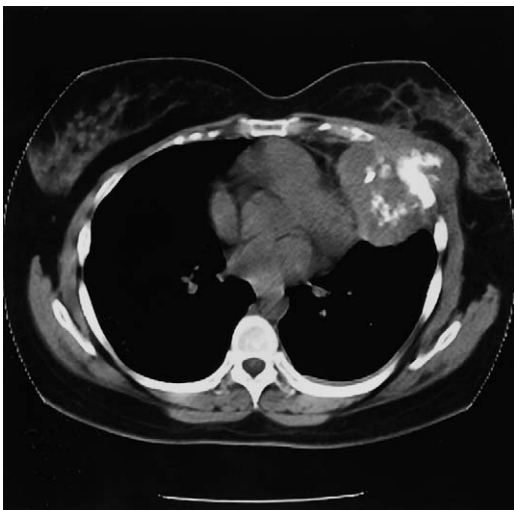


Fig. 8. CT imaging of chondrosarcoma arising from the chest wall.

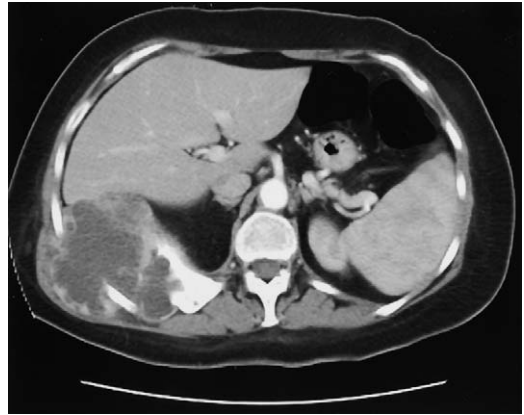


Fig. 9. CT imaging of osteosarcoma arising from the lateral chest wall.

4 cm are considered to be malignant [21,22]. Osteosarcomas are true malignant bony primary tumors and usually arise from a rib. These tumors carry a worse prognosis and have similar radiologic findings to chondrosarcomas (Fig. 9).

Soft tissue tumors

Soft tissue tumors of the chest wall arise from muscular, connective, or neural tissue. The most common soft tissue primary malignant tumors of the chest wall include fibrosarcoma, malignant fibrous histiocytoma, and neurofibrosarcoma [20]. These lesions appear radiographically similar and present as masses of soft tissue density that might be associated with a low-density necrotic area and areas of focal calcification. Malignant schwannomas, rarer tumors, often appear as rounded or elliptical masses adjacent to a rib [21].

The most common benign soft tissue lesion of the chest wall is the lipoma. These lesions can have intrathoracic and extrathoracic components, a dumb-bell-shaped appearance, and tissue density consistent with fat, which makes these lesions easy to identify using CT or MRI. Neurogenic tumors are often benign and usually appear radiographically to originate from intercostal nerve roots. MRI is extremely useful in identifying lesions that encroach on the neural foramen. Hemangiomas are soft tissue masses that are occasionally found in the chest wall and are identified radiographically by the presence of phleboliths and irregular tissue density [22]. Other rare lesions include plasmacytomas and desmoid tumors.

The imaging modalities used most frequently to evaluate chest wall tumors include plain radiographs,

CT, and MRI. CT and MRI clearly provide superior resolution to plain radiographs; however, most tumors are detected initially by a plain radiograph. Because of its broad diagnostic spectrum, low susceptibility to artifacts, wide availability, and lower cost, CT is usually the preferred initial imaging choice in most institutions [31]. Although MRI is expensive, time-consuming, and can be susceptible to motion artifacts, it has several qualities that make it desirable for evaluation of chest wall tumors. Multiplanar imaging and superior soft tissue resolution allow MRI to visualize the relations of tumors to vessels and planes of tissue, which is helpful when evaluating the extent of invasion of a tumor into the chest wall [21,31]. The ability of MRI to help determine the position of a neurogenic tumor in relation to the neural foramen is also an advantage. Lastly, the lack of iodinated contrast material allows a viable option for imaging in patients who had allergic reactions to standard intravenous contrast solutions.

Summary

MPM is a difficult disease to characterize radiographically because of its diffuse nature and propensity to infiltrate between tissue planes. Although significant information is obtained by CT, MRI, and PET, correlation with intraoperative findings is inconsistent. Overall, CT and MRI are similar in predicting surgical resectability of pleural and chest wall malignancies. MRI has a slight advantage in select situations such as Pancoast tumors; however, CT is less expensive and is sufficient in the majority of cases. Because radiologic imaging cannot differentiate benign from malignant lesions with 100% accuracy, surgical biopsy remains the gold standard for diagnosis. Newer imaging modalities such as PET scan and combined PET/CT might provide greater information and warrant further study in the preoperative evaluation of pleural and chest wall tumors.

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