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Pediatric Non-Rhabdomyosarcoma Soft Tissue Sarcomas: Standard of Care and Treatment Recommendations from the European Paediatric Soft Tissue Sarcoma Study Group (EpSSG)

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Abstract: This paper describes the standard of care for patients with non-rhabdomyosarcoma soft tissue sarcomas (NRSTS) and the therapeutic recommendations developed by the European paediatric Soft tissue sarcoma Study Group (EpSSG). NRSTS form a very mixed group of mesenchymal extraskelatal malignancies. Their rarity, heterogeneity, and aggressiveness make the management of children and adolescents with these tumors complex and challenging. The overall cure rate for patients with NRSTS is around 70%, but survival depends on several prognostic variables, such as histotype and tumor grade, extent of disease and stage, tumor size, and tumor site. While surgery remains the mainstay of treatment for most of these tumors, a multimodal therapeutic approach including radiotherapy and chemotherapy is required in many cases. The EpSSG NRSTS 2005 study was the first prospective protocol tailored specifically to NRSTS. Together with the ARST0332 study developed by the North-American Soft Tissue Sarcoma Committee of the Children's Oncology Group (COG), the EpSSG NRSTS 2005 study currently represents the benchmark for these tumors, establishing risk-adapted standards of care. The EpSSG has developed common treatment recommendations for the large group of adult-type NRSTS (including synovial sarcoma), and specific treatment recommendations for other particular adult-type histologies (ie, alveolar soft-part sarcoma, clear cell sarcoma and dermatofibrosarcoma protuberans); other highly malignant tumors with a biology and clinical behavior differing from those of adult-type NRSTS (ie, rhabdoid tumors and desmoplastic small round cell tumor); and soft tissue tumors of intermediate malignancy (ie desmoid-type fibromatosis, inflammatory myofibroblastic tumors, and infantile fibrosarcoma). New effective drugs are needed for patients whose NRSTS carries the worst prognosis, ie, those with unresectable tumors, metastases at diagnosis, or relapsing disease. Progress in this area relies on our ability to develop international integrated prospective collaborations, both within existing pediatric oncology networks and, importantly, between the communities of specialists treating pediatric and adult sarcoma.

Keywords: non-rhabdomyosarcoma soft tissue sarcomas, NRSTS, EpSSG, treatment, recommendations, pediatric

Introduction

Although soft tissue sarcomas are rare (accounting for less than 1% of all malignant tumors), they amount to about 8% of all malignancies in childhood and adolescence. In this age group, soft tissue sarcomas are the fifth most common type of cancer.

About half of the cases are rhabdomyosarcomas, while the remainder are various entities usually grouped by pediatric experts under the label of “non-rhabdomyosarcoma soft tissue sarcomas” (NRSTS).^{1,2}

The term NRSTS describes a very mixed group of mesenchymal extraskeletal malignancies with a clinical behavior varying from relatively benign to highly malignant.^{3,4} The distribution of the different tumor types varies by age: some histotypes typically occur in small children (eg, infantile fibrosarcoma and rhabdoid tumors); others are generally observed in adolescents and young adults (eg, synovial sarcoma); and many are more common in adults, and rare in children (eg, liposarcoma, leiomyosarcoma and undifferentiated pleomorphic sarcoma).¹ Pediatric soft tissue sarcoma experts therefore generally deal with a different pattern of disease from those usually treated by adult sarcoma experts.^{5,6} For many entities, outcomes also vary by age, with a more favorable prognosis for children than for adults.¹

The rarity, heterogeneity, and aggressiveness of NRSTS make the management of children and adolescents with these tumors complex and challenging.⁷ It is strongly recommended that patients be referred to experienced institutions where multidisciplinary teams can plan an appropriate diagnostic and treatment approach, and enroll patients in any available clinical trials.^{8,9} While surgery remains the mainstay of treatment for most NRSTS, a multimodal therapeutic approach – including radiotherapy and chemotherapy – is required in many cases.¹⁰ The overall cure rate for NRSTS patients is around 70%, but survival is known to depend on several prognostic variables, such as histotype and tumor grade, extent and stage of disease, tumor size, and tumor site.^{11–14}

There has historically been a paucity of data on the natural history and treatment of these tumors.^{15–18} In the first decade of the new millennium, pediatric cooperative groups developed multimodal risk-adapted trials tailored specifically to NRSTS. In particular, the European paediatric Soft tissue sarcoma Study Group (EpSSG) designed a comprehensive protocol (the EpSSG NRSTS 2005) consisting of two prospective non-randomized studies for patients <21 years old with localized adult-type NRSTS or localized synovial sarcoma (originally distinguished from other adult-type histologies). The study also included specific clinical recommendations for other NRSTS histotypes found in pediatric patients. It was conducted from 2005 to 2016, and involved 100 academic centers and hospitals in 14 different countries.¹⁹ In terms of rationale, patient stratification and treatment paradigms (based on both pediatric and adult experiences), the EpSSG NRSTS 2005 study was very similar to the ARST0332 study developed by the North-American Soft Tissue Sarcoma Committee of the Children’s Oncology Group (COG), conducted from 2007 to 2012.²⁰

The EpSSG has already reported on its analyses of various specific histological subgroups,^{21–32} and on the results of treatment in the whole series of patients enrolled in the prospective non-randomized part of the protocol.¹⁹ Table 1 shows the main findings they published. These analyses, together with the results of the COG ARST0332 study,²⁰ currently represent the benchmark for NRSTS treatment in pediatric patients, and establish the risk-adapted standard of care.

Standard of Care for NRSTS

The present paper describes the standard of care for NRSTS and the therapeutic recommendations developed by the EpSSG for newly-diagnosed patients. In particular, we focused on the role of systemic treatment. These recommendations were established in parallel with the development of a non-therapeutic biological study, ie, the MYKIDS study (“Molecular Identification and Characterization of non-Rhabdomyosarcoma Soft Tissue Sarcoma in Kids, Adolescents and Young Adults”). The MYKIDS study is described in more detail below.

NRSTS vary considerably, not only in their biology and clinical behavior, but also in their sensitivity to therapy. To give an example, synovial sarcoma is generally more sensitive to standard chemotherapy than tumor types like alveolar soft-part sarcoma or clear cell sarcoma, which are near-resistant.^{21,26,33–35} In the light of this heterogeneity, specific therapeutic recommendations should be adopted for specific histotypes.

Treatment Recommendations Applicable to Adult-Type NRSTS in General

The definition of “adult-type NRSTS” was historically created to identify to identify groups of subtypes which were as homogeneous as possible, ie, “definitely malignant soft tissue sarcomas, typical of adulthood, with morphological features resembling differentiated/mature tissues”.¹³ This historical definition originally included synovial sarcoma, malignant peripheral nerve sheath tumor (MPNST), adult-type fibrosarcoma, epithelioid sarcoma, alveolar soft part sarcoma (ASPS), clear cell sarcoma (CCS), leiomyosarcoma, liposarcoma, malignant fibrous histiocytoma, hemangiopericytoma, angiosarcoma, and

Table 1 Different Published Series and Main Results from the EpSSG NRSTS 2005 Study

Tumor Type and Publication	Main Features
Localized synovial sarcoma Ferrari et al 2015	<ul style="list-style-type: none"> • EpSSG series: 138 patients (2005–2012) • median follow-up 52 months; 3-year EFS 81.9%, 3-year OS 97.2% • Risk groups were the only significant prognostic variable: 3-year EFS was 91.7% for low-risk, 91.2% for intermediate-risk, and 74.4% for high-risk cases • Higher survival rates than previous series • Response to chemotherapy = 55.2%
Infantile fibrosarcoma Orbach et al 2016	<ul style="list-style-type: none"> • EpSSG series: 50 patients, age 0–24 months (2005–2012) • ETV6-NTRK3 transcript: present in 87.2% of the patients investigated • 3-year EFS 84%, 3-year OS 94% • VA chemotherapy was the first-line treatment, with a 70% response rate; alkylating or anthracycline chemotherapy was avoided in 71% of the patients needing chemotherapy; mutilating surgery only in 3 cases
Rhabdoid tumors Brennan et al 2016	<ul style="list-style-type: none"> • EpSSG series: 100 patients (2005–2014), 77 localized, 23 metastatic • 3-year EFS 32.3% and OS 38.4% • Unfavorable prognostic factor: age <1 year, metastatic tumor
Low-risk synovial sarcoma Ferrari et al 2017	<ul style="list-style-type: none"> • Joint EpSSG and COG series: 60 low-risk cases (initial complete resection with histologically free margins, with grade 2 tumors of any size or grade 3 tumors <5 cm), treated with surgery alone • 3-year EFS 90%, 3-year OS 100% • All 8 tumor-related events were local recurrences; all patients with recurrences were effectively salvaged • adjuvant chemotherapy and radiotherapy can be avoided in low-risk synovial sarcoma without jeopardizing outcome
Desmoid-type fibromatosis Orbach et al 2017	<ul style="list-style-type: none"> • EpSSG series: 173 patients (2005–2016) • 35% wait-and-see strategy, 31% immediate surgery, 34% immediate chemotherapy • 5-year PFS 36.5%, with no differences by treatment group • 172/173 alive (one patient died of a secondary tumor) • Response to chemotherapy = 35% complete or partial response (57% to VBL-MTX), 45% stable disease • Prognostic factor: large tumor size (>5 cm)
Alveolar soft part sarcoma Brennan et al 2018	<ul style="list-style-type: none"> • EpSSG series: 22 patients (2005–2015) • 20 patients with localized disease (mostly small and resected), 5-year EFS 94.7%, OS 100% • Response to conventional chemotherapy = 0%
Genomic index in synovial sarcoma Orbach et al 2018	<ul style="list-style-type: none"> • SYNOBIO study - EpSSG series: 61 tumor samples • genomic index 1 (no copy number alterations, flat profile): 55.7% of cases – 5-year EFS 93.8% • genomic index 2 (one or more copy number alterations, rearranged profile): 44.3% of cases – 5-year EFS 64.9% • Genomic index is an independent prognostic factor on multivariate analysis
Epithelioid sarcoma Spunt et al 2019	<ul style="list-style-type: none"> • Joint EpSSG and COG series: 63 cases • 5-year EFS 60.7%, OS 63.6% • Response to chemotherapy = 50% • Prognostic factors: tumor size, histological grade, tumor invasiveness, inadequate tumor resection and metastatic disease
Localized malignant peripheral nerve sheath tumors van Noesel et al 2019	<ul style="list-style-type: none"> • EpSSG series: 51 patients (2005–2016) • 5-year EFS 52.9%, OS 62.1% • Response to chemotherapy = 46% • Unfavorable prognostic factors: neurofibromatosis type 1 (51% of patients)

(Continued)

Table 1 (Continued).

Tumor Type and Publication	Main Features
Inflammatory myofibroblastic tumor Casanova et al 2020	<ul style="list-style-type: none"> • EpSSG series: 60 patients (2005–2016) • 59 had localized disease, 1 had multifocal/metastatic disease • 40 ALK-positive, and 20 ALK-negative • 5-year EFS 82.9% and OS 98.1% • Response to chemotherapy = 55% (80% to VBL-MTX) • Response to ALK-inhibitors = 5/5 • No clinical variables correlated statistically with outcome
Dermatofibrosarcoma protuberans Brennan et al 2020	<ul style="list-style-type: none"> • EpSSG series: 46 patients (2005–2016) • most cases had small (<5 cm) and IRS I tumors; all patients had up-front surgery • 5-EFS 92.6%, OS 100%
Metastatic NRSTS Ferrari et al 2020	<ul style="list-style-type: none"> • Part of the EpSSG BERNIE protocol, ie, open-label, multicenter, randomized phase II study on the role of bevacizumab when added to rhabdomyosarcoma-tailored multi-drug chemotherapy • 49 patients (2008–2013) • 2-year EFS 27.3%, 3-year OS 35.2% • Adding the anti-angiogenic agent did not cause any statistically significant improvement • Patients not receiving any local treatment on primary disease had a worse outcome • Treatment results were better for patients undergoing surgical resection on metastases.
Whole series Ferrari et al 2021	<ul style="list-style-type: none"> • EpSSG NRSTS 2005 series: 569 patients <21 years old with localized synovial sarcoma and adult-type NRSTS* (2005–2016, 100 centers in 14 countries) • 5-year EFS 73.7%, OS 83.8% • 5-year OS was 98.1% in the group treated with surgery alone (n= 250), 88.2% in the adjuvant radiotherapy group (n= 17), 75.8% in the adjuvant chemotherapy group (n= 93), and 70.4% in the neoadjuvant chemotherapy group (n=209) • Excellent outcome for the “surgery-alone” group: adjuvant chemotherapy and radiotherapy can be safely omitted in low-risk NRSTS • Limited sample sizes available to investigate adjuvant chemotherapy. • Better results than in historical series for unresected cases; neoadjuvant ifosfamide–doxorubicin Chemotherapy improved resectability

Notes: *Histotypes included: alveolar soft part, angiosarcoma, clear-cell sarcoma, dermatofibrosarcoma protuberans, epithelioid sarcoma, adult-type fibrosarcoma, leiomyosarcoma, liposarcoma, low-grade fibromyxoid sarcoma, malignant fibrous histiocytoma, malignant peripheral nerve sheath tumor, sarcoma not otherwise specified, synovial sarcoma.

Abbreviations: EpSSG, European paediatric Soft tissue sarcoma Study Group; COG, Children Oncology Group; EFS, event-free survival; PFS, progression-free survival; OS, overall survival; VA, vincristine, actinomycin-D; VBL-MTX, vinblastine–methotrexate; IRS, Intergroup Rhabdomyosarcoma Study.

dermatofibrosarcoma protuberans (DFSP). It excluded other histotypes, such as those characteristically occurring in young patients (ie infantile fibrosarcoma [IFS] or rhabdoid tumor), tumors with a primitive morphology (ie, small round cell sarcomas like extraosseous Ewing sarcoma and desmoplastic small round cell tumor [DSRCT]), and borderline tumors (ie, epithelioid hemangioendothelioma, desmoid-type fibromatosis, and inflammatory myofibroblastic tumors [IMT]).¹³ This original definition of adult-type NRSTS was adopted in the EpSSG NRSTS 2005 protocol.¹⁹

In recent years, the understanding of these tumors has improved, and their classification have been modified accordingly for some tumor entities. To give some examples: undifferentiated high-grade pleomorphic sarcoma is the name currently used for what was previously called malignant fibrous histiocytoma^{3,36}; new entities have been recognized (such as BCOR or CIC-rearranged sarcomas);³⁷ other entities have been recognized as clearly distinct in their clinical behavior, making a combination of ifosfamide–doxorubicin clearly inappropriate as the standard of care (eg, ASPS and CCS).^{26,33–35} In general terms, the definition of adult-type NRSTS may still be of value, however. Although it includes a variety of different tumors (Table 2),³⁸ there is a consensus that most adult-type NRSTS warrant the same treatment approach.

Table 2 A Practical Classification of the Main Pediatric NRSTS Histotypes

- Adult-type NRSTS requiring the same therapeutic approach
 - Synovial sarcoma
 - Malignant peripheral nerve sheath tumor
 - Adult-type fibrosarcoma
 - Epithelioid sarcoma
 - Leiomyosarcoma
 - Liposarcoma
 - Angiosarcoma
 - Undifferentiated high-grade pleomorphic sarcoma
- Adult-type NRSTS requiring a specific therapeutic approach
 - Alveolar soft part sarcoma
 - Clear cell sarcoma
 - Dermatofibrosarcoma protuberans
- Malignant soft tissue tumors requiring a specific therapeutic approach
 - Rhabdoid tumor
 - Desmoplastic small round cell tumor
 - Undifferentiated soft part sarcoma
 - Undifferentiated sarcoma of the liver
 - BCOR family/CIC-rearranged undifferentiated sarcomas
- Soft tissue tumors of intermediate malignancy requiring specific therapeutic approaches
 - Desmoid-type fibromatosis
 - Infantile fibrosarcoma
 - Inflammatory myofibroblastic tumors
 - Epithelioid hemangioendothelioma

Adult-type NRSTS are usually assumed to be relatively insensitive to chemotherapy, with reported tumor response in the range of 40–50%, or even less (and always much lower than is generally seen in rhabdomyosarcoma).³⁹ Surgery remains the unquestionable keystone of treatment. In principle, radiotherapy has a role in local control after incomplete resections and even after wide excisions in the case of large tumors.^{40–43} The indications for radiotherapy are usually more limited in children, however, because of the higher risk of severe late effects. The aggressiveness and intensity of surgery and radiotherapy should be discussed and customized for each patient, based on anatomical site, tumor size, patient's age, and response to initial chemotherapy. The aim is to achieve optimal local control while bearing in mind treatment sequelae, and the preservation of function.

The standard systemic treatment consists of ifosfamide-doxorubicin chemotherapy.^{19,20} Ifosfamide-doxorubicin was historically derived from adult sarcoma experience.^{44–49} Peri-operative chemotherapy is generally given in local/locoregional disease, as front-line treatment in patients with locally advanced disease, and/or when surgeons are not sure they can achieve a complete resection at the first attempt. Chemotherapy is preferably given in the neo-adjuvant setting. Neo-adjuvant chemotherapy may have a role not only in converting such cases into conservative complete resections but also for promptly treating any micrometastases.³⁹

There is much debate on whether adjuvant chemotherapy should be administered for adult-type NRSTS to prevent distant recurrences after initial surgery.^{44–49} Various reports suggest that, after initial tumor resection, a high tumor grade combined with a large tumor size pose a very high risk of metastases, irrespective of the radicality of the initial surgery, so survival might be better in patients given adjuvant chemotherapy.⁵⁰

In the light of the results of the EpSSG NRSTS 2005 study,¹⁹ current EpSSG recommendations divide patients into four treatment groups based on surgical stage according to the Intergroup Rhabdomyosarcoma Study (IRS) classification, tumor size, nodal involvement, and histopathological tumor grade (tumor site is added as a criterion for synovial sarcoma). (Figure 1)

The group recommended for surgery alone includes low-grade adult-type NRSTS treated with an initial R0-R1 resection (IRS group I–II), and high-grade NRSTS smaller than 5 cm treated with an initial R0 resection. The 5-year

Treatment group	Histotypes	Variables	Treatment
SURGERY ALONE group	synovial sarcoma	IRS group I, tumor size ≤5 cm	initial resection only no adjuvant treatment
	"adult-type" NRSTS	IRS group I, ≤5 cm, any tumor grade	
		IRS group I, >5 cm, G1	
		IRS group II, any size, G1	
ADJUVANT RADIOTHERAPY group	"adult-type" NRSTS	IRS group I, >5 cm, G2	radiotherapy 50.4 Gy
		IRS group II, ≤5 cm, G2-G3	radiotherapy 54 Gy
		IRS group II, >5 cm, G2	
ADJUVANT CHEMOTHERAPY group (± radiotherapy)	synovial sarcoma	IRS group I, >5 cm	I-D I-D I-D I-D
		IRS group II, ≤5 cm	I-D I-D I-D radiotherapy 50.4 Gy
		IRS group II, >5 cm	I-D I-D I-D I I I-D radiotherapy 54 Gy
		axial site or resected N1	
	"adult-type" NRSTS	IRS group I-II, >5 cm, G3 or resected N1	
NEOADJUVANT CHEMOTHERAPY group (± radiotherapy)	synovial sarcoma	IRS group III (unresected disease) or unresected N1	I-D I-D I-D surgery ↓ I I radiotherapy 50.4-59.4 Gy I-D ± I-D *
	"adult-type" NRSTS		

Figure 1 EpSSG standard-risk stratification and treatment recommendations for local/locoregional adult-type NRSTS (including synovial sarcoma).
Notes: I-D=ifosfamide (3 g/m² per day intravenously, for 3 days) plus doxorubicin (37.5 mg/m² intravenously per day for 2 days). I=ifosfamide (3 g/m² intravenously per day for 2 days). Ifosfamide should be given with hyperhydration and mesna infusion (3 g/m² per day intravenously). Chemotherapy cycles should be administered every 21 days.
 *Total of 6 courses for synovial sarcoma, 7 courses for the other adult-type NRSTS.
Abbreviations: IRS, Intergroup Rhabdomyosarcoma Study; IRS group I, complete resection at first surgery (initial R0 surgery); IRS group II, microscopic residual disease after initial R1 surgery); IRS group III, biopsy or initial macroscopic residual disease after R2 surgery; IRS group IV, metastatic disease at onset; G, tumor grade (according to the Fédération Nationale des Centres de Lutte Contre le Cancer grading system); N1, nodal involvement.

event-free survival (EFS) and overall survival (OS) recorded for this category in the EpSSG NRSTS 2005 study (ie, 91.4% and 98.1%, respectively) suggest that adjuvant chemotherapy and radiotherapy can be safely omitted for this low-risk population in an effort to contain short- and long-term treatment-related morbidity.¹⁹

Radiotherapy (at a dose of 54.0 Gy) is recommended for high-grade tumors after R1 resections (IRS group II). Based on the NRSTS 2005 study data, the EpSSG also recommends radiotherapy (50.4 Gy) for patients classified as IRS group I, with tumors >5 cm in size, and G2 disease.¹⁹

In the adjuvant chemotherapy group, the recommended number of cycles depends on the variables listed in Figure 1. In the EpSSG NRSTS 2005 study, the 5-year EFS and OS were 65.6% and 75.8%, respectively, suggesting that – despite a generally favorable prognosis for grossly resected NRSTS – patients with high-grade and/or large tumors are at high risk of treatment failure. The study struggled to investigate the role of adjuvant chemotherapy in this patient category, however, due to a relatively limited sample size (93 cases).¹⁹

For the neoadjuvant chemotherapy group (ie, patients with locally advanced and/or unresectable disease), the EpSSG NRSTS 2005 study reported an overall response rate of 54%, and 5-year EFS and OS of 56.4% and 70.4%, respectively.¹⁹ A major open issue remains for this patient category concerning the local treatment to administer after initial chemotherapy, given the diverse clinical situations encountered, relating to patients’ ages, and the tumors’ subtype, size, site, and resectability. The EpSSG recommends planning (and customizing) the “best possible local treatment” with the aim of maximizing the

chances of local control, while minimizing radiation-related sequelae and preserving function. To give an example of the different clinical situations that can occur when delayed resection is feasible, patients might be given radiotherapy (50.4 Gy) before surgery, or surgery without any radiotherapy (before or afterwards), or surgery followed by radiotherapy (50.4 Gy after R0 resections, 54.0 Gy after R1, and 59.4 Gy after R2). Decisions should be based on a multidisciplinary discussion, considering a patient's age (eg, trying to avoid radiotherapy for patients less than 6 years old), or initial tumor size (eg, using radiotherapy for tumors initially over 10 cm in size), or surgical margins at delayed surgery (in principle, postoperative radiotherapy should be recommended after delayed resections other than R0, when re-surgery is not possible or would lead to undesirable anatomic or functional outcomes). Then, there are patients whose tumor cannot be resected: for them, radiotherapy alone is the only local therapy possible, at a recommended dose of 59.4 Gy.

Synovial Sarcoma

Among all adult-type NRSTS, synovial sarcoma is the subtype most often occurring in pediatric age.⁵¹ Its hallmark is a specific t(X;18)(p11.2;q11.2) chromosomal translocation, and the *SYT::SSX* fusion transcript (in its various forms). Many pediatric oncologists had long considered synovial sarcoma separately from the other histotypes, given the relatively high rates of response to chemotherapy reported in historical pediatric synovial sarcoma series (approximately 60%, which is higher than that usually reported for adult soft tissue sarcomas).^{52–57} Up until 2005, most European pediatric oncologists treated synovial sarcoma patients with the protocols designed for rhabdomyosarcoma (which meant, eg, intensive multidrug chemotherapy for at least 6 months, and adjuvant chemotherapy for all patients, even if they had completely excised, small tumors).^{52–57} This changed with the EpSSG NRSTS 2005 study, the “rhabdomyosarcoma-like” strategy was replaced with a treatment approach that also draws on adult experiences with: chemotherapy given according to patients' risk stratification (based on tumor size, site and stage); the ifosfamide-doxorubicin regimen; a shorter duration of chemotherapy, even for higher-risk patients; and the omission of chemotherapy for low-risk cases (completely resected limb tumors under 5 cm in size).^{21,58}

The EpSSG NRSTS 2005 study achieved higher survival rates than those published previously by pediatric groups, with 5-year EFS and OS of 80.7% and 90.7%, respectively, for patients with localized synovial sarcoma.²¹ The study demonstrated the feasibility of a “surgery-alone” strategy for low-risk patients, and this was subsequently confirmed by a joint retrospective EpSSG-COG analysis on 60 cases of small tumors completely resected at diagnosis: there were only 8 local relapses, no metastatic recurrences, and the 3-year EFS and OS were 90% and 100%, respectively.²⁴

Management of Metastatic Disease and Relapsing NRSTS

The EpSSG NRSTS 2005 study did not include patients with adult-type NRSTS who had metastatic disease at diagnosis. Instead, the EpSSG reported on a series of 49 cases of metastatic NRSTS treated between 2008 and 2013 included in the BERNIE protocol. This was an open-label, multicenter, randomized Phase II study assessing the role of bevacizumab in addition to the intensive chemotherapy designed for rhabdomyosarcoma, and including ifosfamide, vincristine, actinomycin-D and doxorubicin (the IVADo regimen), and maintenance therapy with vinorelbine and oral low-dose cyclophosphamide. The 2-year EFS was 27.3% and the 3-year OS was 35.2%. The study showed that adding the anti-angiogenic agent did not prompt any statistically significant improvement in patients' survival.³²

The treatment of metastatic NRSTS remains a big challenge, and a clear standard of care has not yet been defined. Patient management should always be multidisciplinary, taking into account the diverse clinical presentation and histotypes. In principle, patients should be included in specific clinical trials, if available. There is a general agreement to treat metastatic NRSTS patients with systemic therapy and aggressive surgery on the primary tumor and metastatic sites. The ifosfamide-doxorubicin regimen is generally used in children and adolescent with metastatic adult-type NRSTS. In adult experience, there is no formal demonstration that multi-agent chemotherapy is superior to single-agent doxorubicin in terms of OS, though higher response rate and longer progression-free survival were reported.^{59,60}

Similar to patients with metastases at diagnosis, those with relapsing NRSTS also have a very unfavorable prognosis: in a recent study, post-relapse OS was 25.8% at 5 years, with a median survival of 20 months.⁶¹ Poor survival rates are also reported for patients with relapsing synovial sarcoma, despite the better outcomes for patients with primary localized disease compared to other adult-type histologies.⁶²

A detailed discussion of the possible treatment options for patients with relapsing NRSTS goes beyond the scope of this article. As a general recommendation, surgery and radiotherapy should be regarded as a key part of the treatment in cases of local relapse. Aggressive resection may be lifesaving, including extensive procedure that might not have been considered acceptable in primary treatment. Surgery and radiotherapy may have a role in cases of distant relapse as well, especially when the lung is the only site, and when the number of metastases is small.

Effective systemic therapies are limited, and no standardized second-line chemotherapy is available. In patients already treated with the ifosfamide–doxorubicin regimen, possible options might be high-dose ifosfamide^{63–65} (one a particular regimen involves ifosfamide 14 g/m² given in a continuous 14-day infusion via an external pump)⁶⁶; regimens such as gemcitabine–docetaxel, or gemcitabine–vinorelbine^{67,68}; or disease-specific drugs, such as paclitaxel in angiosarcoma, eribulin in liposarcoma, and trabectedin in liposarcoma and DSRCT.^{69–73}

Every effort should be made by the pediatric sarcoma community to develop prospective Phase I–II trials for this patient category.⁷⁴ A stronger cooperation with the adult sarcoma community is also warranted, to enable children and adolescents to benefit from new agents that have already proven effective in adult patients.^{75,76} A good example concerns the T-cell therapies engineered to target MAGE-A4+ in synovial sarcoma. These modified T-cells are only intended for patients positive for HLA-A*02 whose tumors express MAGE-A4 (expected to be 30% of all patients), but this therapy has shown outstanding disease control rates and objective response rates (85% and 35%, respectively) in adults with synovial sarcoma. Importantly, the SPEARHEAD-1 trial is currently open to patients >10 years old at a few selected European pediatric oncology centers. The EpSSG recommends a (remote) prescreening of all patients with relapsing synovial sarcoma at the time of the first relapse, so that suitable patients can be referred to the centers where the trial is running.⁷⁷

Treatment Recommendations Specific to Certain Adult-Type NRSTS

ASPS, CCS, and DFSP necessitate specific treatment recommendations, particularly as concerns medical therapies (Table 3).

Alveolar Soft Part Sarcoma

ASPS is a highly malignant tumor, carrying a high risk of metastatic dissemination, but conventional chemotherapy has proven ineffective.^{26,33,34} In cases of localized ASPS, surgery (possibly combined with radiotherapy) is the treatment of choice, and no adjuvant chemotherapy is recommended. For locally advanced/unresectable or metastatic disease, the clinical approach is more debatable.⁷⁸ Metastatic disease may take an indolent course, and surgery is recommended for its treatment, if feasible. There is a growing body of evidence to indicate that targeted agents like sunitinib, cediranib, pazopanib, tivantinib or bevacizumab may produce a tumor response and prolong survival in cases of ASPS.^{79,80} Promising findings regarding immune checkpoint inhibitors would also suggest a role for immunotherapy (PD1/PDL1 inhibitors) administered within clinical trials (if available) or on compassionate grounds.^{81–84}

Clear Cell Sarcoma

CCS of tendons and aponeuroses is extremely rare in childhood and little information is available on its clinical behaviour in pediatric age.³⁵ It is generally described as a very aggressive tumor with a very limited responsiveness to standard chemotherapy. CCS exhibits an immunohistochemical similarity to melanoma, so the success of immunotherapy with checkpoint inhibitors in cases of melanoma has prompted studies to assess whether the same clinical benefit can be achieved in CCS as well, with promising initial results.⁸⁵

Dermatofibrosarcoma Protuberans

DFSP occurring in children is often reportedly a low-grade, small, superficial tumor, completely resected at diagnosis in most cases.^{31,86} Advanced unresectable or metastatic cases are extremely uncommon in pediatric age, as well as the transformation to high-grade fibrosarcoma. Targeted therapy has proven effective medical treatment in such cases. In most cases, DFSP is caused by a chromosomal translocation resulting in the fusion protein *COL1A1::PDGFB*, which promotes tumor growth through overproduction of platelet-derived growth factor (PDGF). The multi-tyrosine kinase inhibitor imatinib mesylate has been used successfully to obtain a clinical response in adult patients with advanced and

Table 3 Summary of Treatment Recommendations for Specific Histotypes

Histotype	Clinical Features	EpSSG Treatment Recommendations
Adult-type NRSTS requiring a specific therapeutic approach		
Alveolar soft part sarcoma	Highly malignant; conventional chemotherapy is ineffective	Surgery (\pm radiotherapy) for localized resectable tumors (no adjuvant chemotherapy). Targeted agents in case of unresectable/metastatic disease. Promising data on immune checkpoint inhibitors
Clear cell sarcoma	Highly malignant, no response to chemotherapy	Local therapy (surgery \pm radiotherapy). Promising results with immunotherapy
Dermatofibrosarcoma protuberans	Generally low-grade, small, superficial	Wide surgery is the mainstay. Imatinib mesylate in unresectable or metastatic cases (very rare in pediatric age)
Malignant soft tissue tumors requiring a specific therapeutic approach		
Undifferentiated soft part sarcoma	Debated if it is really a clinical entity	Treatment according to strategy for rhabdomyosarcoma (9 courses of IVA), or ifosfamide-doxorubicin as for high-risk adult-type NRSTS
Undifferentiated (embryonal) sarcoma of the liver	Generally good response to conventional chemotherapy	Complete surgery is the mainstay. Patients with initial resection: 4–6 courses of IVA \pm doxorubicin. Patients with unresectable tumor: 9 courses of IVA \pm doxorubicin to shrink the tumor and enable resection
Extra-cranial malignant rhabdoid tumors	Highly aggressive tumors of young children	Dose-intensive multi-drug chemotherapy every 2 weeks (eg VDCy-IE). Local therapy as soon as possible (taking the patient's age into account)
Desmoplastic small round cell tumors	Abdominal mass widely disseminated at diagnosis; poor prognosis	Intensive chemotherapy (eg VDCy-IE, or IVADo or IrIVA), surgery, whole abdominal radiotherapy, maintenance therapy
Soft tissue tumors of intermediate malignancy requiring specific therapeutic recommendations		
Desmoid-type fibromatosis	Intermediate malignancy, local aggressiveness	Wait-and-see for non-evolving disease; low-dose methotrexate plus vinblastine in cases with tumor progression
Inflammatory myofibroblastic tumor	Intermediate malignancy	Surgery remains the mainstay of treatment In cases of advanced disease: vinblastine-methotrexate or targeted therapy (eg ALK inhibitors)
Infantile fibrosarcoma	Low malignant potential; initial rapid growth and huge size at onset	Surgery remains the mainstay of treatment VA chemotherapy and NTRK inhibitors are both options for patients with advanced localized disease.

Abbreviations: IVA, ifosfamide, vincristine, actinomycin-D; IVAd, ifosfamide, vincristine, doxorubicin; VDCy, vincristine–doxorubicin–cyclophosphamide; IE, ifosfamide–etoposide; IVADo, ifosfamide, vincristine, actinomycin-D, doxorubicin; IrIVA, irinotecan, ifosfamide, vincristine, actinomycin-D; VA, vincristine–actinomycin-D.

metastatic DFSP, and may be recommended as systemic treatment in such cases. Target therapy can improve the chances of subsequent complete resection even in cases of advanced disease.^{87–89}

Treatment Recommendations Specific to Other Types of NRSTS

Dedicated treatment recommendations are also needed for certain highly malignant tumors with biological features, and a clinical course and response to treatment clearly different from those of adult-type NRSTS (Table 3). Two particularly challenging histotypes are rhabdoid tumors and DSRCT.

Malignant Rhabdoid Tumor

Extracranial malignant rhabdoid tumors are rare, highly aggressive tumors occurring in infants and young children with biallelic mutations of the *SMARCB1* (95%) or *SMARCA4* (5%) genes encoding respectively for *INI1* and *BRG1*, which

are both core subunits of the *SWI/SNF* chromatin remodeling complex.⁹⁰ Although an aggressive multimodal strategy is generally adopted to treat young patients with rhabdoid tumors, the outcome remains largely unsatisfactory (due partly to the difficulties of delivering optimal local therapy in patients that are often very young).²³ In the absence of dedicated clinical trials, the EpSSG recommends the treatment plan described in the amended version of the EpSSG NRSTS 2005 protocol, ie, dose-intensive chemotherapy every 2 weeks with vincristine-doxorubicin-cyclophosphamide (VDCy), and ifosfamide-etoposide (IE). This treatment proved feasible (with no short-term toxicity of note) in a French series of 35 cases treated between 2014 and 2019, and achieving a 2-year EFS and OS of 47.6% and 42.9%, respectively.⁹¹ Further investigations are needed to better clarify the potential role of targeted therapies, such as epidrugs (eg, EZH2 or HDAC inhibitors)^{92,93} or checkpoint inhibitors.^{94,95}

Desmoplastic Small Round Cell Tumor

Characterized by the recurrent t(11;22)(p13;q12) chromosomal translocation that gives rise to the *EWS::WT1* fusion gene, DSRCT generally occurs in the abdominal and pelvic cavity of teenagers or young adults. It presents as a large abdominal mass and is already widely disseminated at the time of diagnosis in most cases, classically with multiple peritoneal lesions and seeding. DSRCT is associated with a very poor prognosis (median survival reportedly ranging from 17 to 25 months).^{96,97} Attempts to improve the outcome over the past 10–20 years have included aggressive surgery, hyperthermic peritoneal perfusion with cisplatin chemotherapy (HIPEC), high-dose chemotherapy with autologous peripheral stem cell rescue, whole abdomen radiotherapy, and targeted therapy with monoclonal antibodies and multikinase inhibitors.^{98–106} Whilst awaiting new effective therapies and dedicated trials, the EpSSG recommends an intensive therapeutic approach to DSRCT patients, such as Kushner's P6 regimen (which includes VDCy and IE chemotherapy),⁹⁸ the IVADo regimen used for metastatic rhabdomyosarcoma,¹⁰⁷ or chemotherapy with irinotecan, ifosfamide, vincristine, actinomycin-D (IrIVA).¹⁰⁸ Intensive chemotherapy should be integrated with local control measures, including aggressive surgery (with debulking of large peritoneal tumors and resection of all detectable nodules), and whole abdominopelvic radiotherapy. The addition of prolonged vinorelbine and low-dose oral cyclophosphamide maintenance therapy may also be an option.¹⁰⁹

Soft Tissue Sarcomas with *BCOR* and *CIC* Rearrangement

Another category of aggressive tumors is the *BCOR* family of undifferentiated sarcomas, characterized by genetic abnormalities involving *BCOR* (a transcriptional repressor gene, with a key role in regulating development, hematopoiesis and mesenchymal stem cell differentiation).¹¹⁰ *BCOR::CCNB3* sarcomas have a predilection for young males and tend more frequently to involve bones, but also soft tissues and also visceral sites (eg, kidney). *BCOR-ITD* sarcomas are another *BCOR* subtype that reveals internal tandem duplications (ITD).^{110,111}

The *CIC*-rearranged sarcomas (*CIC-DUX4* sarcomas) form another group of aggressive tumors^{112,113} that, like *BCOR* sarcomas, have been identified relatively recently.

Scant information is available on the clinical course of *BCOR* and *CIC* rearranged sarcomas and the best therapeutic approach. These tumors are generally treated using a multimodal approach that includes intensive multi-agent chemotherapy derived from protocols used for Ewing sarcoma. Shared and clear-cut treatment recommendations are lacking, however, and international collaborative studies are being developed to collect more clinical and biological data, compare the available treatments, and hopefully reach an international consensus on how these tumors should be managed.

Treatment Recommendations for Soft Tissue Tumors of Intermediate Malignancy

The vast group of NRSTS also includes three specific entities defined as soft tissue tumors of intermediate malignancy, ie, desmoid-type fibromatosis, IMT and IFS. The approach to the treatment of these three sarcomas has changed to some degree in recent years.

Desmoid-Type Fibromatosis

Desmoid-type fibromatosis (or aggressive fibromatosis) is a deep-seated, musculo-aponeurotic, fibroblastic tumor of borderline malignancy. It is characterized by a marked local aggressiveness and a strong tendency for local recurrence, but no tendency to metastasize (as truly malignant tumors do). Its pathogenesis is multifactorial, and may involve endocrine factors, trauma (including surgical trauma) and genetic predisposition. Desmoid tumors can be sporadic, due mainly to a pathogenic somatic variant in *CTNNB1*, which encodes beta-catenin; or they can arise in the setting of familial adenomatous polyposis (FAP), in which case they often feature mesenteric lesions with a more aggressive behavior.^{114,115}

In the last decade, the approach to treating desmoid-type fibromatosis has shifted significantly from surgery to a wait-and-see strategy in the case of non-evolving disease.¹¹⁶ This is largely because surgery is rarely a definitive solution (while it can be mutilating and also stimulate fibromatosis), and because desmoids may remain stable for lengthy periods, and even regress spontaneously. Based on the results obtained in the prospective series enrolled in its NRSTS 2005 study, the EpSSG recommends first adopting a wait-and-see strategy to assess the tumor's rate of growth (or potential spontaneous regression), especially for tumors not at life-threatening sites (Figure 2).²² Treatment should therefore be considered in cases of frank tumor progression, increasing pain/symptoms, or that involve life-threatening sites. The proposed first treatment in such cases is a minimal-morbidity systemic therapy, ie, low-dose intravenous methotrexate plus vinblastine. The therapy should be given at full dose for at least 6 months (the response may take time), possibly followed by another 6 months with wider-spaced doses (ie, doubling the time between injections). The role of surgery after systemic therapy remains an open question, and it is unclear whether delayed resection (if complete and non-mutilating) or a wait-and-see approach would be better after tumor stabilization. The currently preferred approach is to wait and see, without performing any surgery that might stimulate tumor cell growth during wound healing due to the release of local growth factors.

The pharmacological treatment of desmoids can involve various non-cytotoxic and cytotoxic agents, and the response rate is generally in the range of 25–40%. Multi-tyrosine kinase inhibitors are promising (in particular pazopanib and sorafenib), and in adult patients are often considered the first systemic choice.¹¹⁶ However, their role needs to be clarified in prospective pediatric studies.¹¹⁷ Other novel drugs that hold promise, such as gamma-secretase inhibitors (AL10, Nirogacestat) or β -catenin inhibitors (tegevivint), are now under investigation in adults/adolescents and/or in children.¹¹⁶

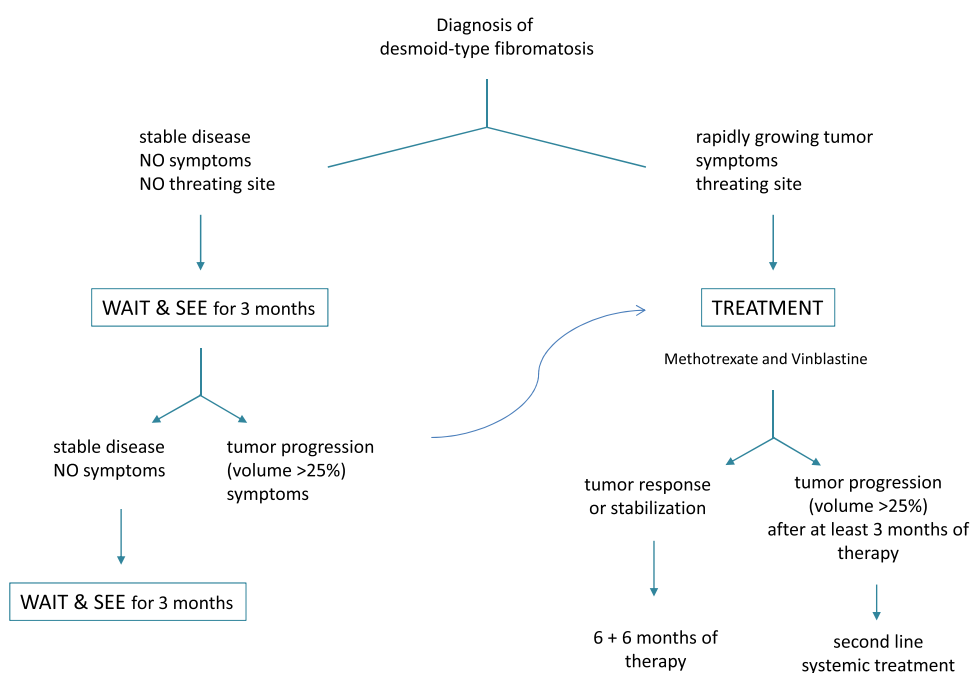


Figure 2 EpSSG flow chart for desmoid-type fibromatosis.

Due to the potential for long-term cosmetic or functional morbidity in children, radiation therapy may have a role only after several systemic therapies have failed, or in the case of progression despite multiple surgical procedures. Finally, it is worth mentioning the recent interest shown in cryotherapy as a safe and effective treatment modality for extra-abdominal desmoid tumors.¹¹⁸

Inflammatory Myofibroblastic Tumors

IMT is another mesenchymal tumor of intermediate malignancy that occurs mainly in the lungs or abdomen of children and young adults (but also at other sites). It is mainly a monoclonal tyrosine-kinase-driven neoplasm characterized by a rearrangement of the *ALK* (anaplastic lymphoma kinase) gene with various partner genes (in more than 60% of the cases) or fusions involving *ROSI*, *PDGFR β* , *RET*, and *NTRK*.¹¹⁹ Although it generally takes a benign course, IMT can be locally aggressive, and even carry some risk of metastases (in 5% of the cases). Surgery remains the mainstay of treatment and the prognosis is usually good when the tumor is widely resected. In cases of advanced disease, the treatment approach was historically based on corticosteroids or chemotherapy. Various degrees of response were reported, with some authors in favor of low-morbidity regimens like those used for desmoid fibromatosis.^{30,120,121}

The treatment strategy has changed substantially in recent years, however, with emerging evidence of the high levels of activity of *ALK* inhibitors (crizotinib, ceritinib, alectinib, and brigatinib), and – more recently – *ROSI*, *RET* and *NTRK* inhibitors (for cases with the corresponding molecular abnormality).^{122,123} The EpSSG recommends no adjuvant therapy after initial R0 or R1 resection, but chemotherapy (vinblastine plus low-dose methotrexate) is still a valid first option in cases of unresectable disease.³⁰ The role of *ALK* inhibitors (like that of tyrosine kinase inhibitors in general) as a first treatment option still needs to be clarified. That said, tyrosine kinase inhibitors (based on the molecular fusion identified) – if available, and preferably within clinical trials – could be a valuable option in the armamentarium of systemic therapies, given the high likelihood of a response. Things are changing rapidly in the field of tyrosine kinase inhibitors, with several clinical trials currently recruiting IMT patients, some even for upfront treatment if non-mutilating surgery is not feasible. When targeted treatments against *ROSI*, *RET* and *NTRK* translocated IMT become available as well, the approach to this disease can be expected to change.¹²⁴

Infantile Fibrosarcoma

IFS is the most common soft tissue sarcoma occurring in infants under 1 year old. It is considered a tumor with a low malignant potential (rarely metastasizing). It is characterized by the recurrent t(12;15)(p13;q25) translocation with the transcript *ETV6::NTRK3*, or, in a minority of cases, by fusions involving other genes, such as *RAF*, *RET*, or *NTRK1*.¹²⁵ IFS is generally located in deep soft tissues of the distal extremities (and less frequently in the trunk). Its clinical behavior may be peculiar, with a rapid initial growth to a huge size, but a good response to preoperative chemotherapy – even with a mild regimen like the vincristine–actinomycin-D (VA) combination – and an excellent prognosis.^{126,127}

The EpSSG recommends conservative tumor resection for localized disease and VA chemotherapy as first-line therapy for patients with unresectable disease (no adjuvant chemotherapy is recommended in cases classified as IRS group I–II).²² More intensive regimens should be considered only in the event of no response to VA. Particular attention should be paid to the dosage of chemotherapy (given patients' very young age) and to limiting the functional sequelae of surgery. The treatment options for IFS have very recently begun to change, however, with the arrival on the scene of very effective biological agents: *NTRK* inhibitors like larotrectinib and entrectinib have produced very rapid responses in the vast majority of children with IFS, with a limited acute toxicity.¹²⁸ An international consensus has proposed front-line treatment with either conventional chemotherapy or *NTRK* inhibitors for patients with advanced localized disease (at the physician's and parents' discretion), while *NTRK* inhibitors might be the best option for patients with metastatic disease, or to avoid mutilating surgery in cases of insufficient response to chemotherapy.¹²⁵

Future Studies

The new challenge for the EpSSG is developing a systematic multicenter molecular and epigenetic characterization of cases of NRSTS as a standard approach at the time of their diagnosis.^{129–133} The EpSSG MYKIDS study is a prospective biological investigation recruiting patients in EpSSG countries, that was ready to start at the time of writing this review.

It aims to identify novel translocations and genetic drivers, and to characterize as yet unknown or unclassified sarcomas using whole-exome sequencing (WES), mRNA sequencing (mRNAseq), and DNA methylation profiling. Ultimately, this should lead to an integrated diagnosis, and a comprehensive understanding of the treatment options for a given patient. MYKIDS also aims to identify new, reproducible molecular signatures for predicting outcome and refine risk stratification. In particular, the study will examine the predictive role of chromosomal instability, assessed with a genomic index or a more complex biological signature known as CINSARC (Complexity Index in Sarcoma, a 67-gene signature related to chromosome integrity and genomic complexity).^{27,134} Other working packages within the MYKIDS study focus on liquid biopsy,¹²⁷ the development of faithful tumor models such as organoids,¹³² and post-treatment molecular changes.

New effective drugs are needed for patients with NRSTS that carry a poor prognosis, ie those with unresected tumors, metastases at diagnosis, or relapsing disease. Pediatric sarcoma experts are looking for novel agents that can target the multiple signaling pathways involved in tumorigenesis across NRSTS subtypes, and might enhance the effect of conventional cytotoxic chemotherapy. The impact of new targeted agents for the pediatric population has not paralleled the progress seen in adult sarcoma patients. More international collaboration between pediatric and adult sarcoma communities is crucial, both to facilitate the transfer of potentially effective new agents from adults to children and adolescents, and to improve research programs. The ultimate goal should be to develop shared clinical trials for children, adolescents and adults with the same disease. Whether the results seen in adults can be achieved in pediatric patients, and whether a given soft tissue subtype has the same behavior (and response to treatment) in different age groups are questions that remain to be answered, and deserve to be explored.

The EpSSG is currently working on the development of a study to investigate whether adding regorafenib to the standard ifosfamide-doxorubicin chemotherapy can improve survival in high-risk NRSTS. If it gets underway, this study will compare to the North-American trial on pediatric and adult NRSTS patients, ie, the COG ARST1321 study conducted between 2014 and 2018, in which pazopanib was added to the standard treatment. At a planned interim analysis, the study showed a significant improvement in the pathological response rate after adding pazopanib, which reached a preset threshold so patient enrolment was stopped.¹³⁵

Conclusions

The current paper describes the state of the art and the therapeutic recommendations developed for NRSTS by the EpSSG. The EpSSG NRSTS 2005 study, together with the COG ARST0332 study, was able to define a risk-adapted standard of care, and demonstrated the importance of a standardized multimodal approach to such rare and diverse tumors as NRSTS.

Improving survival for patients with advanced or metastatic disease remains challenging for a heterogeneous group of tumors with variable or uncertain chemosensitivity. While awaiting new effective drugs with novel mechanisms of action, more standardised or optimised use of available therapy might improve patients' outcome. The current standard of care for pediatric NRSTS demonstrates how, in recent years, the clinical approaches adopted in the pediatric sarcoma community and in adult setting have converged towards common strategies.

To further refine the multidisciplinary treatment strategy for the different tumor types and risk groups, it is important to develop a uniform approach to the specific challenges of managing these tumors, and devise possible solutions together. It is with this goal in mind that the INternational Soft Tissue SaRcoma ConsorTium (INSTRuCT) was recently established. INSTRuCT was founded by three large cooperative groups – the EpSSG, COG, and Cooperative Weichteilsarkom Studiengruppe (CWS) – with the aim of pooling expertise and resources on a broader international level, developing consensus standards to guide diagnosis and treatment, and comparing clinical data across different groups and studies.^{7,10,136}

Disclosure

Daniel Orbach and Max M van Noesel are co-last authors for this study. Dr Susanne Andrea Gatz reports personal fees from TESARO, BAYER, and EMD Serono, outside the submitted work. The authors report no other conflicts of interest in this work.

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