

Protocol for the Examination of Specimens From Pediatric Patients With Rhabdomyosarcoma*

Version: Rhabdomyosarcoma 3.2.0.2

Protocol Posting Date: August 2016

Includes the Intergroup Rhabdomyosarcoma Study Postsurgical Clinical Grouping System

This protocol is NOT required for accreditation purposes

*This protocol applies to all rhabdomyosarcoma variants and ectomesenchymoma

The following should NOT be reported using this protocol:

Tumor Type
Adult Rhabdomyosarcoma [#] (consider using soft tissue protocol)

[#]Rhabdomyosarcoma in adults may be treated differently than pediatric rhabdomyosarcoma, and use of the AJCC TNM staging system remains appropriate for these patients.

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With guidance from the CAP Cancer and CAP Pathology Electronic Reporting Committees.

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Accreditation Requirements

The use of this protocol is recommended for clinical care purposes, but is not required for accreditation purposes.

CAP Laboratory Accreditation Program Protocol Required Use Date: Not applicable

Important Note

First priority should always be given to formalin-fixed tissue for morphologic evaluation. Optimally, at least 100 mg of viable snap-frozen tissue is preferred as the second priority for workup (Note A).

For more information, contact: The Children's Oncology Group Biopathology Center;
Phone: (614) 722-2890 or (800) 347-2486.

Summary of Changes

v3.2.0.2 - Regional lymph node order modified to report number involved before number examined

Surgical Pathology Cancer Case Summary

Protocol posting date: August 2016

RHABDOMYOSARCOMA AND RELATED NEOPLASMS: Biopsy, Resection

Note: This case summary is recommended for reporting Rhabdomyosarcoma, but is not required for accreditation purposes.

Select a single response unless otherwise indicated.

Procedure (Note B)

Biopsy

- ☐ Core needle
- ☐ Incisional
- ☐ Excisional

Resection

- ☐ Marginal resection
- ☐ Wide local resection
- ☐ Radical resection
- ☐ Amputation (specify type): _____
- ☐ Other (specify): _____)
- ☐ Not specified

+ Preoperative Treatment

- + ☐ No known preoperative therapy
- + ☐ Chemotherapy given
- + ☐ Radiation therapy given
- + ☐ Preoperative therapy given, type not specified
- + ☐ Not specified

Tumor Site

- ☐ Bile duct
- ☐ Bladder/prostate
- ☐ Cranial parameningeal
- ☐ Extremity
- ☐ Genitourinary (not bladder/prostate)
- ☐ Head and neck (excluding parameningeal)
- ☐ Orbit
- ☐ Other(s) (includes trunk, retroperitoneum, etc) (specify): _____
- ☐ Not specified

Tumor Size

- Greatest dimension: ____ cm
- + Additional dimensions: ____ x ____ cm
- ☐ Cannot be determined (explain): _____

Histologic Type (Note C)

- ☐ Embryonal
- ☐ Alveolar
- ☐ Spindle cell and sclerosing
- ☐ Ectomesenchymoma

___ Other (specify): _____
 ___ Rhabdomyosarcoma, not otherwise specified (NOS)

Anaplasia (Note D)

___ Not identified
 ___ Focal (single or few scattered anaplastic cells)
 ___ Diffuse (clusters or sheets of anaplastic cells)
 ___ Cannot be determined

Fusion Status (required only if applicable) (Note E)

___ Not performed
 ___ No FOXO1 rearrangement
 ___ FOXO1 rearrangement present (select all that apply)
 + ___ Amplification status (ie, fluorescence in situ hybridization [FISH]) (specify): _____
 + ___ PAX3
 + ___ PAX7
 ___ Other (eg, PAX3-NCOA1 or other variant translocation) (specify): _____

+ Method

+ ___ Karyotype
 + ___ FISH
 + ___ Reverse transcriptase polymerase chain reaction (RT-PCR)
 + ___ Other (specify): _____

Margins (required only for resection specimens) (Note F)

___ Cannot be assessed
 ___ Uninvolved by tumor
 Distance of tumor from closest margin: ___ cm
 Specify margin: _____
 ___ Involved by tumor
 Specify margin(s): _____

Regional Lymph Nodes

___ No nodes submitted or found

Lymph Node Examination (required only if lymph nodes are present in the specimen)

Number of Lymph Nodes Involved

Specify: ___
 ___ Number cannot be determined (explain): _____

Number of Lymph Nodes Examined

Specify: ___
 ___ Number cannot be determined (explain): _____

Distant Metastasis (required only if confirmed pathologically in this case)

___ Present
 Specify site(s), if known: _____

+ Treatment Effect (Note G)

+ ___ No known preoperative therapy (not applicable)
 + ___ Not identified
 + ___ Present
 + Percent tumor necrosis: ___ %
 + Percent therapy-induced cytodifferentiation: ___ %

+ ___ Cannot be determined

+ The Intergroup Rhabdomyosarcoma Study Postsurgical Clinical Grouping System (Note H)

Note: Grouping is based on pretreatment tumor characteristics. Clinical information required to definitively assign stage group (eg, gross residual disease or distant metastatic disease) may not be available to the pathologist. Alternatively, this protocol may not be applicable to some situations (eg, group IIIA). If applicable, the appropriate stage group may be assigned by the pathologist.

+ ___ Not applicable

+ ___ Cannot be assessed (explain): _____

+ Group I

+ ___ A Localized tumor, confined to site of origin, completely resected

+ ___ B Localized tumor, infiltrating beyond site of origin, completely resected

+ Group II

+ ___ A Localized tumor, gross total resection, but with microscopic residual disease

+ ___ B Locally extensive tumor (spread to regional lymph nodes), completely resected

+ ___ C Locally extensive tumor (spread to regional lymph nodes), gross total resection, but microscopic residual disease

+ Group III

+ ___ A Localized or locally extensive tumor, gross residual disease after biopsy only

+ ___ B Localized or locally extensive tumor, gross residual disease after major resection (greater than 50% debulking)

+ Group IV

+ ___ Any size primary tumor, with or without regional lymph node involvement, with distant metastases, without respect to surgical approach to primary tumor

+ Modified Site, Size, Metastasis Staging for Rhabdomyosarcoma (for relevant stage) (select all that apply) (Note H)

Note: Staging is based on pretreatment tumor characteristics. Clinical information required to definitively assign stage (eg, nodal status or distant metastatic disease) may not be available to the pathologist.

+ ___ Not applicable

+ ___ Cannot be assessed (explain): _____

+ ___ Stage I

Note: Stage I requires all of the following to be true:

- Tumor involves favorable site (ie, bile ducts, orbit, head and neck or genitourinary site [excluding bladder, prostate, and cranial paraneural]).
- Tumor metastatic to distant site not identified.

+ ___ Stage II

Note: Stage II requires all of the following to be true:

- Tumor involves unfavorable site (ie, bladder/prostate, extremity, paraneural or other site not mentioned in stage I).
- Tumor size ≤ 5 cm.
- Tumor involvement of lymph nodes not identified.
- Tumor metastatic to distant site not identified.

+ ___ Stage III

Note: Stage III requires that one of the following be true:

- Tumor involves unfavorable site, is ≤ 5 cm, and involves regional lymph nodes, but distant metastases are not identified.
- Tumor involves unfavorable site and is >5 cm, with or without regional lymph node involvement, but distant metastases are not identified.

+ ___ Stage IV

Note: Stage IV requires that distant metastases be present.

+ Additional Pathologic Findings (Note I)

+ Specify: _____

+ Comment(s)

Explanatory Notes

A. Submission of Tissue

A minimum of 100 mg of viable tumor should be snap-frozen for potential molecular studies.¹ If tissue is limited, the pathologist can keep the frozen tissue aliquot used for frozen section (usually done to determine sample adequacy and viability) in a frozen state (-80°C or lower), with the proviso that routine examination of this tissue may be required if the tissue is otherwise inadequate. Molecular studies to evaluate fusion status, FISH or RT-PCR, may be performed on paraffin sections or frozen tissue. When material is scant, FISH can also be performed on touch preparations made from fresh material obtained at the time of biopsy.

B. Procedures

Core needle biopsies can obtain sufficient material for special studies and morphologic diagnosis, but sampling problems may limit tumor subtyping. Inadequate sampling with needle biopsies may be related to specimen size, necrosis, hemorrhage, crush artifact, and specimen adequacy.² Open incisional biopsy consistently provides a larger sample of tissue and maximizes the opportunity for a specific pathologic diagnosis.³ Excisional biopsy may not include an adequate margin of normal tissue, even with an operative impression of total gross removal.³

Resection specimens may be intralesional, marginal, wide, or radical in extent. Intralesional resections extend through tumor planes, with gross or microscopic residual tumor identifiable at surgical margins. A marginal resection involves a margin formed by inflammatory tissue surrounding the tumor. A wide, radical resection has surgical margins that extend through normal tissue, usually external to the anatomic compartment containing the tumor. For all types of resections, marking (tattoo with ink followed by use of a mordant) and orientation of the specimen (*prior to cutting*) are mandatory for accurate pathologic evaluation.³

C. Histologic Type

The International Classification of Rhabdomyosarcoma classified childhood rhabdomyosarcoma (RMS) into prognostically useful histologic categories.⁴ However, recent studies showed that fusion status drives unfavorable outcome for children with rhabdomyosarcoma, and histologic classification is no longer the primary tool for determining prognosis and risk stratification.^{5,6} The 4th edition of *WHO Classification of Tumours of Soft Tissue and Bone* limits the histologic classification of rhabdomyosarcoma to 4 categories: embryonal (including botryoid), alveolar, spindle cell/sclerosing, and pleomorphic subtypes.⁷ Pleomorphic RMS is exceedingly rare and not well characterized in the pediatric population; many of these cases can be considered RMS with diffuse anaplasia. In addition to these subtypes, recent studies have characterized an epithelioid/rhabdoid pattern of RMS. This pattern as well as ectomesenchymoma (RMS with ganglion cell or neuroblastic differentiation) and other histologic patterns are discussed in more detail below. Finally, RMS, not otherwise specified (NOS), is reserved for cases where there is insufficient material for histologic classification.

Embryonal Rhabdomyosarcoma

Embryonal RMS includes the typical (or not otherwise specified), dense and botryoid patterns of RMS. These patterns account for over one-half of all RMS. Embryonal RMS is composed of mesenchymal cells that show variable degrees of cytoplasmic skeletal muscle differentiation. They are moderately cellular, but in the typical pattern often contain both hypo- and hypercellular areas with a loose, myxoid stroma. Either of these components may predominate, particularly in limited biopsies. Sampling of uniformly hypercellular regions produces a dense pattern of embryonal RMS that may resemble solid alveolar RMS; its myogenin immunostaining pattern (focal, not diffuse) and testing for PAX-FOXO1 translocations may assist in making this distinction.⁸ Perivascular condensations of tumor cells in the less cellular regions are common.

In embryonal RMS, tumor cells may be rounded, stellate, or spindle-shaped. Nuclei are generally small with a light chromatin pattern and inconspicuous nucleoli, although occasionally large central nucleoli may be seen. They typically have more irregular or spindled outlines than those of alveolar RMS. Many tumor cells contain generous amounts of eosinophilic cytoplasm, a feature of rhabdomyoblastic differentiation. Cells with elongated tails of cytoplasm (“tadpole cells”) and cells with cytoplasm in the shape of a ribbon or “strap” are helpful in the light-microscopic diagnosis. Cross-striations can be seen in less than one-half of the cases and are not a prerequisite for diagnosis. The dense pattern of embryonal RMS shows similar cytologic features, although rhabdomyoblastic differentiation is minimal. Adjacent to an epithelial surface, embryonal RMS shows a botryoid

pattern, particularly in the bladder, vagina, nasal cavity and sinuses, and biliary tract. These botryoid variants demonstrate a cambium layer (condensed layer of rhabdomyoblasts) underlying an intact epithelium.

Epithelioid (or rhabdoid-like) RMS is a rare type of RMS that shows abundant cells with large amounts of eosinophilic cytoplasm and intermediate-filament globular inclusions similar to those seen in malignant rhabdoid tumors (MRTs).⁹⁻¹¹ Tumors differ from MRT in their nuclear cytologic features; in rhabdoid RMS, the nuclear chromatin tended to be coarse instead of vesicular. Immunohistochemically, the inclusions were positive for vimentin and desmin, and the cytoplasm adjacent to the inclusion was positive for muscle specific actin and desmin. The outcome in this group seems similar to other non-alveolar subtypes of RMS.¹¹ Pure epithelioid RMS may resemble poorly differentiated squamous carcinoma or epithelioid sarcoma. Myogenin and INI-1 staining may be helpful in making the distinction between this neoplasm and true rhabdoid tumor or epithelioid sarcoma. Epithelioid RMS will show nuclear myogenin expression (negative in MRT) and retained expression of INI-1 (lost in MRT).

The differential diagnosis of embryonal RMS includes the sclerosing and spindle cell variants of RMS, as well as the solid pattern of alveolar RMS. Embryonal RMS is often quite heterogeneous, and small foci of a spindled or sclerosing pattern are commonly seen, particularly in primary resections of large paratesticular or retroperitoneal masses. A dominant (at least 80%) spindled or sclerosing pattern is required for diagnosis of this RMS subtype, however. Ectomesenchymoma (discussed below) typically has embryonal RMS along with a neuroblastic/ganglion cell component. Undifferentiated embryonal sarcoma of the liver has some morphologic and phenotypic overlap, but it generally does not express MyoD1 or myogenin by immunohistochemistry and contains characteristic cytoplasmic hyaline globules. Embryonal RMS-like differentiation is a common component of the multipatterned pediatric lung tumor pleuropulmonary blastoma. Occasional Wilms tumors show marked skeletal muscle differentiation and may even have a cambium layer in tumors abutting the renal pelvis. Well-differentiated embryonal RMS can also have some morphologic overlap with fetal rhabdomyoma. The finding of increased mitoses (>15 per 50 high-power fields), marked hypercellularity, a “cambium layer,” and atypical nuclear features are more characteristic of RMS. Giant cell tumors of tendon sheath may lack giant cells, contain cells with eosinophilic cytoplasm, and show desmin positivity; however, they are strongly CD68 positive and myogenin negative. Pseudosarcomatous fibroepithelial polyps of the lower female genital tract are particularly treacherous and should be considered in botryoid lesions occurring in adolescents and adults, particularly during pregnancy. These hypercellular lesions contain pleomorphic cells with a variable mitotic rate and frequently express desmin; however, they lack a cambium layer or striated cells and do not express myogenin.

Alveolar Rhabdomyosarcoma

Alveolar RMS is histologic pattern composed of malignant small rounded cells that are typically discohesive with a tendency to attach to and line up along thin fibrous septa. The tumor cells have some variation in size. Large, multinucleate cells can be found occasionally. Tumor cell nuclei are round and lymphocyte-like with coarse chromatin and one or more indistinct nucleoli. Tumor cells may show a thin rim of eosinophilic cytoplasm. Morphologic evidence of rhabdomyoblastic differentiation including strap cells or cells with cross-striations is often lacking, although multinucleate myoblasts may be seen. It is important to recognize the “solid variant,” in which the tumor cells grow in solid masses of closely aggregated cells. Of note, many if not most “solid variant” alveolar RMS lack evidence of a PAX fusion and are biologically more akin to embryonal RMS. With wide sampling, areas showing cleft-like spaces or a more classically alveolar pattern can usually be found, facilitating recognition of these tumors as alveolar RMS.

The differential diagnosis of alveolar RMS includes the panoply of malignant small round cell neoplasms, particularly Ewing sarcoma/primitive neuroectodermal tumor, poorly differentiated or undifferentiated neuroblastoma, desmoplastic small round cell tumor, poorly differentiated monophasic synovial sarcoma, and lymphoma. A panel of immunohistochemical stains including myogenin, desmin, Myo-D1, cytokeratin, CD99, WT1, synaptophysin, chromogranin, and leukocyte common antigen will distinguish alveolar RMS from these other entities, but unexpected staining with antigens such as cytokeratin may occur. Alveolar RMS shows diffuse and strong nuclear staining for myogenin. Molecular studies show PAX3- and PAX7-FOXO1 fusion gene products occur in approximately 85% of alveolar RMS cases. Molecular testing is required for risk stratification in all alveolar RMS cases.

Spindle Cell and Sclerosing Rhabdomyosarcoma

In the 4th edition of *WHO Classification of Tumours of Soft Tissue and Bone*, spindle cell and sclerosing RMS are considered in the same diagnostic category based on their predilection for the head and neck/extremities and similar clinical behavior.⁷ Both spindle cell and sclerosing RMS are uncommon, together accounting for 5% to 10% of all cases of RMS. In adults spindle cell/sclerosing RMS has a recurrence and metastasis rate of 40% to 50%, although the behavior of sclerosing RMS in the pediatric population is currently unknown.¹² In children, almost one-third of spindle cell RMS are located in the paratesticular region, where they account for 26.7% of RMS in this site, the remainder mostly being typical embryonal RMS.^{13,14} The 5-year survival for patients with spindle cell RMS in the paratesticular location is excellent, at 88%. However, the favorable prognosis of spindle cell RMS does not apply to lesions outside the paratesticular region, as tumors in these other locations have a prognosis similar to typical embryonal RMS in children. Sclerosing RMS is most common in the extremities, where differentiation from alveolar RMS is important.

Spindle cell RMS is composed almost exclusively (minimum 80% of tumor) of elongated spindle cells in 1 of 2 recognizable patterns. The collagen-poor pattern has a whorled, fascicular growth of spindle cells without significant collagen and resembles a smooth muscle tumor both grossly and microscopically. The collagen-rich form shows spindle cells with variable myogenic differentiation in a dense collagenous stroma. The spindle cells have eosinophilic, fibrillar cytoplasm with distinct borders. Cells with cross-striations are easily found. A small component (<20%) of typical embryonal RMS may be seen in some cases, usually at the tumor periphery. Anaplasia is uncommon.

The primary differential diagnosis of spindle cell RMS includes embryonal RMS NOS, leiomyosarcoma, fibrosarcoma, malignant fibrous histiocytoma (MFH), and the more bland entities, rhabdomyoma, leiomyoma, and nodular fasciitis. In general, smooth muscle neoplasms are uncommon in childhood and adolescence. The presence of specific skeletal muscle antigens (eg, myoglobin, MyoD1, myogenin) and the ultrastructural presence of skeletal myofilaments help in distinguishing spindle cell RMS from leiomyosarcoma, fibrosarcoma, and MFH.

Sclerosing RMS is characterized by a dense hyalinizing collagenous matrix with rounded or spindle-shaped tumor cells arranged in small nests, single-file rows, and pseudovascular, microalveolar profiles.¹⁵⁻¹⁷ As with spindle cell RMS, this should be the predominant pattern, present in at least 80% of the tumor. Sclerosing RMS may have only focal positivity for desmin and myogenin (myf4) but typically strongly expresses MyoD1 (myf3). This pattern has morphologic overlap with sclerosing epithelioid fibrosarcoma, infiltrating carcinoma, osteosarcoma, and angiosarcoma. Spindle cell/sclerosing RMS should be PAX-fusion negative and has constituted some “fusion-negative alveolar RMS” in previous studies.⁸ Cytogenetic studies have described aneuploidy and nonrecurrent structural changes. Recent studies have demonstrated recurrent MyoD1 mutations in spindle cell RMS.

Ectomesenchymoma

Ectomesenchymoma is a rare malignant tumor that generally consists of an RMS component (embryonal greater than alveolar) and a ganglionic and/or neuroblastic component. The name originates from the belief that these tumors arise from pluripotent migrating neural crest cells or “ectomesenchyme.” They have a similar age, sex, and site distribution and outcome to embryonal RMS and are treated with RMS-based therapy. Ectomesenchymomas may be further subclassified based on the subtype of RMS seen.

Other

In very rare occasions, an alveolar RMS pattern can be seen in a tumor that would otherwise be classified as embryonal RMS. These mixed alveolar and embryonal tumors resemble “collision” tumors, with differential myogenin expression between alveolar and embryonal components.⁸ These tumors may be fusion positive or fusion negative, although when tested separately each component shows the same genetic profile.

Posttreatment RMS may show extensive cytodifferentiation mimicking epithelioid/rhabdoid RMS or a highly differentiated embryonal RMS (see Note G).

RMS, Not Otherwise Specified

RMS, NOS, is reserved for cases in which a diagnosis of RMS can be made based on immunohistochemistry, but the case cannot be further classified due to extensive necrosis, crush, or other artifact.

Immunohistochemistry

In cases where histological diagnosis of rhabdomyosarcoma is difficult, immunostaining with monoclonal antibodies against the intranuclear myogenic transcription factors MyoD1, myogenin, and desmin is suggested. Nearly all RMS tumors are positive for desmin, myogenin, and MyoD1.^{18,19} On occasion, anti-myogenin reacts with other spindle cell neoplasms,²⁰ and rare RMS cases may be myogenin negative and desmin positive.²¹ Of note, desmin expression is frequent in certain round cell tumors, such as blastemal Wilms tumor, tenosynovial giant cell tumor, and desmoplastic small round cell tumor, and it occurs infrequently in primitive neuroectodermal tumor. Myogenin is more specific but may occur in rare lesions such as melanotic neuroectodermal tumor of infancy, as well as any lesion capable of skeletal myogenesis such as nephroblastoma (Wilms tumor), teratoma, pleuropulmonary blastoma, or malignant Triton tumor (malignant peripheral nerve sheath tumor with rhabdomyoblastic differentiation).

Immunohistochemistry may be useful as a surrogate marker for fusion status in rhabdomyosarcoma and aids in the diagnosis of alveolar RMS. Several studies show that AP2beta is highly sensitive and specific for the detection of fusion-positive RMS.²¹⁻²³ Immunohistochemistry for other antibodies (NOS-1 and HMGA2) in addition to AP2beta may improve the sensitivity for detection of fusion-positive RMS and may aid in the detection of tumors with rare fusion variant translocations (discussed below).²⁴

D. Anaplasia

Anaplasia is found in up to 13% of RMS and may be found in any histologic subtype.^{25,26} Anaplastic tumors are defined using the Wilms tumor definition of large, lobate, hyperchromatic nuclei (at least 3 times the size of neighboring nuclei) and atypical (obvious, multipolar) mitotic figures.

Anaplasia is further defined as to the distribution of the cells: focal (group I) anaplasia, which consists of a single or a few cells, scattered amongst nonanaplastic cells; or diffuse (group II), in which clusters or sheets of anaplastic cells are evident. These features should be visible at low power (10X objective) to avoid confusing it with “nuclear unrest,” characterized by mild degrees of hyperchromatism and nuclear atypia that do not qualify as 3X enlargement, do not contain bizarre mitoses, and do not affect outcome to the same degree.²⁷ Care must also be taken to distinguish anaplasia from the changes of myogenic differentiation, ie, multinucleation, overlapping nuclei, and nuclear atypia. However, this can be avoided by identifying atypical, multipolar mitoses and using caution in cells with abundant cytoplasm.²⁸ Anaplasia is more common in patients with tumors in favorable sites and less commonly observed in younger patients and in those with stage II, III, or clinical group III disease.²⁶ Regardless of focal or diffuse distribution, the presence of anaplasia negatively influences the failure-free survival rate (63% versus 77% at 5 years) and overall survival (68% versus 82% at 5 years) rates in patients with embryonal rhabdomyosarcoma.²¹ This effect is most pronounced in children with intermediate-risk tumors but does not affect outcome in patients with alveolar tumors. Although it has predictive value for clinical outcome, current treatment protocols do not account for anaplasia in stratification of patients, as it has limited value as an independent survival marker when all other prognostic factors are considered. Because of the correlation between anaplastic embryonal RMS and Li-Fraumeni syndrome, screening for germline *TP53* mutations may be indicated in these patients.²⁹

E. Fusion Status

The presence of a t(1;13) (resulting in a PAX7-FOXO1 gene fusion) or a t(2;13) (PAX3-FOXO1 gene fusion) is strongly correlated with the alveolar subtype of rhabdomyosarcoma. These translocations may be found in as many as 85% of alveolar RMS cases, while embryonal RMS cases lack evidence of these gene fusions (with rare exceptions).³ Some tumors with alveolar histology lack a demonstrable PAX fusion. By gene array testing, they do not cluster with PAX fusion-positive tumors and have a genetic signature that more closely resembles embryonal RMS.^{30,31} Recent studies confirmed that presence of a PAX-FOXO1 fusion transcript drives outcome in children with rhabdomyosarcoma.^{5,6} Accordingly, future cooperative group studies conducted by both the Children’s Oncology Group and European Pediatric Soft Tissue Sarcoma Group will use fusion status rather than alveolar histology to assign risk stratification and treatment for patients with RMS. Fusion status is therefore a required element for all patients with alveolar rhabdomyosarcoma. In contrast, embryonal and non-alveolar patterns of rhabdomyosarcoma are nearly always fusion negative and testing is not required. However, fusion studies can be extremely useful in cases with limited or questionable material, those in which histologic classification is difficult or those with unusual clinical characteristics (eg, embryonal subtype arising in an

extremity).⁸ PAX-FOXO1 gene fusions have also been described in mixed alveolar and embryonal rhabdomyosarcoma and ectomesenchymoma with an alveolar RMS component.

Of fusion-positive RMS cases, approximately 30% are positive for PAX7-FOXO1, and the remaining 70% are positive for PAX3-FOXO1. If RT-PCR using PAX3- or PAX7-specific probes is not used to determine fusion status, amplification of FOXO1 on break-apart FISH studies can act as a surrogate marker of PAX7-FOXO1 fusion status.³² Studies suggest that patients with alveolar RMS expressing the PAX3-FKHR gene product have a lower event-free survival than PAX7-FKHR-positive alveolar RMS,²⁵ but the significance of the translocations must still be elucidated. Some data indicate that when gene fusion status is compared in patients with metastatic disease at diagnosis, a striking difference in outcome is seen between PAX7-FKHR and PAX3-FKHR (estimated 4-year overall survival of 75% for PAX7-FKHR and 8% for PAX3-FKHR; $P=.002$).³³

Although rare, several variant fusion transcripts have been described in alveolar RMS. Most include fusion of PAX3 with an alternate partner, such as NCOA1, NCOA2, or FOXO4. Less often FOXO1 is preserved and fused with another partner, such as FGFR1. Due to the low incidence of these variant fusion transcripts, the prognostic significance is unknown. Some evidence suggests different fusion transcripts may confer different prognostic effects,³⁴ but until more is known these tumors are treated under fusion-positive RMS protocols.

F. Margins

The extent of resection (ie, gross residual disease versus complete resection) has the strongest influence on local control of malignancy.^{35,36} The definition of what constitutes a sufficiently “wide” margin of normal tissue in the management of RMS has evolved over time from resection of the whole muscle to resection with a 2- to 3-cm margin.

G. Treatment Effect

Posttreatment (chemotherapy or radiation), RMS may undergo extensive cytodifferentiation.³⁷ This appears to be more common in embryonal RMS than alveolar RMS. Studies suggest that tumors cells that have undergone maturation have little, if any, malignant potential.

H. Clinical Grouping and Modified “TNM” Staging

The American Joint Committee on Cancer (AJCC) and the International Union Against Cancer (UICC) TNM staging systems currently do not apply to RMS. The Intergroup Rhabdomyosarcoma Study Postsurgical Clinical Grouping System is recommended by this protocol. The Clinical Grouping System is used to plan radiation therapy and relies on pathologic examination.³⁸

Also provided in this protocol is the “TNM” staging system modified for use with rhabdomyosarcoma. This system is based on a surgical, site-based, pretreatment assessment, which is used to plan chemotherapy. This modified staging system is predictive of outcome in rhabdomyosarcoma.^{2,4,38}

Clinical classification usually is carried out by the referring physician before treatment, during initial evaluation of the patient or when pathologic classification is not possible.

I. Relevant History

Relevant historical factors include any previous therapy, family history of malignancy, and the presence of congenital anomalies. If preoperative therapy has been given, assessment may be limited to the estimate of viable and necrotic RMS.² The tumor may also show extreme cytodifferentiation and nuclear pleomorphism. These factors may preclude accurate subtyping of the RMS.

There is a specific concern for increased risk of a familial cancer when the specific diagnosis of embryonal RMS or other soft tissue sarcoma is made within the first 2 years of life, especially in a male child.³⁹ Such syndromes include Li-Fraumeni syndrome, basal cell nevus syndrome, neurofibromatosis, and pleuropulmonary blastoma syndrome (pleuropulmonary blastoma plus associated malignancies).^{2,40} A genetic predisposition to cancer is thought to be present in 7% to 33% of children with soft tissue sarcomas.⁴¹

Rhabdomyosarcoma is specifically associated with a variety of congenital anomalies.⁴² These include congenital anomalies of the central nervous system, genitourinary tract, gastrointestinal tract, and cardiovascular system.

References

1. Qualman SJ, Morotti RA. Risk assignment in pediatric soft-tissue sarcoma: an evolving molecular classification. *Curr Oncol Rep*. 2002;4:123-130.
2. Willman JH, White K, and Coffin CM. Pediatric core needle biopsy: strengths and limitations in evaluation of masses. *Pediatr Dev Pathol*. 2001;4(1):46-52.
3. Coffin CM, Dehner LP. Pathologic evaluation of pediatric soft tissue tumors. *Am J Clin Pathol*. 1998;109(suppl 1):S38-S52.
4. Coffin CM. The new International Rhabdomyosarcoma Classification, its progenitors, and consideration beyond morphology. *Adv Anat Pathol*. 1997;4:1-16.
5. Missiaglia E, Williamson D, Chisholm J, et al. PAX3/FOXO1 fusion gene status is the key prognostic molecular marker in rhabdomyosarcoma and significantly improves risk stratification. *J Clin Oncol*. 2012;30:1670-77.
6. Skapek SX, Anderson JR, Barr FG, et al. PAX/FOXO1 fusion status drives unfavorable outcome for children with rhabdomyosarcoma. *Pediatr Blood Cancer*. 2013;60(9):1411-1417.
7. Fletcher CDM, Bridge JA, Hogendoorn PCW, Mertens F, eds. *WHO Classification of Tumours of Soft Tissue and Bone*. 4th ed. Geneva, Switzerland: WHO Press; 2013.
8. Rudzinski ER, Teot LA, Anderson JR, et al. Dense pattern of embryonal rhabdomyosarcoma, a lesion easily confused with alveolar rhabdomyosarcoma: a report from the Soft Tissue Sarcoma Committee of the Children's Oncology Group. *Am J Clin Pathol*. 2013;140:82-90.
9. Kodet R, Newton WA Jr, Hamoudi AB, Asmar L. Rhabdomyosarcomas with intermediate-filament inclusions and features of rhabdoid tumors. Light microscopic and immunohistochemical study. *Am J Surg Pathol*. 1991;15:257-267.
10. Jo VY, Marino-Enriquez A, Fletcher CD. Epithelioid rhabdomyosarcoma: clinicopathologic analysis of 16 cases of a morphologically distinct variant of rhabdomyosarcoma. *Am J Surg Pathol*. 2011;35:1523-30.
11. Zin A, Bertorelle R, Dall'Igna P, et al. Epithelioid rhabdomyosarcoma: a clinicopathologic and molecular study. *Am J Surg Pathol*. 2014;38:273-278.
12. Rudzinski ER, Anderson JR, Hawkins DS, Skapek SX, Parham DM, Teot LA. The World Health Organization Classification of skeletal muscle tumors in pediatric rhabdomyosarcoma: a report from the Children's Oncology Group. *Arch Pathol Lab Med*. 2015;139(10):1281-1287.
13. Cavazzana AO, Schmidt D, Ninfo V, et al. Spindle cell rhabdomyosarcoma: a prognostically favorable variant of rhabdomyosarcoma. *Am J Surg Pathol*. 1992;16:229-235.
14. Leuschner I, Newton WA Jr, Schmidt D, et al. Spindle cell variants of embryonal rhabdomyosarcoma in the paratesticular region: a report of the Intergroup Rhabdomyosarcoma Study. *Am J Surg Pathol*. 1993;17:221-230.
15. Mentzel T, Katenkamp D. Sclerosing, pseudovascular rhabdomyosarcoma in adults: clinico-pathological and immunohistochemical analysis of three cases. *Virchows Arch*. 2000;436:305-311.
16. Folpe AL, McKenney JK, Bridge JA, Weiss SW. Sclerosing rhabdomyosarcoma in adults: report of four cases of a hyalinizing, matrix-rich variant of rhabdomyosarcoma that may be confused with osteosarcoma, chondrosarcoma, or angiosarcoma. *Am J Surg Pathol*. 2002;26(9):1175-1183.
17. Chiles MC, Parham DM, Qualman SJ, et al. Sclerosing rhabdomyosarcomas in children and adolescents: a clinicopathologic review of 13 cases from the Intergroup Rhabdomyosarcoma Study Group and Children's Oncology Group. *Pediatr Dev Pathol*. 2004;7:583-594.
18. Qualman SJ, Coffin CM, Newton WA, et al. Intergroup Rhabdomyosarcoma Study: update for pathologists. *Pediatr Dev Pathol*. 1998;1:550-561.
19. Parham DM. Pathologic classification of rhabdomyosarcomas and correlations with molecular studies. *Mod Pathol*. 2001;14:506-514.
20. Cessna MH, Zhou H, Perkins SL, et al. Are myogenin and myoD1 expression specific for rhabdomyosarcoma? A study of 150 cases, with emphasis on spindle cell mimics. *Am J Surg Pathol*. 2001;25(9):1150-1157.
21. Morotti RA, Nicol KK, Parham DM, et al. An immunohistochemical algorithm to facilitate diagnosis and subtyping of rhabdomyosarcoma: the Children's Oncology Group experience. *Am J Surg Pathol*. 2006;30(8):962-968.
22. Wachtel M, Runge T, Leuschner I, et al. Subtype and prognostic classification of rhabdomyosarcoma by immunohistochemistry. *J Clin Oncol*. 2006;24:816-822.

23. Grass B, Wachtel M, Behke S, et al. Immunohistochemical detection of EGFR, fibrillin-2, p-cadherin and AP2beta as biomarkers for rhabdomyosarcoma diagnostics. *Histopathology*. 2009;54:873-879.
24. Rudzinski ER, Anderson JR, Lyden ER, et al. Myogenin, AP2beta, NOS1 and HMGA2 are surrogate markers of fusion status in rhabdomyosarcoma: a report from the soft tissue sarcoma committee of the Children's Oncology Group. *Am J Surg Pathol*. 2014;38(5):654-659.
25. Kodet R, Newton WA Jr, Hamoudi A, Asmar L, Jacobs DL, Maurer H. Childhood rhabdomyosarcoma with anaplastic (pleomorphic) features: a report of the Intergroup Rhabdomyosarcoma Study. *Am J Surg Pathol*. 1993;17:443-453.
26. Qualman S, Lynch J, Bridge J, Parham D, Teot L, Meyer W, Pappo A. Prevalence and clinical impact of anaplasia in childhood rhabdomyosarcoma: a report from the Soft Tissue Sarcoma Committee of the Children's Oncology Group. *Cancer*. 2008;113(11):3242-3247.
27. Faria P, Beckwith JB, Mishra K et al. Focal versus diffuse anaplasia in Wilms tumor: A report from the National Wilms Tumor Study Group. *Am J Surg Pathol*. 1996;20:909-920.
28. Zuppan CW, Beckwith JB, Luckey DW. Anaplasia in unilateral Wilms tumor: a report from the National Wilms Tumor Study Pathology Center. *Hum Pathol*. 1998;19(10):1199-1209.
29. Hettmer S, Archer NM, Somers GR et al. Anaplastic rhabdomyosarcoma in TP53 germline mutation carriers. *Cancer*. 2014;120(7):1068-1075.
30. Davicioni E, Anderson MJ, Finckenstein FG, et al. Molecular classification of rhabdomyosarcoma--genotypic and phenotypic determinants of diagnosis: a report from the Children's Oncology Group. *Am J Pathol*. 2009;174(2):550-564.
31. Williamson D, Missiaglia E, de Reynies A, et al. Fusion gene negative alveolar rhabdomyosarcoma is clinically and molecularly indistinguishable from embryonal rhabdomyosarcoma. *J Clin Oncol* 2010;28:2151-2158.
32. Duan F, Smith LM, Gustafson DM, et al. Genomic and clinical analysis of fusion gene amplification in rhabdomyosarcoma: a report from the Children's Oncology Group. *Genes Chromosomes Cancer* 2012;51:662-674.
33. Kelly KM, Womer RB, Sorensen PH, Xiong QB, Barr FG. Common and variant gene fusions predict distinct clinical phenotypes in rhabdomyosarcoma. *J Clin Oncol*. 1997;15(5):1831-1836.
34. Wilson RA, Teng L, Bachmeyer KM, et al. A novel algorithm for simplification of complex gene classifiers in cancer. *Cancer Res*. 2013;73:5625-5632.
35. Marcus KC, Grier HE, Shamberger RC, et al. Childhood soft tissue sarcoma: a 20-year experience. *J Pediatr*. 1997;131:603-607.
36. Fletcher C, Kempson RL, Weiss S. Recommendations for reporting soft tissue sarcomas. *Am J Clin Pathol*. 1999;111:594-598.
37. Smith LM, Anderson JR, Coffin CM. Cytodifferentiation and clinical outcome after chemotherapy and radiation for rhabdomyosarcoma. *Med Pediatr Oncol*. 2002;38:398-404.
38. Raney RB, Anderson JR, Barr FG, et al. Rhabdomyosarcoma and undifferentiated sarcoma in the first two decades of life: a selective review of Intergroup Rhabdomyosarcoma Study Group experience and rationale for Intergroup Rhabdomyosarcoma Study V. *Am J Pediatr Hematol Oncol*. 2001;23(4):215-220.
39. Birch JM, Hartley AL, Blair V, et al. Cancer in the families of children with soft tissue sarcoma. *Cancer*. 1990;66:2239-2248.
40. Dehner LP, Jarzembowski JA, Hill DA. Embryonal rhabdomyosarcoma of the uterine cervix: a report of 14 cases and a discussion of its unusual clinicopathological associations. *Mod Pathol*. 2012;25:602-614.
41. Hartley AL, Birch JM, Blair V, et al. Patterns of cancer in the families of children with soft tissue sarcoma. *Cancer*. 1993;72:923-930.
42. Ruymann FB, Maddux HR, Ragab A, et al. Congenital anomalies associated with rhabdomyosarcoma. *Med Pediatr Oncol*. 1988;16:33-39.