PREDICTORS OF SURVIVAL IN MALIGNANT TUMORS OF THE STERNUM

From 1930 to 1994, 54 patients with primary malignant tumors of the sternum were seen. Fifty patients were first seen with a mass, and one half of them also had pain in the sternal region. Two patients had no symptoms at presentation. Among 39 solid tumors were 26 chondrosarcomas, 10 osteosarcomas, 1 fibrosarcoma, 1 angiosarcoma, and 1 malignant fibrous histiocytoma. Of these, 25 were low-grade and 14 were high-grade tumors. Among 15 small cell tumors were 8 plasmacytomas, 6 malignant lymphomas, and 1 Ewing's sarcoma. Partial or subtotal sternectomy was done in 37 patients and total sternectomy in 3. Of the remaining 14 patients, 3 had local excision; 10 had external radiation or chemotherapy without operation, or both; and 1 had no treatment. All but one patient treated by wide resection ($N = 40$) had some form of skeletal reconstruction of the chest wall defect. Thirty-one (78%) underwent repair with Marlex mesh, and in 25 this was combined with methyl methacrylate. The skin edges were closed per primum in 32 patients; 8 required muscle, omentum, or skin flaps. Resection in chondrosarcomas yielded a 5-year survival (Kaplan-Meier) of 80% (median follow-up, 17 years). The 5-year survival in osteosarcomas was 14%. Resection was curative in 64% of low-grade sarcomas but in only 7% of high-grade sarcomas. In small cell tumors, resection and radiation were helpful for local control; all failures were a result of distant metastases. We conclude that primary sarcomas of the sternum though uncommon are potentially curable by wide surgical excision. With rigid prostheses to repair the skeletal defects, the surgical complication rates are low. Overall survival after complete surgical resection is related to tumor histologic type and grade. (*J THORAC CARDIOVASC SURG* 1996;111:96-106)

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PPrimary malignant tumors of the sternum generally fall into two categories: solid tumors, which include primary bony or cartilaginous tumors and soft tissue sarcomas, and small cell tumors, which are usually systemic but may present as a localized

sternal mass. This latter group includes Ewing's sarcomas, plasmacytomas, and lymphomas.

Since our report 2 decades ago,¹ new methods of evaluation and surgical treatment and advances in techniques of skeletal and musculocutaneous reconstructions have facilitated the treatment of these uncommon tumors. To assess results and identify predictors of survival, we reviewed our total experience with these tumors.

Patients and methods

From 1930 to 1994, 54 patients with primary malignant tumors of the sternum were seen and treated at Memorial Sloan-Kettering Cancer Center. The clinical, surgical, and pathologic reports of all patients were carefully reviewed to ensure that the tumors were malignant and originated from the sternum and no other site. Each tumor was

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Table I. Histologic type of primary sternal tumors 1930 to 1994

Type	No.
Solid tumors	39
Chondrosarcoma	26
Osteosarcoma	10
Angiosarcoma	1
Fibrosarcoma	1
MFH	1
Small cell tumors	15
Plasmacytoma	8
Malignant lymphoma	6
Ewing's sarcoma	1

MFH, Malignant fibrous histiocytoma.

evaluated for size, histologic type, grade, and location. The treatments rendered were also recorded. In those patients in whom resection was the primary therapy, the mode and extent of resection, the size of the skeletal defect, and the type of skeletal and cutaneous reconstructions were noted. Follow-up status and recurrent sites if any were also recorded. Survival was calculated by the Kaplan-Meier method,² and postoperative deaths and all cancer-related deaths were included. Differences in survival were determined by the log-rank test³ and differences in frequency data by the χ^2 test. Significance was defined as $p \leq 0.05$.

Of 39 solid tumors, most were chondrosarcomas or osteosarcomas (Table I). The 15 small cell tumors were mainly plasmacytomas and malignant lymphomas.

There was a near equal sex distribution for all tumors seen except for chondrosarcomas for which the male-to-female ratio was 2 to 1. The age range was 19 to 78 years, with a median age of 54 years. The median age was 55 years in patients with chondrosarcoma, 40 years for osteosarcoma, 59 years for plasmacytoma, and 48 years for malignant lymphoma.

Fifty patients were first seen with a palpable mass, and one half of them also had pain in the sternal region. Two patients had no symptoms or signs at presentation and the disease was detected on lateral chest radiographs.

The size of the tumor ranged from 3 to 24 cm in maximum diameter with a median of 7 cm. All patients had imaging studies of the sternum. A few of the earlier patients had only radiographs of the chest taken in the posteroanterior and lateral positions with views of the sternum in the oblique and cross table lateral positions (Table II). Since then, progressively more refined imaging techniques included planar tomograms, skeletal surveys, bone scans, selective angiograms, and, more recently, computed tomographic (CT) scans and magnetic resonance imaging (MRI).

Radiographic features were specific only in cartilaginous tumors. All patients with chondrosarcoma had coarse, mottled calcification within the tumor. Differentiation between benign and malignant cartilaginous tumors was not possible by radiographic criteria, unless cortical destruction and involvement of soft tissues were visualized. The remaining tumors of the sternum showed no constant or diagnostic features. Most tumors were avas-

Table II. Pretreatment imaging studies in 54 patients*

Study	No.
Plain chest radiography	54
Planar tomography	16
CT scanning	28
Bone scan	18
Skeletal survey	10
MRI	7

*Most patients had two or more studies.

cular. CT and MRI scans were most helpful in defining tumor extent (Fig. 1). Radiographically, portions of the sternum were free of tumor in all but five patients. The extent of tumor involvement is shown in Fig. 2.

Tissue diagnosis was established by fine-needle aspiration biopsy in 3 patients, open biopsy in 38, and at the time of definitive operation in 13. Of 39 solid tumors, 25 were low-grade sarcomas and 14 were high-grade tumors. Of the 26 chondrosarcomas, 9 were grade I, 15 grade II, and 2 grade III. The one patient with angiosarcoma had a low-grade tumor; all others were high grade.

Seven of 10 patients with osteosarcomas of the sternum had prior external irradiation for Hodgkin's disease in 4 patients, breast carcinoma in 1, thymoma in 1, and rhabdomyosarcoma in 1.

All patients with small cell tumors underwent bone scans to rule out multiple sites.

Of 39 patients with solid tumors, 1 received no treatment, 1 received radiation therapy, 2 had local excisions, and 35 had wide resections (Table III). Among 15 patients with small cell tumors, primary treatment consisted of wide resections in 5, external radiation therapy in 7, chemotherapy in 2, and radiation plus chemotherapy in 1.

The extent of resection paralleled the extent of sternal involvement. Partial or subtotal sternectomy was done in 37 patients and total sternectomy in 3. All but 1 patient treated by wide resection ($N = 40$) required some form of skeletal reconstruction of the chest wall. Thirty-one (78%) underwent repair with Marlex mesh (Bard Implants, Billerica, Mass.), and in 25 this was combined with methyl methacrylate (Table IV). The soft tissue and skin edges were closed per primum in 32 patients (Table V). Unless the entire sternum was involved by tumor, an effort was made to conserve part of it, usually the proximal rim of the manubrium, and to maintain the circumferential continuity of the thoracic cage. By this method, combined with adequate skeletal reconstruction, paradoxical motion was avoided. The size of skeletal defects in our series ranged from 36 cm² (6 × 6 cm) to 324 cm² (18 × 18 cm) with a median skeletal defect of 120 cm² (10 × 12 cm).

There were two postoperative deaths both as a result of respiratory failure (1 because of inadequate stabilization after total sternectomy and 1 because of pneumonia). There were four nonlethal complications: pneumonia (1), infection necessitating removal of the prosthesis (2), and bleeding (1). Since the advent of rigid prostheses, respiratory assistance has not been necessary after operation. Before the use of Marlex mesh by us in 1971, two patients had an elective tracheostomy. Additionally there were

Fig. 1. Chondrosarcoma of sternum in 48-year-old female patient. **A**, Axial CT scan shows 7 cm lobular tumor replacing sternum, extending externally to subcutaneous soft tissue and deep to pericardial surface. It cannot be determined with certainty whether pericardium is involved. *R*, right. **B**, Axial T1-weighted MRI scan with cardiac gating. Deep extent of tumor is well demonstrated. Pericardium is not seen on scan, which suggests adherence to or invasion of pericardium. **C**, Sagittal T1-weighted cardiac gated MRI scan. Superficial and deep extents of tumor are well demonstrated. Again pericardium is indistinct, suggesting involvement by tumor. Patient underwent total sternectomy and remains without evidence of recurrence.

delayed infections in two patients who had a skeletal repair with methyl methacrylate at 9 and 10 years, respectively, as a result of injury necessitating removal of the prostheses. This was preceded in one patient by an episode of acute arrhythmia that had necessitated external cardiac massage, which may have caused injury to the sternum. The second patient, an avid tennis player, was found at 9 years after operation to have an unexplained fracture in the upper portion of the methyl methacrylate prosthesis near its attachment to the manubrium. This is presumed also to have been a sternal injury from his sports activities. It is likely that in both instances there was a hematoma in the parasternal area that became secondarily infected with persistent purulent sinus drainage, which necessitated removal of the prostheses.

Surgical technique. The technical approach in skeletal reconstruction of chest wall defects with Marlex mesh and methyl methacrylate has been previously described by us.⁴ For sternal tumors, wide resection includes resection of the affected part of the sternum and approximately 2 to 3 cm of costochondral cartilages bilaterally (Fig. 3). Usually both internal thoracic vessels are sacrificed. The surgical procedure begins with a vertical elliptical incision from the sternal notch to 3 to 4 cm below the tip of the xiphoid process. The ellipse must encompass the prior biopsy site of skin and soft tissues. In general the skin and overlying soft tissues in primary sternal tumors are not involved and are undermined laterally for 5 to 6 cm from each of the lateral borders of the sternum. Except when the xiphoid is to

Fig. 2. Extent of sternal involvement in 54 patients.

Table III. Treatment

Primary treatment	Solid tumors	Small cell tumors	Total
Wide resection	35	5	40
Resection only	29	2	31
With chemotherapy	6	1	7
With radiation		1	1
With radiation and chemotherapy		1	1
Local excision with radiation	2	1	3
Radiation only	1	6	7
Chemotherapy only		2	2
Radiation and chemotherapy		1	1
No treatment	1		1
Total	39	15	54

be spared, the subxiphoid space is entered, allowing digital palpation of the retrosternal space. Mobilization is then begun first on one side of the sternum, with exposure and division of the ribs at the costochondral cartilages. Dissection and mobilization are advanced cephalad to the junction of the body and the manubrium or extend into the manubrium itself, sparing the uppermost 1 cm of the manubrium in most instances. When similar dissection is done on both sides of the midline, a Gigli saw is used to transect the sternum in its upper free margin. Both internal thoracic vessels by this time would have been identified, dissected out, and doubly ligated before division. The number of ribs generally resected varies from two to eight.

Chest wall stabilization is achieved in all patients with Marlex mesh with or without methyl methacrylate. Sutures are placed either through drill holes in adjoining ribs or through pericostal soft tissues.

After skeletal reconstruction, the skin, subcutaneous tissues, and underlying muscles are mobilized and then approximated generally in the midline in two layers. Although the incision is often placed in the midline over the Marlex mesh, healing is per primum and the risk of

Table IV. Types of skeletal reconstruction after wide resection

Type	No.
Marlex mesh plus methyl methacrylate	25
Marlex mesh	6
Ox fascia	3
Fascia lata	2
Rib struts and fascia lata	1
Tantalum mesh	1
Pectoral muscle flap	1
None	1
Total	40

infection is small if the overlying tissues are adequately vascularized. Cosmetic and functional results are satisfactory and the procedure is generally safe.

Results

Results of treatment in solid tumors. Overall survival in patients with solid tumors was 49% at 5 years with a median survival of 33 months (Fig. 4). Survival in solid tumors of the sternum was influenced by the grade of the tumor. Among 25 patients with low-grade sarcomas, 24 of which were chondrosarcomas, the 5-year survival was 73% as opposed to 7% in 14 patients with high-grade tumors, 10 of which were osteosarcomas (Fig. 5). Resection was curative in 16 patients with low-grade sarcomas, but was curative in only 1 patient with a high-grade tumor.

Overall survival in patients with chondrosarcoma was 66% at 5 years and 56% at 10 years with a median survival of 17 years. Only 1 patient with osteosarcoma was alive and free of disease at 5 years (median survival, 12 months).

Fig. 3. Radiograph of resected chest wall in 54-year-old man with low-grade chondrosarcoma of body of sternum. Resection included body, xiphoid process, and lower portion of manubrium. Tumor is clearly seen in upper part of body of sternum.

Twenty-two patients with chondrosarcoma of the sternum were treated by complete resection, 20 by partial or subtotal sternectomy, and 2 by total sternectomy. Fifteen had no recurrence, 5 had pulmonary metastases, and 2 had local recurrence in the lower sternal region despite a presumed complete resection. In both instances, the manubrium was uninvolved and spared. Of note is that five patients treated by wide resection had prior local excisions and external radiation therapy with recurrence at presentation to our center. Three of these had no further recurrence, and two had local recurrences. Both of these patients were treated before the advent of synthetic prostheses and their skeletal defects were repaired with fascia lata. One patient with high-grade chondrosarcoma died of extensive pulmonary metastases despite a complete resection. All four patients not treated by wide excision died of local recurrence.

All 10 patients with high-grade osteosarcomas of the sternum had subtotal resections of the sternum. Three of the resections had positive margins and were considered incomplete; local recurrence and

Table V. *Types of soft-tissue/cutaneous reconstruction*

Type	No.
Primary closure	32
With undermining skin edges only	30
With relaxing midaxillary incisions	2
Pectoral muscle rotation flap*	3
Omental flap with split thickness skin graft*	2
Myocutaneous flap†	2
Delayed pedicle flap	1
Total	40

*Repair dictated by two prior local excisions in one patient and preoperative radiation in one patient.

†Both patients had osteosarcoma after radiation.

subsequent pulmonary metastases developed in the patients. Seven patients were considered to have had a complete resection of all tumor. One died after operation of pneumonia and no residual tumor was found at autopsy. Five had disseminated metastases, and one remains alive and free of disease.

Survival after complete resection in patients with chondrosarcoma of the sternum ($n = 22$) was 80% at 5 years (median, 17 years). One of seven patients with completely resected osteosarcoma of the sternum survived 5 years (median, 16 months) and is alive and well at 11 years (Fig. 6).

The one patient with low-grade angiosarcoma of the sternum remains alive and well 7 years after resection. However, the two patients with fibrosarcoma and malignant fibrous histiocytoma, respectively, died of the disease within 6 months.

Results of treatment in small cell tumors. Among eight patients with plasmacytomas of the sternum, five had no operation, one had local curetting plus radiation therapy, and two had wide resections of the sternum. In four of these eight patients multiple myeloma subsequently developed and the patients died of the disease. Of the four patients who have remained free of disease, one was treated by local curetting and radiation (alive at 29 months), one by wide resection (alive at 12 months), one is alive free of disease at 8 years after chemotherapy only, and the fourth, treated by radiation only, died of an unrelated cause 14 years after treatment.

All six malignant lymphomas of the sternum were high-grade tumors; four patients had no operation and two had sternectomies. Three of those treated nonsurgically received external radiation therapy and one had chemotherapy. One patient treated by radiation for stage I lymphoma remains alive and well at 11 years. A second patient treated by radia-

Fig. 4. Overall survival.

Fig. 5. Survival by grade in patients with solid tumors ($N = 39$).

tion had repeated local recurrences treated with more radiation and remains free of disease at 16 years. The third patient died of local recurrence and distant metastases at 5 months. The one patient treated with chemotherapy only is alive and well at 1 year, but this follow-up is too short to be conclusive. One of the two patients treated by wide resection was initially thought to have a chondrosarcoma on the basis of open biopsy results before operation but the diagnosis of lymphoma was established on paraffin studies of the resected specimen. He remains free of disease 11 years after treatment. The second patient had received preoperative radiation and chemotherapy before resection for persistent disease and was lost to follow-up at 9 months after operation.

Overall survival in patients with plasmacytoma was 69% at 10 years with a median survival of 132 months; survival in patients with lymphoma of the sternum was 83% at 10 years with a median survival not yet reached (Fig. 7).

The one patient with Ewing's sarcoma was a 19-year-old girl who died of massive local recurrence within 4 months despite intensive chemotherapy and complete resection.

Discussion

Primary tumors of the sternum represent about 1% of primary bone tumors and fall into two categories: solid tumors, the treatment of which is surgical, and small cell tumors, for which treatment is primarily

Fig. 6. Survival after resection in patients with chondrosarcoma and osteosarcoma.

Fig. 7. Survival by histologic type in patients with small cell tumors.

medical with operation offered selectively for local control.^{1,5}

Careful radiologic investigation is necessary to assess the extent of the tumor. The mass evident on examination is often part of a much larger tumor invading the sternum. Planar tomography and skeletal surveys, previously considered part of the standard evaluation, have been replaced by CT scans to evaluate the extent of the tumor and search for pulmonary metastases.⁶ High-resolution scans may help assess the extent of the primary tumor, particularly with respect to mediastinal invasion. MRI scans may be useful for large tumors in which mediastinal invasion of the pericardium, heart, or great vessels may be present. MRI sagittal views may be a useful addition to conventional axial scanning. Nuclear bone scanning serves to identify osseous

metastases at other sites. Pulmonary function testing is important in patients with chronic obstructive pulmonary disease, in the elderly, and in those with large tumors necessitating a wide resection.

In early series most authors recommended resection for both diagnosis and treatment. However, an effort to establish a preoperative diagnosis is advisable to identify those patients whose primary treatment consists of chemotherapy or radiation, or both, and to distinguish primary from metastatic tumors and inflammatory conditions.

It is recommended that all tumors of the sternum be regarded as malignant until proved otherwise. Most patients in our series had an incisional biopsy done for diagnosis. Aspiration biopsy was not routinely recommended because of the low accurate diagnostic yield. However, core needle biopsy may

be of value, though it was not used in our series. It is important to emphasize that the biopsy site should be planned in such a manner as to permit its excision with the primary tumor if resection becomes the treatment of choice.

Open biopsy may not distinguish between benign and malignant cartilaginous tumors. Consequently, wide resection becomes necessary in questionable cases. Primary resection without biopsy may be justified for small lesions less than 3 to 4 cm in diameter or when a cartilaginous tumor is suspected on a CT or MRI scanning.

Chondrosarcoma is the most common primary malignant tumor of the sternum.⁷ Its management previously consisted of biopsy, curettage, and radiotherapy with little chance of long-term survival before wide resection became the treatment of choice.

The aim of operation in solid tumors of the sternum is to remove all tumor with clear margins.⁸⁻¹³ However, this does not necessarily mean total sternectomy. Unless the entire sternum is involved by tumor, an effort is made to conserve part of it with its attachments to the remaining rib cage. Paradoxical motion can be avoided if the circumferential continuity of the thoracic cage is maintained and adequate skeletal reconstruction is done. If the tumor is located in the lower sternum, all or part of the manubrium can usually be spared. However, tumors that involve the upper sternum generally necessitate resection of the manubrium and the body of the sternum, as well as the adjacent costal cartilages. To provide stability to the chest and avoid flail, skeletal defects are reconstructed with Marlex mesh and methyl methacrylate.¹⁴⁻¹⁷ Cutaneous reconstruction is rarely a problem in primary sternal tumors despite extensive resection of the sternum. The placement of skin sutures in the midline over the Marlex mesh does not deter primary healing.

With the use of rigid prostheses, pulmonary function is preserved, early extubation is possible in nearly all patients, and hospitalization becomes shorter because of fewer complications. In a review from M. D. Anderson Cancer Center,¹⁸ it was noted that ventilator use was fivefold more frequent in patients who had no Marlex mesh reconstruction and that the hospital stay was also prolonged. The chest wall is generally well-healed and stable in 4 to 6 weeks.

The grade of the tumor appears to dictate curability. Chondrosarcomas usually are low-grade tumors and patients with these do well. The high-grade variants are uncommon but appear not to be

eradicated by resection. Osteosarcomas of the sternum are usually high-grade tumors and many are radiation induced. Again, a total sternectomy is not essential. However, adjuvant systemic treatment is necessary. For the less frequent sarcomas, the extent of resection and survival are guided by tumor grade.

When the skin and soft tissues of the chest wall are also involved by tumor or their vascularity compromised by prior radiation therapy, extensive soft-tissue coverage may be necessary and should be properly planned in advance with a plastic surgeon. Omentum may be interposed between the Marlex mesh and the skin to improve vascularity. Pedicle skin flaps and rotation flaps used in earlier years are now replaced by myocutaneous and free flaps. An overall wound infection rate of 5% is reported in the literature,^{14, 15, 19} and this is consistent with our experience. The risks of infection are small if the overlying tissues are adequately vascularized. When the skin and soft tissues are sacrificed, the infection rate may be as high as 20%, because of tissue necrosis necessitating removal of the synthetic prostheses.

Two synthetic prostheses are currently in popular use,^{15, 20, 21} Marlex mesh, which we have used in most of our patients, and polytetrafluoroethylene* prostheses. Either are adequate and the reported differences in their benefits are marginal. Providing adequate and immediate reconstruction is important. Major sternal resections can be done safely and can be curative. Full-thickness resections are more complex, require advanced planning, and have higher complication rates, mainly because of tissue necrosis and secondary infection.

The use of Marlex mesh to cover chest wall defects was described in 1960 by Graham and associates.²² In 1981, McCormack and associates⁴ reported on 155 patients with chest wall resection. Of these 94 underwent repair with Marlex and 12 with methyl methacrylate. The overall prevalence of wound infection at the time was 5%.

When repeated resections are done because of recurrence after limited excisions, sufficient scarring of the mediastinum may obviate the need for skeletal reconstruction even after a total sternectomy. Otherwise, total sternectomy necessitates rigid prosthetic reconstruction. Paradoxical motion of the chest may be so severe as to require permanent or prolonged artificial ventilatory assistance. In our early

*Gore-Tex prostheses: Gore-Tex is a registered trademark of W. L. Gore & Associates, Inc., Newark, Del.

experience, this occurred in one patient who required ventilator support for 6 months and eventually died of respiratory failure. Unfortunately, despite the introduction of methyl methacrylate in skeletal reconstruction of the chest wall and sternum more than 20 years ago, there are still occasional cases that are treated currently with myocutaneous flaps and soft-tissue reconstruction without the use of a rigid prosthesis.

The predictors of survival in 126 patients with primary bony and cartilaginous sarcomas of the chest wall were reported earlier by us⁵ and included the grade of the tumor, the presence of pulmonary metastases at presentation, inadequate or no resection, and local recurrence. The same predictors held true for the subgroup of tumors originating in the sternum. In chondrosarcomas, the single most important factor that predicts good outcome is the ability to perform a complete resection of the tumor at the first operation to prevent local recurrence and subsequent metastases. This is not necessarily true for cases of osteosarcoma in which survival is poor despite resection and adjuvant chemotherapy becomes necessary. Radiation therapy is generally not applicable because most (7 of 10 in our series) are postradiation sarcomas.

Although resection has selectively benefited patients with plasmacytoma or malignant lymphoma, treatment is generally as effective with external radiation therapy or chemotherapy. The overriding factor that predicts survival in plasmacytoma is the subsequent development of multiple myeloma.²³ In this series, multiple myeloma developed in 50% of the patients, and these died of the disease. Because of this, it is suggested that chemotherapy be a part of the primary treatment in these patients.

In primary lymphomas of the sternum, treatment consists of chemotherapy and irradiation. Operation is confined to cases in which the diagnosis is in doubt or done for salvage after local recurrence or persistent local disease.

Only one patient was seen with Ewing's sarcoma confined to the sternum. Diagnosis was made by an incisional biopsy and despite a complete resection and chemotherapy, extensive local recurrence occurred within 2 to 3 months. The primary treatment for Ewing's sarcoma of other sites is currently chemotherapy followed by resection, and this is probably applicable to patients who are seen with sternal involvement.

In summary, we conclude that prognosis and survival in primary malignant tumors of the sternum

are tumor dependent. Most solid tumors, notably chondrosarcomas, are potentially curable by wide surgical excision. With the use of rigid prostheses to repair the skeletal defect, the surgical complication rates are low. The two main prognostic factors are the grade of the tumor and the completeness of the resection. High-grade tumors and incomplete resections are adverse factors for long-term survival. Local recurrence and pulmonary metastases are the most common reasons for failure of treatment.

Treatment of plasmacytoma and primary lymphomas of the sternum is nonsurgical, except when the diagnosis is in doubt or as a salvage operation if the tumor is still localized after radiation therapy and chemotherapy. Hence, it is important to identify these tumors before treatment is rendered.

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Discussion

Dr. Geoffrey M. Graeber (*Morgantown, W.Va.*). As this presentation has pointed out, primary malignant tumors of the sternum are quite rare. In this paper, the authors state that only 54 patients were seen during a 64-year period at their facility. In a series that I presented previously documenting the experience at the military medical centers associated with the Uniformed Services University, 110 patients had chest wall neoplasms during a 31-year period (*Ann Thorac Surg* 1982;34:664-73). Only two patients, both of them with chondrosarcomas, were seen with primary sternal malignancies in that series. Benign neoplasms of the sternum do occur, but are extremely rare. Metastases to the sternum also occur, but generally are part of a disseminated malignancy. Initial presentation of a metastasis as a mass in the sternum without radiographic or clinical evidence of other malignant disease does occur, but is exceptionally unusual. In my own personal experience, I have seen but one patient with this unusual presentation.

The current authors have carefully documented that accurate diagnosis of chest wall malignancies, and partic-

ularly of sternal malignancies, is difficult by either needle aspiration or by frozen section. Incisional biopsy may be undertaken, but may yield spurious results, particularly in chondromatous neoplasms. Unfortunately, incisional biopsies may sample some of the least malignant areas of a chondromatous malignancy. The true malignant potential of any such neoplasm can only be ascertained after thorough examination of the entire mass by a pathologist.

The authors are quite right that the outcome of treatment of any chest wall malignancy is directly related to the grade of the tumor and to the completeness of the initial resection, when resection is the most appropriate method of treatment. The survival reported here of 80% at 5 years in malignant chondromatous neoplasms is comparable to the 89% we reported when we summarized the military experience approximately a decade ago. The experience of the Memorial Sloan-Kettering group with osteosarcomas should be viewed with the perspective that 7 of the 10 osteosarcomas of the sternum they reported arose in previously radiated fields. Malignancies caused by radiation, and particularly sarcomas induced by radiation therapy, are vicious tumors with unusually malignant potential. Most of these tumors prove refractory to virtually any therapeutic measures used.

The work of this group highlights the dilemma of proper treatment for small cell tumors of the chest wall. Solitary plasmacytomas of the chest wall may well be the first presentation of multiple myeloma in a patient. The treatment of such patients must be individualized with the knowledge that in the majority multiple myeloma will develop. Therapeutic options available for treating a chest wall plasmacytoma must be selected carefully. If radiation is selected to treat the plasmacytoma, then the dosage used must be sufficient to eradicate the neoplasm completely because a patient who has received a full course of radiation therapy to a tumor without complete resolution presents a therapeutic challenge. Such patients usually are seen with an open, infected ulcer that has tumor at its base. Resection and reconstruction of such a lesion is difficult and dangerous because infection and complications are much more common.

The experience of Dr. Martini and his colleagues with reconstruction of the chest wall after resection is commendable. They have clearly demonstrated that stabilization of the chest wall obviates the need for long-term ventilation in virtually all cases. Morbidity and mortality rates associated with major chest wall resection and reconstruction are low, as they have documented. If a prosthesis becomes infected, either in the immediate or late postoperative period, removal of the prosthetic material associated with proper drainage of the remaining pouch yields excellent resolution of the problem. The fibrous tissues that have been deposited in reaction to the prosthesis and the infection usually yield sufficient stability to the chest wall so that respiratory dynamics are not compromised significantly.

I have three questions for Dr. Martini. First, would he please document the Memorial Sloan-Kettering experience with benign neoplasms of the sternum and tell us the most common type of benign neoplasm they have encountered? Second, what is his experience and that of his colleagues with sternal metastases? Third, what is his

opinion of the malignant behavior of radiation-induced malignancies, and particularly of sarcomas, of the chest wall?

Dr. Martini. In answer to the first question, the benign primary tumors of the sternum are even rarer than the malignant tumors. In a report by us more than 20 years ago we had identified only four benign tumors of the sternum, three of which were chondromas and one was a giant cell tumor. Since then, we have added perhaps two more. They are very rare. On the other hand, because these tumors are mostly chondromas, tissue diagnosis between chondromas and chondrosarcomas may be difficult and a wide resection may be necessary for definitive diagnosis. Of greater concern is that chondromas are reportedly a group of tumors that can undergo malignant degeneration.

To answer the second question, the focus of our paper was on primary tumors of the sternum. Metastases to the sternum do occur also, but just as uncommonly. The most frequent ones we see are metastases as a result of recurrence of breast cancer into the chest wall with invasion of the sternum and, rarely, solitary metastases from kidney or thyroid. The numbers of the latter are very small.

The last question concerned radiation-induced sarcomas. Our experience has been only with osteosarcomas, and, as you well know, osteosarcomas result in poor outcomes at any site in the chest wall, be it scapula, rib, or sternum, regardless of complete resection, and this is where combined-modality therapy has a role.

Dr. Peter C. Pairolero (Rochester, Minn.). Dr. Martini and associates have a large experience with an uncommon problem. Because two thirds of all sternal tumors are metastatic, the remaining primary tumors are then exceedingly rare, and almost all of these are bone tumors. The rarity is again emphasized when one recognizes that bone tumors virtually never involve the manubrium or sternum. From 1905 to 1993, 11,087 primary bone tumors were seen at the Mayo Clinic; however, only 70, or 0.6%, were sternal tumors, which is essentially the same prevalence that Dr. Martini has just reported. Of these 70 tumors, 67 were malignant, and, as with Memorial's experience, chondrosarcoma was the most common tumor.

As we have heard, chondrosarcomas can be cured by aggressive operation. Wide radical excision, which does not necessarily have to involve the entire bone involved but must have a wide margin, preferably 4 cm, is the procedure of choice. Osteosarcoma, however, is much more aggressive, with virtually no 5-year survival, as evidenced by only a 14% survival here in the current

study. This poor overall survival for osteosarcoma raises the question of neoadjuvant therapy, especially preoperative radiation, and in our experience, survival appears to be greater with this modality. I would like to know whether the authors, too, believe that these patients are better served with preoperative radiation therapy, and, for the same reason, should patients with osteogenic sarcoma receive postoperative therapy?

Aggressive wide radical resection must be balanced against durable reconstruction, and this can be achieved by a number of methods. In the authors' experience, 95% of the patients had skeletal reconstruction. We, too, favor this approach, but not for physiologic reasons, inasmuch as large portions of the anterior chest wall can be repaired with only soft tissue reconstruction and without any compromise of pulmonary function. Instead, we favor a skeletal reconstruction for protective and cosmetic reason.

My last question concerns postoperative management and follow-up. What are the authors' recommendations? For example, how frequently should a CT scan of the chest be obtained?

Dr. Martini. In osteosarcomas, our experience has been with neoadjuvant chemotherapy rather than radiation, and in all instances the patients also received adjuvant chemotherapy. In this handful of patients who had osteosarcoma, this combination therapy did not seem to translate into long-term survival as you noted. Whether the radiation therapy appended in the neoadjuvant fashion would result in better survival, I do not know.

As regards reconstruction, I think with the advent of synthetic prostheses, be they polytetrafluoroethylene or Marlex mesh, it has become so easy to place the material for reconstruction that perhaps we have extended our indications even for smaller skeletal defects. In this review we have some patients who had only 6 by 6 cm skeletal defects who underwent repair with Marlex mesh. It is true that in the smaller-sized defects cosmetics is probably the main reason for use of these prostheses, but in the larger defects it is more than cosmetic, it is reconciling and avoiding a flail chest.

In the postoperative follow-up of these patients we do not have any specific recommendations. As with all soft-tissue sarcomas and bone sarcomas, our main concern is local recurrence and pulmonary metastases, and follow-up with CT scanning to identify pulmonary metastases is advisable. The frequency of this is individualized. Local recurrences are normally noted on routine visits of the patient to us. Ordinarily we see these patients every 3 months for the first year or two and every 6 months thereafter.