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CONSENSUS STATEMENT

Consensus recommendations for systemic therapies in the management of relapsed Ewing sarcoma: A report from the National Ewing Sarcoma Tumor Board

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Abstract

Ewing sarcoma (ES) is a malignant tumor of bone and soft tissue that most often occurs in children, adolescents, and young adults. Debate and controversy remain in the management of relapsed/refractory ES (RR-ES). The authors leveraged the expertise assembled by the National Ewing Sarcoma Tumor Board, a multidisciplinary virtual tumor board that meets monthly to discuss challenging cases of ES. In this review, they focus on select topics that apply to the management of patients with RR-ES. The specific topics covered include the initial approach of such patients and discussion of the goals of care, the role of molecular testing, chemotherapy regimens and novel agents to consider, the role of maintenance therapy, and the use of high-dose chemotherapy with autologous stem cell rescue. The data referenced are often limited to subgroup analyses and/or compiled from multiple sources. Although not intended to replace the clinical judgement of treating physicians, these guidelines are intended to support clinicians and provide some clarity and recommendations for the management of patients with RR-ES.

Plain Language Summary

- Ewing sarcoma (ES) is a bone and soft tissue cancer that most often occurs in teenagers and young adults.
- This article uses the experience of the National Ewing Sarcoma Tumor Board, a multi-institution, multidisciplinary virtual tumor board that meets monthly to discuss challenging cases of ES and to address questions related to the treatment of patients with relapsed ES.

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- Although not intended to replace the clinical judgement of treating physicians and limited by available data, these consensus recommendations will support clinicians who treat patients with this challenging malignancy, made even more difficult when it recurs.

KEYWORDS
consensus, Ewing sarcoma, metastasis, refractory, relapse, stem cell transplantation

INTRODUCTION

Ewing sarcoma (ES) is an aggressive malignant tumor of bone and soft tissue of children, adolescents, and young adults. Despite advances in upfront treatment, relapses occur in approximately 25% of patients with localized disease and 70% of patients with metastatic disease.[1] Treatment of relapsed/refractory ES (RR-ES) remains a clinical challenge; the 5-year survival rate is less than 15%, and the majority of patients suffer a subsequent episode of progressive disease within 6 months of initial relapse.[2]

We leveraged the experience assembled by the formation of the National Ewing Sarcoma Tumor Board, a multidisciplinary virtual conference that meets monthly to discuss challenging cases of ES and to construct a list of frequent clinical questions relevant to RR-ES. We previously published on controversies related to upfront therapy.[3] In this review, we focus on topics that apply to systemic therapies in the management of RR-ES. The topics are limited to those that have a clinical and practical impact and for which there are some, albeit limited, data to support general recommendations. Although local control measures play a critical role in the management of RR-ES and will be explored in a separate article, the current report focuses on systemic therapies.

The data referenced are often limited to subgroup analyses and/or compiled from multiple sources. Although not intended to replace the clinical judgement of treating physicians, the recommendations are focused on providing pediatric and adult oncologists—who may or may not possess specific sarcoma expertise—some clarity and support for the management of patients with RR-ES.

Question 1: What should be considered when approaching RR-ES with curative intent?

The approach to a patient with RR-ES begins with a clear understanding of the initial diagnosis and treatment response, stage (localized vs. metastatic vs. combined relapse), difficult-to-treat locations, overall burden of disease at the time of relapse (oligometastatic vs. diffusely metastatic), and time to relapse. Each of these factors is prognostic, as reviewed below.

The most consistently reported determinant of prognosis is the time to first relapse. Patients who have a greater than 2-year relapse-free interval from the time of *initial diagnosis* have superior event-free survival (EFS) and overall survival (OS) across multiple single-institution and multi-institutional series.[4–9] In an analysis of the Children's Cancer Group–Pediatric Oncology Group Cooperative Group Study INT-0091, patients whose disease relapsed 2 years or more after initiation of treatment had an estimated 5-year OS of 30% compared with 7% in those whose disease relapsed within 2 years.[5]

Stage and sites of disease at diagnosis and relapse can also affect prognosis. A retrospective analysis of 55 patients reported that the 5-year OS rate in RR-ES patients with localized disease at initial diagnosis was 31% versus 12% for those with upfront metastatic disease.[4] For initially localized disease in first relapse, rates of second complete response (CR2) were 84% in patients with local recurrence versus 48% of patients with pulmonary-only metastases, 20% of patients with bone-only metastases, and 2.4% of patients with both.[10] The 5-year OS rate was 35%–50% for patients with local recurrence versus 10%–20% for those with distant-only recurrence (lung *or* bone), and 0%–10% for those with both.[4,9] Patients who initially presented with appendicular primary tumors had an 18% chance of achieving CR2 versus 6% for patients with pelvic primary tumors, and 9% for those with tumors at other sites, with 5-year EFS rates of 10.7%, 4.1%, and 0%, respectively.[8] In patients with upfront metastatic disease, 82% of patients developed distant-only relapse, 5% relapsed locally only, and 13% had both.[11] Patients who had pulmonary-only metastatic disease at diagnosis had a 3-year EFS rate of 54% compared with 26% for those who had non-pulmonary metastatic disease.[12]

Medical providers should have an open discussion with the patient and family about their prognosis at relapse, factoring in all available data about their disease. Addressing patient priorities, which may evolve, will dictate how the medical team presents and recommends therapeutic options like chemotherapy, local control, clinical trial enrollment, and supportive care. Additional factors to consider are the uncertainties of treatment efficacy, toxicities of therapy, and optimizing quality of life (QoL). For example, younger patients may feel differently about pursuing additional cancer-directed therapies than older patients. It is important to readdress goals of care at times of subsequent relapse or disease progression or after the development of treatment-related toxicity. Furthermore, patients with RR-ES may become *metavivors*, a term used to describe people living with cancer as a chronic and terminal illness.[13] This group of patients experiences unique biopsychosocial challenges, such as management of acute and chronic symptoms caused by previous and current cancer treatment, psychological distress, financial toxicity, and changing caregiver dynamics.[14] Early incorporation of palliative medicine in the care of patients with RR-ES is essential for symptom management and discussion of goals of care.[15]

New biomarkers are needed to better identify which patients with first recurrent ES may still be cured. In addition, evaluations of

health-related QoL measures and patient-reported outcomes are needed to fully understand the psychosocial impact and needs of patients with RR-ES.

Consensus statement: Although the best outcomes in patients with RR-ES have been seen in patients with late and localized relapses, discussion with the patient should be informed by the circumstances of their current disease, predicted outcomes, current organ function, and the patient's goals of care. Psychosocial support is critical for patients who have RR-ES. We strongly suggest consultation with supportive/palliative care at the time of relapse, if not already involved.

Question 2: What is the role of molecular testing at relapse in this tumor type?

Molecular testing for somatic aberrations, most commonly through DNA and RNA sequencing, has become customary in the diagnostic workup of high-risk solid tumors. Although identification of hallmark fusions between *EWSR1* and *ETS* family members is useful for diagnosis, patients with ES generally have fewer actionable alterations compared to other tumors. For example, of the 104 patients with RR-ES who were screened on the National Cancer Institute Children's Oncology Group Pediatric MATCH trial, only 12 (11.5%) had study-defined actionable alterations, with four patients (3.8%) enrolling for treatment using a molecularly targeted agent.[16] Loss-of-function mutations in *STAG2* and *TP53* are among the most common[17] but unfortunately are not yet targetable. Alterations in other targetable genes are infrequently identified, such as *PIK3R1*, *FGFR1*, and *EZH2*, along with alterations in cell cycle control and DNA damage repair genes.[18–20] In terms of germline findings, ES has been associated with as high as 13% germline pathogenic or likely pathogenic variants in genes involved in DNA damage repair, including *FANCC*, *CHEK2*, *BRCA1*, and *BRCA2*,[21,22] which may justify sequencing normal cells (buccal cells, peripheral blood, etc.) plus either archival tumor from diagnosis or tumor tissue obtained at relapse.

Unfortunately, RR-ES has not proportionally benefitted from advances in the current molecular era. Further investigation is needed to identify genomic, epigenomic, proteomic and metabolomic abnormalities as well as changes in the tumor microenvironment and immune response. Molecular biomarkers of response are also essential to understand why certain patients respond to targeted therapies.

Consensus statement: Molecular testing of RR-ES occasionally can identify additional/pathogenic alterations, but targetable alterations are infrequent, and the therapeutic efficacy of agents targeting these molecular alterations is not yet established. Biopsy of recurrent tumor may be beneficial for scenarios in which confirmation of recurrence is needed or archival tissue is unavailable for families and physicians interested in comparative germline testing.

Question 3: What is the chemotherapy regimen of choice?

Several regimens have demonstrated efficacy in RR-ES in single-arm clinical trials, including irinotecan and temozolomide with or without vincristine (IT/VIT), cyclophosphamide and topotecan (TC), high-dose ifosfamide (IFOS), gemcitabine and docetaxel (GD), oral etoposide, and others (Table 1).[23–37]

The rEECur trial (Clinical trial identifier ISRCTN36453794), a European, multiarm, multistage phase 2/3 randomized study, compared outcomes between four regimens (IT, TC, IFOS, and GD) in patients with recurrent and primary refractory ES.[30,38–40] Using a probability-based Bayesian approach with multiple pairwise comparisons, early termination of the GD arm at the first interim assessment and of the IT arm at the second interim assessment occurred after patients had a predicted inferior objective response rate (ORR) by Response Evaluation Criteria in Solid Tumors, version 1.1, compared with the other arms. The phase 3 portion of the study compared the remaining arms, TC and IFOS, and demonstrated a 95% posterior probability that EFS and OS were better with IFOS than with TC. The median EFS was 3.7 months (95% confidence interval [CI], 2.1–6.2 months) for TC and 5.7 months (95% CI, 3.8–7.0 months) for IFOS, and the median OS was 10.4 months (95% CI, 7.5–15.5 months) for TC and 16.8 months (95% CI, 11.1–25.8 months) for IFOS. In addition, a greater survival difference occurred in patients younger than 14 years compared with those aged 14 years and older. Further pairwise comparisons demonstrated overlapping outcomes between TC and IT and high levels of confidence disfavoring GD against any of the other regimens.

In rEECur, the IT treatment arm did not contain vincristine, and irinotecan was dosed intravenously over 5 days. However, there is no standardized approach to the administration of IT/VIT in RR-ES, and data are mostly extracted from retrospective studies.[41,42] Recently, a randomized controlled phase 2 trial for RR-ES assessed a 10-day lower dose versus a 5-day higher dose intravenous irinotecan schedule in combination with vincristine.[43] The ORR at 12 weeks was significantly higher for the protracted irinotecan schedule (54.5% vs. 20.8%; $p = .019$), but there was no difference in progression-free survival (PFS) or OS. Grade 3/4 gastrointestinal adverse events were higher in those who received 5-day irinotecan. These results align with a recent review that compared the ORR of both dosing schemas across a variety of trials, revealing an ORR of 53% (47 of 89 patients) for the 10-day irinotecan schedule versus an ORR of 29% (52 of 180 patients) for the 5-day irinotecan schedule.[42] Although the ORR may be higher with a lower side-effect profile using 10-day lower dose irinotecan in combination with temozolomide with or without vincristine, the feasibility of this schedule for patients, combined with a lack of impact on PFS and OS, should be considered by care teams. Another consideration is the use of oral irinotecan (usually mixed with cranberry-grape juice to mask the bitter taste), which has been studied using both 5-day and 10-day schedules. Objective responses have been seen with both dosing schedules, with greater toxicity in the protracted schedule.[27,34] However, the palatability of oral administration limits its use for many patients, and there are ongoing efforts to address this.[44]

The interpretation of rEECur data is further limited by differences in sample size, prognostic indicators of survival (such as the time to first recurrence and the extent of disease at first recurrence), differences in the primary end point between interim analyses and the phase 3 portion of the study, local control measures, and the number of cycles of therapy received.[5,41,45] Moreover, before the

TABLE 1 Characteristics of various systemic therapy regimens for relapsed-refractory Ewing sarcoma.

Regimen	Agents	Schedule	Cycle length	GOCS'	Toxicity profile	Reference(s)	Design	No.	ORR	Partial response	Complete response	6-month PFS	Median TTP, months
IT/VIT 5 day	Irinotecan 50 mg/m^2/day IV or Irinotecan 90 mg/m^2/day PO	Days 1–5	21 days	No	N/V/D, less alopecia (unless vincristine used)	Raciborska 2013,[23] Palmerini 2018[24]	Retrospective, Retrospective	22, 51	55%, 34%	32%, 24%	23%, 10%	NR, 49%	3.0, 3.9
	Temozolomide 100–150 PO mg/m^2/day	Days 1–5											
	Vincristine 1.5 mg/m^2/day IV	Day 1											
IT/VIT 10 day	Irinotecan 10–20 mg/m^2/day IV or Irinotecan 35 mg/m^2/day PO (Wagner 2010[27])	Days 1–5, days 8–12	21 days	No	N/V/D, less alopecia (unless vincristine used)	Van Winkle 2005,[25] Casey 2009[26]	Prospective RCT, Retrospective	22, 20	55%, 63%	50%, 37%	5%, 26%	41%,[a] NR	4.3, 8.3
	Temozolomide 100–150 PO mg/m^2/day	Days 1–5											
	Vincristine 1.5 mg/m^2/day IV	Days 1, 8											
TC	Topotecan 0.75 mg/m^2/day	Days 1–5	21 days	Yes	Bone marrow suppression, N/V, alopecia	Hunold 2006[28]	Retrospective	54	33%	33%	0%	NR	NR
	Cyclophosphamide 250 mg/m^2/day	Days 1–5											
IFOS	Ifosfamide 3 g/m^2/day IV	Days 1–5	21 days	Yes	Bone marrow suppression, N/V, alopecia, renal insufficiency	Ferrari 2009[29]	Prospective single arm	35	34%	29%	6%	NR	NR
	Mesna 3 g/m^2/day IV	Days 1–5											
GD	Gemcitabine 675–900 mg/m^2/day IV	Days 1, 8	21 days	Yes	Bone marrow suppression, N/V, alopecia, neuropathy, edema	McCabe 2019[30]	Prospective RCT	66	11.5%	NR	NR	NR	3
	Docetaxel 75–80 mg/m^2/day IV	Day 8											
	Dexamethasone 3 mg/m^2/day (up to 8 mg) PO/IV	Days 7–9											
ICE	Ifosfamide 1.8 g/m^2/day IV	Days 1–5	21 days	Yes	Bone marrow suppression, N/V, alopecia, renal insufficiency, ototoxicity	Van Winkle 2005[25]	Prospective single-arm strata	22	48%	22%	29%	NR	NR
	Carboplatin 400 mg/m^2/day IV	Days 1, 2											
	Etoposide 100 mg/m^2/day IV	Days 1–5											

(Continues)

TABLE 1 (Continued)

Regimen	Agents	Schedule	Cycle length	GOCS'	Toxicity profile	Reference(s)	Design	No.	ORR	Partial response	Complete response	6-month PFS	Median TTP, months
CE	Carboplatin AUC 2.2/day IV or Carboplatin AUC 7.5/day IV Etoposide 100 mg/m^2/day IV	Days 1, 8, 15 Day 1 Days 1–3	21 days	Yes	Bone marrow suppression, N/V, alopecia, renal insufficiency, ototoxicity	van Maldegem 2015[31]	Retrospective	61	51%	20%	31%	50%[a]	NR
Trabectedin/ irinotecan	Trabectedin 1 mg/m^2 IV Irinotecan 25mg/m^2 IV	Day 1 Days 2, 4	21 days	No	Fatigue, transaminitis, bone marrow suppression, N/V	Grohar 2024[32]	Prospective single arm	23	35%	35%	0%	40%	2.9
Cabozantinib	Cabozantinib 60 mg/day (or 40 mg/m^2/day in patients younger than 16 years) PO	Days 1–28	28 days	No	Rash, HTN, nephrotoxic, hepatoxicity, impaired wound healing	Italiano 2020[33]	Prospective single arm	45	26%	26%	0%	33%	4.4<zaq; a5>
Regorafenib	Regorafenib 160 mg/day (or 82 mg/m^2/day in patients younger than 16 years) PO	Days 1–21	28 days	No	Rash, HTN, nephrotoxic, hepatoxicity, impaired wound healing	Bagatell 2014,[34] Attia 2023[35]	Prospective, prospective RCT	23, 30	13%, 10%	13%, 10%	0%	26%, 36% (4-month)	2.9, 3.7
Oral etoposide	Etoposide 40–50 mg/m^2/day PO	Days 1–21	28 days	No	N/V, mild bone marrow suppression	Podda 2016[36]	Retrospective	58	19%	19%	<5%	NR	NR

Abbreviations: AUC, area under the curve; CE, carboplatin and etoposide; GCSF, granulocyte colony stimulating factor; GD, gemcitabine and docetaxel/dexamethasone; HTN, hypertension; ICE, ifosfamide, carboplatin, and etoposide; IFOS, ifosfamide; IT, irinotecan and temozolomide; IT/VIT, irinotecan and temozolomide with or without vincristine; IV, intravenous; N/V, nausea/vomiting; NR, not reported; ORR, overall response rate; PFS, progression-free survival; PO, per mouth; RCT, randomized clinical trial; TC, topotecan and cyclophosphamide; TTP, time to progression; VIT, vincristine, irinotecan, and temozolomide.

[a]Estimated PFS from graphical data.

two-arm phase 3 portion, patients and investigators had the option of limiting the regimens for which a patient was eligible to be randomized, introducing the potential for bias.

Toxicity profiles affecting organ function and QoL also need to be considered. In rEECur, GD was associated with fewer grade 3/4 adverse events compared with the other treatment arms. IT was associated with more nausea, vomiting, and diarrhea compared with TC and IFOS, and IFOS was associated with more infection, renal toxicity, and encephalopathy compared with TC. Given the adverse profile of high-dose IFOS in heavily pretreated patients, alternative schedules of IFOS (e.g., continuous infusion) may be useful, albeit with limited data to support its use in ES.[46] Similarly, liposomal doxorubicin is a means of rechallenging with doxorubicin and has decreased overall cardiotoxicity, although data are limited to support its use in this setting.[47,48]

Ultimately, the choice of regimen, schedule, and duration should take into account the plan for local control, toxicity, response, and patient and family preferences. To briefly address optimal duration of therapy, it is important to note that the median EFS in the rEECur study was 4.6 months, with other single-arm studies faring worse; therefore, duration of therapy is tailored by the duration of disease control or tolerability.[49–51] In patients who attain exceptional, enduring responses or stability with therapy, the optimal duration of therapy is unknown; for patients who have no evidence of disease, 6 to 12 months of adjuvant therapy is commonly used, but the authors are unaware of any data to specifically support this timeframe.

DNA minor groove binders, such as trabectedin or lurbinectedin, have shown preclinical activity in ES, with evidence that these agents can sequester the fusion oncoprotein in the nucleolus.[52] These agents have entered clinical trials for patients with RR-ES. A phase 1 study of trabectedin as a 3-hour infusion reported that one of three patients (33%) with RR-ES had a complete response.[53] A subsequent phase 2 trial administered trabectedin as a 24-hour infusion, and no responses were observed.[54] A follow-up phase 1/2 trial evaluating a 1-hour infusion together with low-dose irinotecan recently reported that five of 18 patients (28%) had objective responses in the phase 2 portion of the trial, or eight of 23 (35%) if the phase 1 patients who were treated at the phase 2 recommended dose (RP2D) were included.[32,55] The median duration of response in the phase 2 portion was 7.5 months, and the study reported a 6-month PFS rate of 40%. A phase 2 trial of lurbinectedin monotherapy reported a 14.3% ORR, but the median duration of response was only 4.2 months.[50] Although the results of this phase 1/2 trial evaluating trabectedin with irinotecan are promising, interpretation of these findings must consider that it is based on only 23 patients, and additional study may be warranted before moving this combination into the front-line treatment of RR-ES outside of the setting of a clinical trial.

Additional studies are required to identify the best sequence, intensity, and schedule of agents in the setting of first RR-ES. QoL considerations may take precedence over therapeutic efficacy because it is unknown which patients have the greatest benefit from more aggressive approaches outside of patients younger than 14 years.

Consensus statement: We recommend considering enrollment in a clinical trial at first relapse and beyond. In the absence of an accessible clinical trial, we recommend consideration of individual patient factors, including cumulative toxicities and goals of care, in choosing between IT/VIT, TC, IFOS, or any other regimen at first or subsequent relapse. GD is no longer recommended for first recurrent disease.

Question 4: What is the role of novel agents?

Several multitargeted tyrosine kinase inhibitors have been investigated in RR-ES. Cabozantinib was evaluated in a phase 2 trial (CABONE) in patients with RR-ES and reported a 26% ORR (ClinicalTrials.gov identifier NCT02243605).[33] Regorafenib has been tested in two phase 2 trials. The Sarcoma Alliance through Research and Collaboration (SARC) trial reported an ORR of 10% and a median PFS of 14.8 weeks (ClinicalTrials.gov identifier NCT02048371),[35] and a separate randomized, placebo-controlled phase 2 trial (REGOBONE) reported a 21.7% ORR and a median PFS of 11.4 weeks (ClinicalTrials.gov identifier NCT02389244).[56] Regorafenib was combined with vincristine and irinotecan in a phase 1 trial for pediatric patients with relapsed solid tumors (ClinicalTrials.gov identifier NCT02085148). Discontinuous dosing was tolerable, and three of five patients with ES on the trial had objective responses.[57] Catequentinib (anlotinib) has also been studied in a phase 1b/2 trial with vincristine and irinotecan in Chinese patients with RR-ES without central nervous system metastases.[58] Patients in phase 1b who were treated at the RP2D were included in the phase 2 analysis, resulting in a total of 24 adults (aged 16 years or older in this study) and 12 children. In the phase 2 portion, the majority of patients (92%) had metastatic disease, 44% had lung-only target lesions, and 64% had received only one prior line of chemotherapy. Irinotecan was given over 10 days (the RP2D was 15 mg/m^2 in adults and 20 mg/m^2 in children) and catequentinib concurrently over 14 days. Toxicity data were not available on a per-patient basis, but overall the regimen appeared to be myelosuppressive. The ORR was 69%, with a higher response rate of 83% in children. Whole-lung irradiation or surgical resection was allowed for patients who achieved a partial response (PR), and patients were censored at those time points, leading to a high rate of protocol violations and an overall PFS of 8–10 months. These results have not yet been validated.

DNA damage response inhibitors that target PARP, ATR, WEE1, CDC7, and others have demonstrate robust preclinical activity in ES.[59–63] However, multiple early phase trials of PARP inhibitors alone and in combination with chemotherapy have had disappointing results.[51,64–66] Scheduling and dosing may make a difference, because a more recent phase 1/2 trial of a protracted PARP inhibitor schedule plus low-dose irinotecan (arm D of the AcSe-ESMART trial) reported one complete response and one PR, and seven of 26 patients (35%) had stable disease (ClinicalTrials.gov identifier NCT02813135).[59,60,67] In a phase 1 trial of a WEE1 inhibitor with irinotecan, one of four patients with ES had a single confirmed PR on study.[68] Ongoing studies include the ONITT protocol (ClinicalTrials.gov identifier NCT04901702), which is examining the combination of liposomal irinotecan with a PARP inhibitor or temozolomide, and a phase 1/2 study of an ATR inhibitor, both with RR-ES–specific cohorts.[69,70]

Preclinical investigations identified a role for targeting CDK4 in ES,[71,72] leading to at least three clinical trials. One trial combined palbociclib with the IGF-1R monoclonal antibody ganitumab. No patients responded to this combination, although five out of 10 patients (50%) had stable disease.[73] Two ongoing trials are evaluating palbociclib (ClinicalTrials.gov identifier NCT03709680) or abemaciclib (ClinicalTrials.gov identifier NCT05440786) with chemotherapy in patients with RR-ES. Other cyclin-dependent kinase inhibitors, including CDK9 inhibition, are earlier in clinical development.

Several strategies targeting ES fusion oncoprotein have been investigated. LSD1 inhibition is thought to impede transcriptional reprogramming by the fusion oncoprotein.[74] The LSD1 inhibitor seclidemstat was tested as monotherapy[75] and in combination with TC in patients with RR-ES but had minimal efficacy.[76] Another drug, TK216, is thought to block the fusion oncoprotein transcriptional activity through RNA helicase A. This agent was evaluated as monotherapy and in combination with vincristine, but because only two of 28 patients (7%) had a complete response, further development in ES is yet to be determined.[77]

Patients with RR-ES have not derived significant benefit from immune checkpoint inhibitors and tumor vaccines. A phase 2 trial of pembrolizumab included an RR-ES cohort, with no responses.[78] In a pediatric phase 2 trial of nivolumab/ipilimumab, one of 14 patients (7%) with RR-ES had a complete response.[79] An autologous tumor vaccine, gemogenovatucel-T (Vigil), has been evaluated in patients with RR-ES both with and without irinotecan/temozolomide, and two of 10 patients (20%) demonstrated PRs in the most recent study.[80,81] Several antigens of potential interest for cellular immunotherapies are expressed in ES, including GD2,[82] B7H3,[83] STEAP1, etc.[84,85] No clinical results targeting these or other antigens have yet been published in this population.

Given the limited practical understanding of the genomics and epigenomics of ES outside of the characteristic fusion and the high toxicity of currently successful approaches in RR-ES, the interest in targeted therapies is well founded but unfortunately has had limited success. Research is critically needed to better understand the reasons why some subsets of patients respond to agents like multitargeted tyrosine kinase inhibitors, PARP inhibitors, CDK inhibitors, fusion oncoprotein inhibitors, DNA minor groove binders, or immunotherapy and why the majority of patients do not respond. The ethics of aggressive care in the setting of poor outcomes may also be a field in need of better illumination to help clinicians, patients, and families optimize patient-centered decision making.

Consensus statement: We recommend enrollment in clinical trials to explore novel therapies. Several targeted therapies have either shown activity in patients with RR-ES or are undergoing evaluation at various stages of clinical development in this population. The risks and benefits of these potential options and/or of participating in clinical trials must be weighed in the context of overall goals of care for this group of patients with very poor outcomes.

Question 5: What is the role of maintenance-style therapy in CR2?

Maintenance chemotherapy has been proven to be effective in acute lymphoblastic leukemia and rhabdomyosarcoma.[86,87] Efficacy has not been established in RR-ES. Two randomized trials using maintenance therapy (ganitumab[12] or zoledronic acid[88]) after the completion of standard treatment in newly diagnosed patients have shown no benefit. Other studies using oral trofosphamide[89] or oral cyclophosphamide plus either celecoxib[90] or vinorelbine[91] have demonstrated feasibility, but the precise benefit is difficult to determine because of short follow-up or the absence of a randomized control. Studies exploring maintenance therapy as part of upfront treatment for newly diagnosed patients with metastases are ongoing (INTER-EWING1 and iEuroEwing), yet to be reported (ClinicalTrials.gov identifier NCT03011528), or planned.[92] Studies to address maintenance therapy approaches in the second-remission setting, including the use of tyrosine kinase inhibitors, are ongoing (ClinicalTrials.gov identifier NCT05135975).[93] It is hoped that more sensitive disease assessments, such as circulating tumor DNA monitoring,[94] will better inform the necessity, length, and effectiveness of maintenance therapies.

Consensus statement: The clinical value of maintenance therapy in patients with RR-ES is not established. Consequently, we recommend that the use of maintenance therapy be restricted to a clinical trial setting or after a robust conversation with the patient regarding the lack of data and the risks and benefits of such an approach.

Question 6: What is the role of high-dose therapy with autologous stem cell rescue?

Dating back 40 years, high-dose therapy with autologous stem cell rescue (HDT) has been attempted for the treatment of patients with ES, in both the upfront and relapsed settings.[8,95] Although HDT has been incorporated into the treatment of patients with high-risk neuroblastoma and high-risk medulloblastoma, its role in the treatment of patients with ES remains controversial.[96]

Whether because of the retrospective nature of studies comparing patients treated with and without HDT or the few prospective studies comparing the same, there are consistent concerns regarding potential selection bias and modest benefit. Patients who proceed with HDT often have clinical features associated with a good response to conventional salvage chemotherapy,[4] prompting questions about the true impact of HDT in patients with RR-ES. Importantly, although it is generally considered less toxic than allogeneic stem cell transplantation, HDT has significant morbidity and mortality. A recent investigation compared 64 patients with RR-ES who received HDT, 98 patients who received standard therapy without HDT (non-HDT), and 34 patients who received no systemic therapy.[97] The median post-relapse survival was significantly longer in the HDT cohort compared with the non-HDT cohort (76 months vs. 10.5 months; $p < .0005$), and the post-relapse survival rate was higher in the HDT group compared with the non-HDT group at 2 years (67.9% vs. 52.7%) and at 5 years (20.5% vs. 2.0%). However, the authors keenly point out that the patients with the worst prognosis based on sites of relapse, those with concomitant local and pulmonary relapse, and those with extrapulmonary sites of relapse were disproportionately represented in the non-HDT group. Therefore, it is unclear whether HDT provides benefit in RR-ES. More data are required in the form of randomized controlled trials to establish that

any benefit offsets the known toxicity associated with this treatment approach.

Consensus statement: The clinical value of HDT in patients with RR-ES is not established because of the lack of randomized or prospective data. Although some patients with chemotherapy-responsive disease appear to achieve modest benefit from HDT, it is unclear whether this is a result of this specific treatment approach versus selection bias of a cohort likely to experience superior results with any therapy. Consequently, we recommend that the use of HDT be restricted to a clinical trial setting or after a robust conversation with the patient regarding the lack of data and the risks and benefits of such an approach.

CONCLUSION

In conclusion, this review offers consensus recommendations for the management of common clinical questions relevant to systemic therapies for the care of patients with RR-ES, as identified through the National Ewing Sarcoma Tumor Board. We provide a curated, high-level review of the available literature to inform these recommendations and highlight the work that remains to be done for the RR-ES population. For example, prospective clinical trials for RR-ES should collect known and anticipated prognostic data, including time to relapse, prior treatment regimens, and disease burden at initial presentation (size and location of primary, metastatic sites if present), to help contextualize results. In addition, although molecular evaluation of RR-ES has yet to yield benefits proportional to other diseases in the current molecular era, collection of these data with clinical annotation, including enrollment in prospective precision oncology endeavors, may be key to catalyzing clinically relevant progress (identification of prognostic, predictive, and surveillance biomarkers). Finally, many important questions exist beyond those discussed in this review, and we recommend bringing these questions to multidisciplinary discussions with experts in the field, like those that occur at the National Ewing Sarcoma Tumor Board.

AUTHOR CONTRIBUTIONS

Ajay Gupta: Conceptualization, writing–original draft, and writing–review and editing. **Matthew S. Dietz**: Writing–original draft, writing–review and editing, conceptualization, and visualization. **Richard F. Riedel**: Writing–original draft, conceptualization, and writing–review and editing. **Aditi Dhir**: Conceptualization, writing–original draft, and writing–review and editing. **Scott C. Borinstein**: Conceptualization, writing–review and editing, and writing–original draft. **Michael S. Isakoff**: Conceptualization, writing–review and editing, and writing–original draft. **Jamie M. Aye**: Conceptualization, writing–original draft, and writing–review and editing. **Nino Rainusso**: Conceptualization, writing–original draft, and writing–review and editing. **Amy E. Armstrong**: Conceptualization, writing–original draft, and writing–review and editing. **Steven G. DuBois**: Conceptualization, writing–original draft, and writing–review and editing. **Lars M. Wagner**: Conceptualization, writing–original draft, and writing–review and editing. **Jeremy M. Rosenblum**: Conceptualization, writing–original draft, and writing–review and editing. **Sarah Cohen-Gogo**: Conceptualization, writing–original draft, and writing–review and editing. **Catherine M. Albert**: Conceptualization, writing–original draft, and writing–review and editing. **Stacey Zahler**: Conceptualization, writing–original draft, and writing–review and editing. **Rashmi Chugh**: Conceptualization, writing–original draft, and writing–review and editing. **Matteo Trucco**: Conceptualization, writing–original draft, writing–review and editing, and supervision.

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REFERENCES

1. Leavey PJ, Laack NN, Krailo MD, et al. Phase III trial adding vincristine-topotecan-cyclophosphamide to the initial treatment of patients with nonmetastatic Ewing sarcoma: a Children's Oncology Group report. *J Clin Oncol*. 2021;39(36):4029-4038. doi:10.1200/jco.21.00358
2. Collier AB 3rd, Krailo MD, Dang HM, et al. Outcome of patients with relapsed or progressive Ewing sarcoma enrolled on cooperative group phase 2 clinical trials: a report from the Children's Oncology Group. *Pediatr Blood Cancer*. 2021;68(12):e29333. doi:10.1002/pbc.29333
3. Gupta A, Riedel RF, Shah C, et al. Consensus recommendations in the management of Ewing sarcoma from the National Ewing Sarcoma Tumor Board. *Cancer*. 2023;129(21):3363-3371. doi:10.1002/cncr.34942
4. Barker LM, Pendergrass TW, Sanders JE, Hawkins DS. Survival after recurrence of Ewing's sarcoma family of tumors. *J Clin Oncol*. 2005;23(19):4354-4362. doi:10.1200/jco.2005.05.105
5. Leavey PJ, Mascarenhas L, Marina N, et al. Prognostic factors for patients with Ewing sarcoma (EWS) at first recurrence following multi-modality therapy: a report from the Children's Oncology Group. *Pediatr Blood Cancer*. 2008;51(3):334-338. doi:10.1002/pbc.21618
6. Rodriguez-Galindo C, Billups CA, Kun LE, et al. Survival after recurrence of Ewing tumors: the St Jude Children's Research Hospital experience, 1979–1999. *Cancer*. 2002;94(2):561-569. doi:10.1002/cncr.10192
7. Shankar AG, Ashley S, Craft AW, Pinkerton CR. Outcome after relapse in an unselected cohort of children and adolescents with Ewing sarcoma. *Med Pediatr Oncol*. 2003;40(3):141-147. doi:10.1002/mpo.10248
8. Bacci G, Ferrari S, Longhi A, et al. Therapy and survival after recurrence of Ewing's tumors: the Rizzoli experience in 195 patients treated with adjuvant and neoadjuvant chemotherapy from 1979 to 1997. *Ann Oncol*. 2003;14(11):1654-1659. doi:10.1093/annonc/mdg457
9. McTiernan AM, Cassoni AM, Driver D, Michelagnoli MP, Kilby AM, Whelan JS. Improving outcomes after relapse in Ewing's sarcoma: analysis of 114 patients from a single institution. *Sarcoma*. 2006;2006(1):83548. doi:10.1155/srcm/2006/83548
10. Bacci G, Longhi A, Ferrari S, et al. Pattern of relapse in 290 patients with nonmetastatic Ewing's sarcoma family tumors treated at a single institution with adjuvant and neoadjuvant chemotherapy between 1972 and 1999. *Eur J Surg Oncol*. 2006;32(9):974-979. doi:10.1016/j.ejso.2006.01.023
11. Stahl M, Ranft A, Paulussen M, et al. Risk of recurrence and survival after relapse in patients with Ewing sarcoma. *Pediatr Blood Cancer*. 2011;57(4):549-553. doi:10.1002/pbc.23040
12. DuBois SG, Krailo MD, Glade-Bender J, et al. Randomized phase III trial of ganitumab with interval-compressed chemotherapy for patients with newly diagnosed metastatic Ewing sarcoma: a report from the Children's Oncology Group. *J Clin Oncol*. 2023;41(11):2098-2107. doi:10.1200/jco.22.01815
13. Beadnell T, Borriello L, Christenson J, et al. Meeting report: Metastasis Research Society (MRS) 17th Biennial Conference and associated Young Investigator Satellite Meeting (YISM) on cancer metastasis. *Clin Exp Metastasis*. 2019;36(2):119-137. doi:10.1007/s10585-018-09953-y
14. Spoozak L, Wulff-Burchfield E, Brooks JV. Rallying cry from the place in between. *JCO Oncol Pract*. 2020;16(8):451-452. doi:10.1200/op.20.00183
15. Lord S, Weingarten K, Rapoport A. Palliative care consultation should be routine for all children who enroll in a phase I trial. *J Clin Oncol*. 2018;36(11):1062-1063. doi:10.1200/jco.2017.76.3938
16. Parsons DW, Janeway KA, Patton DR, et al. Actionable tumor alterations and treatment protocol enrollment of pediatric and young adult patients with refractory cancers in the National Cancer Institute-Children's Oncology Group Pediatric MATCH Trial. *J Clin Oncol*. 2022;40(20):2224-2234. doi:10.1200/jco.21.02838
17. Crompton BD, Stewart C, Taylor-Weiner A, et al. The genomic landscape of pediatric Ewing sarcoma. *Cancer Discov*. 2014;4(11):1326-1341. doi:10.1158/2159-8290.Cd-13-1037
18. Jagodzińska-Mucha P, Sobczuk P, Mikuła M, et al. Mutational landscape of primary and recurrent Ewing sarcoma. *Contemp Oncol (Pozn)*. 2021;25(4):241-248. doi:10.5114/wo.2021.112234
19. Ogura K, Elkrief A, Bowman AS, et al. Prospective clinical genomic profiling of Ewing sarcoma: ERF and FGFR1 mutations as recurrent secondary alterations of potential biologic and therapeutic relevance. *JCO Precis Oncol*. 2022;6:e2200048. doi:10.1200/po.22.00048
20. Chi SN, Yi JS, Williams PM, et al. Tazemetostat for tumors harboring SMARCB1/SMARCA4 or EZH2 alterations: results from NCI-COG pediatric MATCH APEC1621C. *J Natl Cancer Inst*. 2023;115(11):1355-1363. doi:10.1093/jnci/djad085
21. Brohl AS, Patidar R, Turner CE, et al. Frequent inactivating germline mutations in DNA repair genes in patients with Ewing sarcoma. *Genet Med*. 2017;19(8):955-958. doi:10.1038/gim.2016.206

22. Gillani R, Camp SY, Han S, et al. Germline predisposition to pediatric Ewing sarcoma is characterized by inherited pathogenic variants in DNA damage repair genes. *Am J Hum Genet*. 2022;109(6):1026-1037. doi:10.1016/j.ajhg.2022.04.007
23. Raciborska A, Bilska K, Drabko K, et al. Vincristine, irinotecan, and temozolomide in patients with relapsed and refractory Ewing sarcoma. *Pediatr Blood Cancer*. 2013;60(10):1621-1625. doi:10.1002/pbc.24621
24. Palmerini E, Jones RL, Setola E, et al. Irinotecan and temozolomide in recurrent Ewing sarcoma: an analysis in 51 adult and pediatric patients. *Acta Oncol*. 2018;57(7):958-964. doi:10.1080/0284186x.2018.1449250
25. Van Winkle P, Angiolillo A, Krailo M, et al. Ifosfamide, carboplatin, and etoposide (ICE) reinduction chemotherapy in a large cohort of children and adolescents with recurrent/refractory sarcoma: the Children's Cancer Group (CCG) experience. *Pediatr Blood Cancer*. 2005;44(4):338-347. doi:10.1002/pbc.20227
26. Casey DA, Wexler LH, Merchant MS, et al. Irinotecan and temozolomide for Ewing sarcoma: the Memorial Sloan-Kettering experience. *Pediatr Blood Cancer*. 2009;53(6):1029-1034. doi:10.1002/pbc.22206
27. Wagner LM, Perentesis JP, Reid JM, et al. Phase I trial of two schedules of vincristine, oral irinotecan, and temozolomide (VOIT) for children with relapsed or refractory solid tumors: a Children's Oncology Group Phase I Consortium study. *Pediatr Blood Cancer*. 2010;54(4):538-545. doi:10.1002/pbc.22407
28. Hunold A, Weddeling N, Paulussen M, Ranft A, Liebscher C, Jürgens H. Topotecan and cyclophosphamide in patients with refractory or relapsed Ewing tumors. *Pediatr Blood Cancer*. 2006;47(6):795-800. doi:10.1002/pbc.20719
29. Ferrari S, del Prever AB, Palmerini E, et al. Response to high-dose ifosfamide in patients with advanced/recurrent Ewing sarcoma. *Pediatr Blood Cancer*. 2009;52(5):581-584. doi:10.1002/pbc.21917
30. McCabe MG, Moroz V, Khan M, et al. Results of the first interim assessment of rEECur, an international randomized controlled trial of chemotherapy for the treatment of recurrent and primary refractory Ewing sarcoma [abstract]. *J Clin Oncol*. 2019;37(15 suppl):11007. doi:10.1200/JCO.2019.37.15_suppl.11007
31. van Maldegem AM, Benson C, Rutkowski P, et al. Etoposide and carbo-or cisplatin combination therapy in refractory or relapsed Ewing sarcoma: a large retrospective study. *Pediatr Blood Cancer*. 2015;62(1):40-44. doi:10.1002/pbc.25230
32. Grohar PJ, Ballman KV, Heise R, et al. SARC037: Phase II results of trabectedin given as a 1-hour (h) infusion in combination with low dose irinotecan in patients (pts) with relapsed/refractory Ewing sarcoma (ES) [abstract]. *J Clin Oncol*. 2024;42(16 suppl):11508. doi:10.1200/JCO.2024.42.16_suppl.11508
33. Italiano A, Mir O, Mathoulin-Pelissier S, et al. Cabozantinib in patients with advanced Ewing sarcoma or osteosarcoma (CABONE): a multicentre, single-arm, phase 2 trial. *Lancet Oncol*. 2020;21(3):446-455. doi:10.1016/s1470-2045(19)30825-3
34. Bagatell R, Norris R, Ingle AM, et al. Phase 1 trial of temsirolimus in combination with irinotecan and temozolomide in children, adolescents and young adults with relapsed or refractory solid tumors: a Children's Oncology Group study. *Pediatr Blood Cancer*. 2014;61(5):833-839. doi:10.1002/pbc.24874
35. Attia S, Bolejack V, Ganjoo KN, et al. A phase II trial of regorafenib in patients with advanced Ewing sarcoma and related tumors of soft tissue and bone: SARC024 trial results. *Cancer Med*. 2023;12(2):1532-1539. doi:10.1002/cam4.5044
36. Podda MG, Luksch R, Puma N, et al. Oral etoposide in relapsed or refractory Ewing sarcoma: a monoinstitutional experience in children and adolescents. *Tumori*. 2016;102(1):84-88. doi:10.5301/tj.5000419
37. Reed DR, Hayashi M, Wagner L, et al. Treatment pathway of bone sarcoma in children, adolescents, and young adults. *Cancer*. 2017;123(12):2206-2218. doi:10.1002/cncr.30589
38. McCabe MG, Kirton L, Khan M, et al. Results of the second interim assessment of rEECur, an international randomized controlled trial of chemotherapy for the treatment of recurrent and primary refractory Ewing sarcoma (RR-ES) [abstract]. *J Clin Oncol*. 2020;38(15 suppl):11502. doi:10.1200/JCO.2020.38.15_suppl.11502
39. McCabe M, Kirton L, Khan M, et al. Phase III assessment of topotecan and cyclophosphamide and high-dose ifosfamide in rEECur: an international randomized controlled trial of chemotherapy for the treatment of recurrent and primary refractory Ewing sarcoma (RR-ES) [abstract]. *J Clin Oncol*. 2022;40(17 suppl):LBA2. doi:10.1200/JCO.2022.40.17_suppl.LBA2
40. McCabe M, Kirton L, Gaunt P, et al. Pairwise comparisons of the four chemotherapy regimens initially included in the rEECur trial for the treatment of primary refractory and recurrent Ewing sarcoma (RR-ES). Paper presented at: Annual Connective Tissue Oncology Society Meeting; November 16–192, 2022; Vancouver, British Columbia, Canada. Accessed June 1, 2024. https://www.eventscribe.net/2022/CTOS/fsPopup.asp?efp=QUpSRUVSU1AxNzQ5Ng&PresentationID=1137022&rnd=1.570392E-02&mode=presinfo
41. Van Mater D, Wagner L. Management of recurrent Ewing sarcoma: challenges and approaches. *Onco Targets Ther*. 2019;12:2279-2288. doi:10.2147/ott.S170585
42. Slotkin EK, Meyers PA. Irinotecan dose schedule for the treatment of Ewing sarcoma. *Pediatr Blood Cancer*. 2023;70(1):e30005. doi:10.1002/pbc.30005
43. Xu J, Xie L, Sun X, et al. Longer versus shorter schedules of vincristine, irinotecan, and temozolomide (VIT) for relapsed or refractory Ewing sarcoma: a randomized controlled phase 2 trial. *Clin Cancer Res*. 2023;29(6):1040-1046. doi:10.1158/1078-0432.Ccr-22-3546
44. Bacha JA, Brown D, Geller JI, et al. A pilot clinical study of oral irinotecan HCl (VAL-413) in patients with recurrent pediatric solid tumors [abstract]. *J Clin Oncol*. 2023;41(16 suppl):TPS10073. doi:10.1200/JCO.2023.41.16_suppl.TPS10073
45. Wood GE, Graves LA, Rubin EM, Reed DR, Riedel RF, Strauss SJ. Bad to the bone: emerging approaches to aggressive bone sarcomas. *Am Soc Clin Oncol Educ Book*. 2023;43:e390306. doi:10.1200/edbk_390306
46. Meazza C, Casanova M, Luksch R, et al. Prolonged 14-day continuous infusion of high-dose ifosfamide with an external portable pump: feasibility and efficacy in refractory pediatric sarcoma. *Pediatr Blood Cancer*. 2010;55(4):617-620. doi:10.1002/pbc.22596
47. Skubitz KM. Phase II trial of pegylated-liposomal doxorubicin (Doxil) in sarcoma. *Cancer Invest*. 2003;21(2):167-176. doi:10.1081/cnv-120016412
48. Trucco MM, Meyer CF, Thornton KA, et al. A phase II study of temsirolimus and liposomal doxorubicin for patients with recurrent and refractory bone and soft tissue sarcomas. *Clin Sarcoma Res*. 2018;8:21. doi:10.1186/s13569-018-0107-9
49. McCabe M, Kirton L, Khan M, et al. Analysis of rEECur trial data to evaluate potential prognostic factors in recurrent and primary refractory Ewing sarcoma (RR-ES). Paper presented at: Annual Connective Tissue Oncology Society Meeting; November 16–19, 2022; Vancouver, British Columbia, Canada. Accessed June 1, 2024. https://www.eventscribe.net/2022/CTOS/fsPopup.asp?efp=QUpSRUVSU1AxNzQ5Ng&PosterID=525874&rnd=0.6478212&mode=posterinfo
50. Subbiah V, Braña I, Longhi A, et al. Antitumor activity of lurbinectedin, a selective inhibitor of oncogene transcription, in patients with relapsed Ewing sarcoma: results of a basket phase II study. *Clin Cancer Res*. 1 2022;28(13):2762-2770. doi:10.1158/1078-0432.Ccr-22-0696
51. Choy E, Butrynski JE, Harmon DC, et al. Phase II study of olaparib in patients with refractory Ewing sarcoma following failure of standard chemotherapy. *BMC Cancer*. 2014;14:813. doi:10.1186/1471-2407-14-813
52. Harlow ML, Maloney N, Roland J, et al. Lurbinectedin inactivates the Ewing sarcoma oncoprotein EWS-FLI1 by redistributing it within the

nucleus. *Cancer Res*. 2016;76(22):6657-6668. doi:10.1158/0008-5472.Can-16-0568
53. Lau L, Supko JG, Blaney S, et al. A phase I and pharmacokinetic study of ecteinascidin-743 (Yondelis) in children with refractory solid tumors. A Children's Oncology Group study. *Clin Cancer Res*. 2005;11(2 pt 1):672-677.
54. Baruchel S, Pappo A, Krailo M, et al. A phase 2 trial of trabectedin in children with recurrent rhabdomyosarcoma, Ewing sarcoma and non-rhabdomyosarcoma soft tissue sarcomas: a report from the Children's Oncology Group. *Eur J Cancer*. 2012;48(4):579-585. doi:10.1016/j.ejca.2011.09.027
55. Grohar P, Ballman KV, Heise R, et al. SARC037: Results of phase I study of trabectedin given as a 1-hour (h) infusion in combination with low dose irinotecan in relapsed/refractory Ewing sarcoma (ES) [abstract]. *J Clin Oncol*. 2023;41(16 suppl):11519. doi:10.1200/JCO.2023.41.16_suppl.11519
56. Duffaud F, Blay J-Y, Le Cesne A, et al. Regorafenib in patients with advanced Ewing sarcoma: results of a non-comparative, randomised, double-blind, placebo-controlled, multicentre phase II study. *Br J Cancer*. 2023;129(12):1940-1948. doi:10.1038/s41416-023-02413-9
57. Casanova M, Bautista F, Campbell-Hewson Q, et al. Regorafenib plus vincristine and irinotecan in pediatric patients with recurrent/refractory solid tumors: an Innovative Therapy for Children with Cancer study. *Clin Cancer Res*. 2023;29(21):4341-4351. doi:10.1158/1078-0432.Ccr-23-0257
58. Xu J, Xie L, Sun X, et al. Anlotinib, vincristine, and irinotecan for advanced Ewing sarcoma after failure of standard multimodal therapy: a two-cohort, phase Ib/II trial. *Oncologist*. 2021;26(7):e1256-e1262. doi:10.1002/onco.13726
59. Garnett MJ, Edelman EJ, Heidorn SJ, et al. Systematic identification of genomic markers of drug sensitivity in cancer cells. *Nature*. 2012;483(7391):570-575. doi:10.1038/nature11005
60. Stewart E, Goshorn R, Bradley C, et al. Targeting the DNA repair pathway in Ewing sarcoma. *Cell Rep*. 2014;9(3):829-841. doi:10.1016/j.celrep.2014.09.028
61. Martin JC, Sims JR, Gupta A, Bakin AV, Ohm JE. WEE1 inhibition augments CDC7 (DDK) inhibitor-induced cell death in Ewing sarcoma by forcing premature mitotic entry and mitotic catastrophe. *Cancer Res Commun*. 2022;2(6):471-482. doi:10.1158/2767-9764.crc-22-0130
62. Koppenhafer SL, Goss KL, Terry WW, Gordon DJ. Inhibition of the ATR-CHK1 pathway in Ewing sarcoma cells causes DNA damage and apoptosis via the CDK2-mediated degradation of RRM2. *Mol Cancer Res*. 2020;18(1):91-104. doi:10.1158/1541-7786.Mcr-19-0585
63. Jess J, Sorensen KM, Boguslawski EA, et al. Cell context is the third axis of synergy for the combination of ATR inhibition and cisplatin in Ewing sarcoma. *Clin Cancer Res*. 2024;30(16):3533-3548. doi:10.1158/1078-0432.Ccr-23-3063
64. Chugh R, Ballman KV, Helman LJ, et al. SARC025 arms 1 and 2: a phase 1 study of the poly(ADP-ribose) polymerase inhibitor niraparib with temozolomide or irinotecan in patients with advanced Ewing sarcoma. *Cancer*. 2021;127(8):1301-1310. doi:10.1002/cncr.33349
65. Schafer ES, Rau RE, Berg SL, et al. Phase 1/2 trial of talazoparib in combination with temozolomide in children and adolescents with refractory/recurrent solid tumors including Ewing sarcoma: a Children's Oncology Group Phase 1 Consortium study (ADVL1411). *Pediatr Blood Cancer*. 2020;67(2):e28073. doi:10.1002/pbc.28073
66. Federico SM, Pappo AS, Sahr N, et al. A phase I trial of talazoparib and irinotecan with and without temozolomide in children and young adults with recurrent or refractory solid malignancies. *Eur J Cancer*. 2020;137:204-213. doi:10.1016/j.ejca.2020.06.014
67. Gatz SA, Berlanga P, Archambaud B, et al. Abstract CT088: Phase I/II study of the PARP inhibitor olaparib in combination with irinotecan in children with advanced malignancies: arm D of the AcSé-ESMART trial. *Cancer Res*. 2023;83(8 suppl):CT088. doi:10.1158/1538-7445.Am2023-ct088
68. Cole KA, Pal S, Kudgus RA, et al. Phase I clinical trial of the WEE1 inhibitor adavosertib (AZD1775) with irinotecan in children with relapsed solid tumors: a COG Phase I Consortium report (ADVL1312). *Clin Cancer Res*. 2020;26(6):1213-1219. doi:10.1158/1078-0432.Ccr-19-3470
69. Stewart E, Blankenship K, Freeman B, Federico S, Dyer M. Abstract 6716: Preclinical evaluation of nano-liposomal irinotecan in pediatric solid tumor patient-derived xenografts. *Cancer Res*. 2023;83(7 suppl):6716. doi:10.1158/1538-7445.Am2023-6716
70. Ortiz MV, Bender JLG, Minard CG, et al. A phase 1/2 study of bay 18953444 (Elimusertib) in pediatric patients with relapsed or refractory solid tumors: initial report of the phase 1 results of PEPN2112 [abstract]. *J Clin Oncol*. 2023;41(16 suppl):e15131. doi:10.1200/JCO.2023.41.16_suppl.e15131
71. Kennedy AL, Vallurupalli M, Chen L, et al. Functional, chemical genomic, and super-enhancer screening identify sensitivity to cyclin D1/CDK4 pathway inhibition in Ewing sarcoma. *Oncotarget*. 2015;6(30):30178-30193. doi:10.18632/oncotarget.4903
72. Guenther LM, Dharia NV, Ross L, et al. A combination CDK4/6 and IGF1R inhibitor strategy for Ewing sarcoma. *Clin Cancer Res*. 2019;25(4):1343-1357. doi:10.1158/1078-0432.Ccr-18-0372
73. Shulman DS, Merriam P, Choy E, et al. Phase 2 trial of palbociclib and ganitumab in patients with relapsed Ewing sarcoma. *Cancer Med*. 2023;12(14):15207-15216. doi:10.1002/cam4.6208
74. Sankar S, Theisen ER, Bearss J, et al. Reversible LSD1 inhibition interferes with global EWS/ETS transcriptional activity and impedes Ewing sarcoma tumor growth. *Clin Cancer Res*. 2014;20(17):4584-4597. doi:10.1158/1078-0432.Ccr-14-0072
75. Reed DR, Chawla SP, Setty B, et al. Phase 1 trial of seclidemstat (SP-2577) in patients with relapsed/refractory Ewing sarcoma [abstract]. *J Clin Oncol*. 2021;39(15 suppl):11514. doi:10.1200/JCO.2021.39.15_suppl.11514
76. Reed DR, Chawla SP, Setty B, et al. Phase 1 expansion trial of the LSD1 inhibitor seclidemstat (SP-2577) with and without topotecan and cyclophosphamide (TC) in patients (pts) with relapsed or refractory Ewing sarcoma (ES) and select sarcomas [abstract]. *J Clin Oncol*. 2021;39(15 suppl):TPS11577. doi:10.1200/JCO.2021.39.15_suppl.TPS11577
77. Ludwig JA, Federman NC, Anderson PM, et al. TK216 for relapsed/refractory Ewing sarcoma: interim phase 1/2 results [abstract]. *J Clin Oncol*. 2021;39(15 suppl):11500. doi:10.1200/JCO.2021.39.15_suppl.11500
78. Tawbi HA, Burgess M, Bolejack V, et al. Pembrolizumab in advanced soft-tissue sarcoma and bone sarcoma (SARC028): a multicentre, two-cohort, single-arm, open-label, phase 2 trial. *Lancet Oncol*. 2017;18(11):1493-1501. doi:10.1016/s1470-2045(17)30624-1
79. Davis KL, Fox E, Isikwei E, et al. A phase I/II trial of nivolumab plus ipilimumab in children and young adults with relapsed/refractory solid tumors: a Children's Oncology Group study ADVL1412. *Clin Cancer Res*. 2022;28(23):5088-5097. doi:10.1158/1078-0432.Ccr-22-2164
80. Ghisoli M, Barve M, Mennel R, et al. Three-year follow up of GMCSF/bi-shRNA(furin) DNA-transfected autologous tumor immunotherapy (Vigil) in metastatic advanced Ewing's sarcoma. *Mol Ther*. 2016;24(8):1478-1483. doi:10.1038/mt.2016.86
81. Anderson P, Ghisoli M, Crompton BD, et al. Pilot study of recurrent Ewing's sarcoma management with vigil/temozolomide/irinotecan and assessment of circulating tumor (ct) DNA. *Clin Cancer Res*. 2023;29(9):1689-1697. doi:10.1158/1078-0432.Ccr-22-2292
82. Kailayangiri S, Altvater B, Meltzer J, et al. The ganglioside antigen G (D2) is surface-expressed in Ewing sarcoma and allows for MHC-independent immune targeting. *Br J Cancer*. 2012;106(6):1123-1133. doi:10.1038/bjc.2012.57
83. Majzner RG, Theruvath JL, Nellan A, et al. CAR T cells targeting B7-H3, a pan-cancer antigen, demonstrate potent preclinical activity

against pediatric solid tumors and brain tumors. *Clin Cancer Res*. 2019;25(8):2560-2574. doi:10.1158/1078-0432.Ccr-18-0432
84. Mooney B, Negri GL, Shyp T, et al. Surface and global proteome analyses identify ENPP1 and other surface proteins as actionable immunotherapeutic targets in Ewing sarcoma. *Clin Cancer Res*. 2024;30(5):1022-1037. doi:10.1158/1078-0432.Ccr-23-2187
85. Cheung IY, Feng Y, Danis K, et al. Novel markers of subclinical disease for Ewing family tumors from gene expression profiling. *Clin Cancer Res*. 2007;13(23):6978-6983. doi:10.1158/1078-0432.Ccr-07-1417
86. Schmiegelow K, Nielsen SN, Frandsen TL, Nersting J. Mercaptopurine/methotrexate maintenance therapy of childhood acute lymphoblastic leukemia: clinical facts and fiction. *J Pediatr Hematol Oncol*. 2014;36(7):503-517. doi:10.1097/mph.0000000000000206
87. Bisogno G, De Salvo GL, Bergeron C, et al. Vinorelbine and continuous low-dose cyclophosphamide as maintenance chemotherapy in patients with high-risk rhabdomyosarcoma (RMS 2005): a multicentre, open-label, randomised, phase 3 trial. *Lancet Oncol*. 2019;20(11):1566-1575. doi:10.1016/s1470-2045(19)30617-5
88. Dirksen U, Koch R, Bhadri V, et al. Efficacy of maintenance therapy with zoledronic acid in patients with localized Ewing sarcoma: report from the International Ewing 2008 trial [abstract]. *J Clin Oncol*. 2020;38(15 suppl):11523. doi:10.1200/JCO.2020.38.15_suppl.11523
89. Raciborska A, Bilska K, Rodriguez-Galindo C. Maintenance treatment with trofosfamide in patients with primary bone Ewing sarcoma—single center experience. *Dev Period Med*. 2019;23(1):39-44. doi:10.34763/devperiodmed.20192301.3944
90. Puma N, Sebastian AD, Paioli A, et al. Maintenance therapy with oral cyclophosphamide plus celecoxib in patients with metastatic Ewing sarcoma: results of the Italian Sarcoma Group/AIEOP EW-2 study [abstract]. *J Clin Oncol*. 2020;38(15 suppl):10517. doi:10.1200/JCO.2020.38.15_suppl.10517
91. Koscielniak E, Sparber-Sauer M, Scheer M, et al. Extraskeletal Ewing sarcoma in children, adolescents, and young adults. An analysis of three prospective studies of the Cooperative Weichteilsarkom-studiengruppe (CWS). *Pediatr Blood Cancer*. 2021;68(10):e29145. doi:10.1002/pbc.29145
92. Metts J, Russell T, Reed D, Trucco M. A proposed trial design for the treatment of widely metastatic Ewing sarcoma inspired by evolutionary dynamics. *Cancers (Basel)*. 2022(3):14. doi:10.3390/cancers14030736
93. Shah N. CaboMain: a phase 2 study of cabozantinib as a maintenance agent in patients with ultra-high risk pediatric solid tumors [abstract]. *J Clin Oncol*. 2022;40(16 suppl):TPS10060. doi:10.1200/JCO.2022.40.16_suppl.TPS10060
94. Hayashi M, Chu D, Meyer CF, et al. Highly personalized detection of minimal Ewing sarcoma disease burden from plasma tumor DNA. *Cancer*. 2016;122(19):3015-3023. doi:10.1002/cncr.30144
95. Ekert H, Tiedemann K, Waters KD, Ellis WM. Experience with high dose multiagent chemotherapy and autologous bone marrow rescue in the treatment of twenty-two children with advanced tumours. *Aust Paediatr J*. 1984;20(3):195-201. doi:10.1111/j.1440-1754.1984.tb00077.x
96. Fraser CJ, Weigel BJ, Perentesis JP, et al. Autologous stem cell transplantation for high-risk Ewing's sarcoma and other pediatric solid tumors. *Bone Marrow Transplant*. 2006;37(2):175-181. doi:10.1038/sj.bmt.1705224
97. Windsor R, Hamilton A, McTiernan A, et al. Survival after high-dose chemotherapy for refractory and recurrent Ewing sarcoma. *Eur J Cancer*. 2022;170:131-139. doi:10.1016/j.ejca.2022.04.007

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