Comparison of two chemotherapy regimens in newly diagnosed Ewing sarcoma – results of the EURO EWING 2012 (EE2012) randomised phase 3 trial

Prof Bernadette Brennan[1]MD, Laura Kirton[2]MSc, Perrine Marec-Bérard[3,4,5]MD, Nathalie Gaspar[4,5,6]MD, Valerie Laurence [4,5,7]MD, Javier Martín-Broto[8]MD, Ana Sastre[9]MD, Prof Hans Gelderblom[10]MD, Cormac Owens[11]MD, Nicola Fenwick[2]BMedSc, Sandra Strauss[12,13]MD, Veronica Moroz[2]MSc, Prof Jeremy Whelan[13]MD, Prof Keith Wheatley[2]PhD.

Institutions:

1. Royal Manchester Children's Hospital, Manchester, United Kingdom
2. Cancer Research UK Clinical Trials Unit, University of Birmingham, United Kingdom
3. Centre Léon Bérard, Lyon, France
4. Société Française de Lutte contre les Cancers et Leucémies de l'Enfant et de l'Adolescent (SFCE), Paris, France
5. Groupe Sarcome Français (GSF-GETO)
6. Institut Gustave Roussy, Villejuif, France
7. Institut Curie, Paris, France
8. Medical Oncology Department, Fundacion Jimenez Diaz University Hospital; Instituto de Investigacion Sanitaria Fundacion Jimenez Diaz (IIS/FJD); and University Hospital General de Villalba, Madrid. Spain
9. Hospital Universitario La Paz, Madrid, Spain
10. Leiden University Medical Center, Leiden the Netherlands, on behalf of European Organisation for Research and Treatment of Cancer (EORTC), Brussels, Belgium
11. Our Lady's Children's Hospital, Dublin, Ireland
12. University College London, London, United Kingdom
13. University College London Hospitals NHS Foundation Trust, London, United Kingdom

Correspondence to:

Prof Bernadette Brennan

Department of Paediatric Oncology and Haematology
Royal Manchester Children's Hospital
Manchester
United Kingdom
bernadette.brennan@mft.nhs.uk
01617018430

Summary

Background Internationally, a single standard chemotherapy treatment for Ewing sarcoma (ES) is not defined. EE2012 compared two different chemotherapy regimens, one used in Europe and one in the United States of America.

Methods EE2012 was a European academic, open label, randomised controlled phase III trial performed in 10 countries , to compare two different induction/consolidation chemotherapy strategies: arm A (VIDE regimen) vincristine, ifosfamide, doxorubicin and etoposide (VIDE) induction, and vincristine, actinomycin D, with ifosfamide or cyclophosphamide, or busulfan and melphalan (VAI/VAC/BuMel) consolidation and arm B (VDC/IE regimen) vincristine, doxorubicin, cyclophosphamide, ifosfamide and etoposide (VDC/IE) induction,

and ifosfamide and etoposide, vincristine and cyclophosphamide, or vincristine, actinomycin D and ifosfamide, with busulfan and mephalan (IE/VC/VAI/BuMel) consolidation (randomisation R1). Patients were included from age 2 years to less than 50 years, with any histologically and genetically confirmed ES of bone or soft tissue, or 'Ewing's-like' sarcomas. The eligibility criteria originally excluded patients with extrapulmonary metastatic disease, but this was amended in protocol version 3.0 in September 2016. The primary outcome measure was event free survival (EFS). A Bayesian approach was taken for the design, analysis and interpretation of the results. Patients who received at least one dose of study treatment were considered in the safety analysis. The trial was registered with EudraCT number 2012-002107-17 and ISRCTN number 54540667.

Findings Between 21 March 2014 and 1 May 2019, 640 patients were entered into EE2012, 320 allocated to each arm. Median follow-up of surviving patients is 47 months (range 0-84). EFS at 3 years was 61% with arm A-VIDE and 67% with arm B- VDC/IE, with an adjusted hazard ratio (HR)=0.71, 95% credible interval (CrI) 0.55-0.92 in favour of VDC/IE. The probability that the true HR was <1.0 was >0.99. Febrile neutropenia as a grade 3-5 treatment toxicity occurred in 234 (74%) patients receiving VIDE induction but less in those receiving VDC/IE induction 183 (58%). Patients receiving VIDE induction required more platelet transfusions compared to VDC/IE induction, 205 patients with at least 1 versus 138 respectively. Conversely, more blood transfusions were required for VDC/IE arm versus VIDE arm 286 and 277 respectively

Interpretation Dose intensive chemotherapy with VDC/IE/VC/VAI is more effective, less toxic and more convenient for all stages of newly diagnosed ES and should now be the standard of care for ES.

Funding

This project has received funding from the European Union's Seventh Framework Programme for research, technological development, and demonstration under grant agreement n°602856. The National Coordinating Centre in France, Centre Léon Bérard, receives additional funding from SFCE and Ligue contre le cancer. The Coordinating Sponsor, United Kingdom is funded by Cancer Research UK (grant award reference C5952/A14745). Funding allowed set up of the study in each country, sponsorship, data collection and analysis.

Research in context

Evidence before this study

We searched PubMed for randomised trials in Ewing sarcoma between 1 January 1990 and 31 December 2010. We searched for published papers with the search terms "Ewing sarcoma" and "chemotherapy trials". We did

not find any randomised studies comparing different standard regimens of chemotherapy used in Europe and USA.

Added value of this study

To our knowledge, this is the first randomised study demonstrating that the dose intense USA standard chemotherapy regimen of VDC/IE is more effective than the European non dose intense VIDE regimen.

Implications of all the available evidence

Dose intensive chemotherapy with VDC/IE regimen is more effective, less toxic and more convenient for all stages of newly diagnosed Ewing sarcoma and should now be the standard of first line care for all patients with Ewing Sarcoma.

Introduction

Ewing sarcoma (ES) is a cancer of the bone and soft tissue with 80% occurring in adolescents and young adults and a peak incidence in the second decade of life.[1] ES is rare, with fewer than 70 cases per year in the UK, 100 in France and 400 in the rest of Europe, so any randomised trials must be international to yield robust results in a timely manner. With current multimodal programmes, including combination chemotherapy of doxorubicin, etoposide, cyclophosphamide, vincristine and ifosfamide, using different doses and schedules of administration, as well as surgery and radiotherapy, outcome for localised disease is good, with event-free survival (EFS) of 65% and overall survival (OS) of 75% at 3 years with standard chemotherapy regimens.[2,3] For metastatic disease, 3-year OS is 68% for patients with isolated pulmonary and/or pleural metastases and only 29% for multi-metastatic disease.[4-10]

Internationally, a single standard chemotherapy treatment for ES is not defined. The EURO-E.W.I.N.G. 99 trial employed VIDE induction chemotherapy (six cycles of vincristine, ifosfamide, doxorubicin and etoposide given about every 3 weeks prior to local control) followed by risk-adapted randomised treatment of either vincristine, actinomycin D and ifosfamide or cyclophosphamide (VAI/VAC) as consolidation chemotherapy or high-dose busulfan/melphalan. The toxicity of VIDE induction chemotherapy has been published.[11]

The other widely used treatment regimen for ES, employed mainly in the USA, is from the Children's Oncology Group (COG) AEWS0031 trial.[2] In that study, patients with localised ES received alternating cycles of vincristine-doxorubicin-cyclophosphamide and ifosfamide-etoposide (VDC/IE) as induction chemotherapy and alternating

cycles of ifosfamide-etoposide and vincristine-cyclophosphamide (IE/VC) as consolidation chemotherapy, either 3-weekly or 2-weekly. The 2 weekly schedule was significantly more effective than the 3 weekly schedule and is now standard of care in USA. As different chemotherapy regimens were standard in Europe and the USA for newly diagnosed ES, and in the absence of novel agents to investigate, a randomised comparison of these two strategies was considered worthwhile to establish the regimen of choice, taking account of both clinical outcome (EFS and OS) and toxicity.

Methods

Study design and participants

EE2012 was a European academic, open label, randomised controlled phase III trial performed in 10 countries and in 110 sites (appendix for sites and countries). All patients with ES, except widely metastatic disease until September 2016, were eligible for randomisation (R1) to receive either the European regimen (Arm A) of VIDE induction and VAI or VAC consolidation or the USA regimen (Arm B) of compressed VDC/IE induction and IE/VC consolidation. Following induction chemotherapy, all patients were eligible for a second randomisation (R2) of the addition of zoledronic acid to the consolidation chemotherapy assigned at R1. Furthermore, the R2 randomisation is stratified by allocated treatment in R1, age at R1 randomisation (<14 years; ≥14 years), sex, disease status (localised disease or regional lymph node involvement of lymph nodes only at diagnosis and good risk after induction, localised disease or regional lymph node involvement only at diagnosis and of lymph nodes only poor risk after induction, lung or pleural metastases at diagnosis, other metastasis at diagnosis), and country (UK, France or other).

The results of R2 will be reported in a future publication. Deviations to the protocol are detailed in the consort diagram (figure 1)

Patients were eligible from the age of 2 years to less than 50 years with any histologically and genetically confirmed ES of bone or soft tissue, or 'Ewing's-like' round cell sarcomas but negative for EWSR1 gene rearrangement, who were medically fit to receive trial treatment. The eligibility criteria originally excluded patients with extrapulmonary metastatic disease, but this was amended in protocol version 3.0 in September 2016. The trial was overseen by a trial management and steering groups. An independent data monitoring committee reviewed safety and efficacy during the trial. The study was conducted in accordance with the Declaration of

Helsinki and the Good Clinical Practice guidelines. Informed written consent was obtained from all patients / parents/ legal guardians as per local practice.

Randomisation

Patients were allocated in a 1:1 ratio to the two arms. Randomisation was performed by staff at participating centres online by using the randomisation function of the electronic remote data capture (eRDC) system designed and maintained by the coordinating sponsor. The randomisation was stratified using minimisation to ensure a balance between treatments within the strata defined by these key prognostic factors and country. The minimisation factors were age at randomisation (<14 years or ≥14 years), gender, disease type (absence of metastases or involvement of regional lymph nodes only; lung or pleural metastases only; other metastases), volume of tumour at diagnosis (<200 mL or ≥200 mL) and country (the UK, France or other).

Procedures

At diagnosis, the work-up consisted of MRI/CT scan of the primary tumour and staging, including bone marrow assessment, CT scan of the chest and radionuclide bone scan (18F-fluorodeoxyglucose PET was an alternative to a bone scan in some trial sites). Resection of the primary tumour at diagnosis was not recommended and for the majority of patients, a biopsy was obtained to establish the diagnosis.

At trial entry, patients were randomised to one of the following treatment arms:

Arm A (VIDE strategy): **VIDE induction, VAI/VAC/BuMel consolidation**.

Induction chemotherapy: six cycles of VIDE.

Consolidation chemotherapy: one cycle of VAI plus seven cycles of VAC (good risk localised disease) - VAC

or one cycle of VAI plus one cycle of BuMel (poor risk localised disease without contraindication to BuMel) - BuMel.

or eight cycles of VAI (poor risk localised disease with contraindication to BuMel, and/or regional lymph node(s) involvement and/or metastatic disease) - VAI

Arm B (VDC/IE strategy): **VDC/IE induction, IE/VC/VAI/BuMel consolidation**.

Induction chemotherapy: nine cycles of alternating VDC and IE.

Consolidation chemotherapy: five cycles of alternating IE and VC - (good risk localised disease and/or regional lymph node(s) involvement and/or metastatic disease; or poor risk localised disease with contraindication to BuMel) - IE/VC

or one cycle VAI plus BuMel (poor risk localised disease without contraindication to BuMel) – BuMel.

A summary of the enrolment, interventions and the main assessments has been published,[12] and a SPIRIT (Standard Protocol Items: Recommendations for Interventional Trials) checklist is supplied in appendix (page 2-6). The full schedule of treatments is provided in appendix (page 7-11) and full details of trial treatments and conduct has been published.[12] Following induction chemotherapy, local control of the primary tumour was performed, where feasible with a complete surgical resection or, if not, definitive radiotherapy. Radiotherapy was recommended to be given concurrently with consolidation chemotherapy to the primary site. In patients with pulmonary and/or pleural metastatic disease, whole lung radiotherapy was recommended to be given on completion of consolidation chemotherapy. Radiotherapy to bony metastases was given either during consolidation or at the end of chemotherapy. Patients who received radiotherapy only as their local control and had measurable disease before radiotherapy had an MRI or CT scan performed at the end of treatment. If the end-of-treatment scan showed residual disease, another scan was performed six months after the end of treatment. Adverse events were monitored at least weekly and were assessed according to National Cancer Institute Common Toxicity Criteria (NCI CTC) version 4.0. After treatment, patients were followed up with clinical evaluation and scanning for a minimum of five years or until disease progression or death if sooner.

Outcome measures

The primary outcome measure was EFS. EFS was defined as the time from randomisation to first event, where an event was the first of progression without complete or partial response, recurrence (following complete or partial remission), second malignancy or death by any cause without a preceding event; patients who did not

have an event were censored at the date they were last seen. The secondary outcome measures were OS, defined as the time from randomisation to death, irrespective of the cause, with surviving patients censored at their date last seen; adverse events and toxicity; histological response of the primary tumour to induction chemotherapy if surgery was performed; response of the primary tumour, regional lymph nodes and/or metastases, using the volume of the whole primary tumour, diameter of the largest node (or group if not separate), and number of lung and/or pleural and other metastases respectively; and achievement of local control at the end of treatment. Response data was not complete or of sufficient quality for further analysis and reporting.

Trial design and statistical analysis

Due to the rarity of ES and the comparison being between two standard chemotherapy regimens, a Bayesian approach was taken for the design, analysis and interpretation of R1 (see Discussion for a justification of this design). No prior assumptions that one chemotherapy arm was likely to be better than the other were made. With a five-year accrual period, it was anticipated that at least 600 patients could be randomised across participating countries. Hence, the minimum sample size was set at 600 with a minimum of two years and a maximum of seven years' follow-up, with at least 150 events expected. Non-informative priors were used, so the posterior distribution gives Pr (parameter data) (i.e., the probability of the treatment effect). The ln (hazard ratio [HR]) was assumed to be normally distributed with variance 4/n, where n is the total number of events in both arms.[13]

Based on the EURO-E.W.I.N.G. 99 data, 3-year EFS was anticipated to be approximately 70% with VIDE.[3] A 5% absolute difference in 3-year EFS corresponds to a HR of 1.21 (or inversely 0.81). Different scenarios were considered to establish the probabilities that one treatment was better than the other, or not more than 5% worse, from posterior probability distributions. These were based on a study sample size of 600 patients and a range of observed HRs for the data. The probability that VDC/IE was more than 5% worse or better than VIDE, given an observed HR of 1.00 (i.e., no apparent difference between randomly assigned groups in terms of EFS), would be 10% or 7% respectively. Under the premise of no difference in efficacy (EFS), it would then be reasonable to base the decision on which regimen has a more tolerable toxicity profile. In addition, with an observed HR of 0.81 (i.e., an absolute improvement of approximately 5% in EFS with VDC/IE compared to VIDE, or vice versa), there would be an 8% probability that the apparently better regimen was worse. Finally, with an observed HR of 0.90 (i.e., about a 2.5% absolute difference in EFS in favour of one or other arm), there would be a probability of 25% that the apparently better regimen was worse and a probability of 3% that it was more than 5% worse. The

probabilities from these scenarios were all within the limit of clinical acceptability based on expert opinion at the design stage, confirming that 600 was an acceptable sample size.

For time-to-event outcome measures, Cox regression models were used to compare the treatment arms, adjusted for stratification variables. The proportional hazards (PH) assumption was assessed by examining the Schoenfeld residuals. In addition, Kaplan-Meier survival estimates were obtained at 3 and 5 years. Exploratory hypothesis-generating subgroup analyses were performed for all stratification variables and interpretation focused on 95% confidence intervals. Tests for heterogeneity were performed by the likelihood ratio test, comparing Cox models with and without an interaction term between the treatment variable and stratification variable. All analyses were intention-to-treat, with all patients analysed in the arm to which assigned at randomisation.

The statistical software Stata v17.0 was used to perform all statistical analyses.

Role of the funding source.

The funders of the study had no role in study design, data collection, data analysis, data interpretation, writing of the paper or decision to submit the paper.

Results

Between 21 March 2014 and 1 May 2019, 640 patients were entered into EE2012, with 320 allocated to each arm for the R1 randomisation (figure 1). At the date of data cut off 28 November 2021, median follow-up of surviving patients is 47 months (range 0-84). Four patients formally withdrew consent for further data collection. Loss to follow-up is very low and balanced between arms (six patients on VIDE and three on VDC/IE). Baseline clinical characteristics were well balanced across the two arms (table 1). There were 20 patients with Ewing- like sarcoma, nine in VIDE arm, and 11 in VDC/IE arm. In the VIDE arm 19 (7%) patients received Bu/Mel and in the VDC/IE

arm six (2%). In the VIDE arm 134 (42%) were randomised in the R2 randomisation, and 183 (44%) in the VDC/IE arm.

99% of patients started their allocated treatment (three withdrawals of consent to treatment, one recurrence prior to starting treatment, one reason not given, one no record to support having treatment or not having treatment). In the VIDE arm, 95% of patients received all six induction courses; in the VDC/IE arm, 91% of patients received all nine induction courses. In the VIDE arm, 58% of patients received all 8 consolidation courses; in the VDC/IE arm, 75% of patients received all five consolidation courses. (figure1)

The local therapy received to primary tumour is described in table 2. The majority of patients received radiotherapy to the primary tumour, 208 (65%) in VIDE arm and 199 (62%) in VDC/IE arm. In the VIDE arm 34 (64%) with lung and/or pleural metastases received lung radiotherapy and in the VDC/IE arm 30 (57%) with lung and/or pleural metastases received lung radiotherapy.

A total of 240 events was recorded, 131 and 109 in the VIDE and VDC/IE arms respectively. The types of events are shown in table 3. EFS at 3 years was 61% with VIDE and 67% with VDC/IE, with a HR=0.71, 95% CrI 0.55-0.92 (figure 2a) in favour of VDC/IE. The probability that the true HR was <1.0 was >0.99 (figure 3a), while there was a 0.81 probability that the true HR<0.8 in favour of VDC/IE. The PH assumption held.

A total of 163 deaths was recorded, 95 and 68 in the VIDE and VDC/IE arms respectively. The causes of death are shown in table 3. OS at 3 years was 74% with VIDE and 82% with VDC/IE, with a HR=0.62, 95% CrI 0.46-0.85 (figure 2b) in favour of VDC/IE. The probability that the true HR was <1.0 was >0.99 (figure 3b), while there was a 0.94 probability that the true HR<0.8 in favour of VDC/IE. The PH assumption held.

There was no evidence that the treatment effect for VIDE compared to VDC/IE differed across patient and disease subgroups for either EFS or OS (figure 4a and 4b respectively), with all confidence intervals for the interaction

effects including values consistent with no significant subgroup effects. Within all subgroups, the point estimate for the HR was in favour of VDC/IE.

Among patients who started trial treatment, similar numbers experienced grade 3-5 AEs in both arms: for VIDE and VDC/IE respectively, 91% and 90% during induction chemotherapy and 66% and 67% during consolidation. However, febrile neutropenia as a grade 3-5 AE occurred in 234 (74%) patients receiving VIDE induction but less in those receiving VDC/IE induction 183 (58%) (table 4). The difference in febrile neutropenia between the two arms were also seen in E-SARs, again greater in the VIDE arm. There was no difference in gastrointestinal toxicities, and infections and infestations between the two arms. (Table 4)

In-patient stays and supportive care: Patients receiving VIDE induction required more platelet transfusions compared to VDC/IE induction, 205 patients with at least 1 versus 138 respectively. Conversely, more blood transfusions were required for VDC/IE arm versus VIDE arm 286 and 277 respectively. More unscheduled visits were required in the VIDE arm versus VDC/IE arm with the median number of days being 13 and 9 respectively (table 5). The length of treatment for VDC/IE was on average 61 days shorter than VIDE regimen.

In those patients who had surgery after induction chemotherapy, a greater number had good necrosis in the VDC/IE arm compared to VIDE arm 104 versus 82 respectively. (Table 6) Response data was not complete or of sufficient quality for further analysis and reporting.

Discussion

The results of this international randomised trial for 2–50-year-old patients with newly diagnosed Ewing sarcoma clearly show that VDC/IE chemotherapy is substantially superior to VIDE for both EFS and OS survival, with a greater than 99% chance that it is better for both outcome measures. This benefit is consistent across all baseline stratification parameters, which are also important prognostic factors. There is no excess toxicity with VDC/IE, fewer supportive care requirements and the total time to complete treatment averages 12 weeks less with VDC/IE. These are all clinically meaningful findings. Hence, these results have led to a practice change in Europe and many other countries. VDC/IE chemotherapy has become the standard regimen for all newly diagnosed Ewing sarcomas in Europe, following its earlier adoption in the USA. Furthermore, the trial used Bayesian statistical

models for what is a rare tumour, which allowed a timely answer to the randomised question as the number of patients required was smaller than frequentist methodology.

At the time of designing this study, arm B VDC/IE was the standard of care for Ewing sarcoma, for all stages of disease, in the USA through the COG research group. This followed the COG AEWS0031 trial, which compared three-weekly chemotherapy VDC/IE versus more intensive two-weekly VDC/IE (arm B in our trial).[2] The OS for the comparable arm in AEWS0031 was 83 % at 5 years versus 87 % at 3 years in EE2012 arm B. While these results seem comparable, the AEWS0031 study only included localised ES versus all stages in EE2012. Pragmatically VAI/Bu/Mel was allowed in arm B after induction in EE2012, following the results of EE99 R2 loc randomisation for poor risk localised disease, and therefore differed to AEWS0031 but not significantly as only 6 (2%) of arm B received Bu/Mel.[18]

Furthermore, the median age of subjects in AEWS0031 was lower, known to confer a better prognosis in ES.[4] The AEWS0031 study had also compared a more dose dense chemotherapy, maintaining the doses but reducing the interval between chemotherapy.[2] Their strategy followed Norton's dose density model and with the use of granulocyte colony-stimulating factor G-CSF, as in our study, they were able to maintain this dose intensity with superior results [14]. Arm A – VIDE in this study was standard of care in Europe and other countries from the EURO-E.W.I.N.G. 99 trial.[2,4,4,10] It is difficult to make any direct comparisons as no data has been published for the whole study including all stages of disease.

Previous publications have focused on individual disease types or risk groups related to extent of disease or stage, either in single arm studies or randomised.[2,4,6,10] In EE2012, all disease groups of ES were (eventually) included in the upfront randomisation R1, but there was stratification for these disease groups along with other factors such as age and tumour volume, for example. The disease type was balanced between the two arms. We performed subgroup analysis for all baseline parameters and used heterogeneity tests (p-value of the interaction term between treatment variable and covariate in the adjusted Cox model), visually demonstrated by forest plots, to investigate whether the treatment effect differed between these groups. For both EFS and OS, the benefit of VDC/IE was not different for disease type or indeed any other stratification variables. This provides good evidence to treat all ES with the VDC/IE regimen and hence for it to become the standard of care internationally. This is particularly

important for widely metastatic disease who were not included in the AEWS0031 study. [2] Ewing-like sarcoma were included in the study, but their numbers were small in both arms and therefore unlikely to have had any effect on the outcomes reported.

A limitation of this study was that widely metastatic patients were not included at the start of the study but only from September 2016 (and as there was a competing study in France, they were not entered at all from France). Therefore, the percentage of patients with widely metastatic disease was less than expected from the population data.[15] The group with widely metastatic disease was, however, balanced between the two arms and subgroup analysis showed that the benefit of VDC/IE was consistent for this disease group along with other disease groups. As a randomised study, the type of local therapy and hence radiation or not received was balanced, and although there was guidance for the dose of, and indications for radiotherapy, it is likely there was variability for this amongst sites and countries both on indications and dose received, as this was not mandatory. Going forward, the ES research community needs to develop an evidence base for radiotherapy doses in ES, as currently there is variability in practice.

A Bayesian approach was chosen because two standard chemotherapy regimens – one European, one North American – were to be compared. Therefore, a less stringent decision criterion for accepting one as being better than the other was considered appropriate compared to a conventional frequentist p=0.05.[16] An informal survey of the trial's lead clinicians revealed that they would be happy to accept a regimen as the standard going forward if there were an 80% chance that it was better than the other. Furthermore, had a frequentist design been used, it was not clear whether superiority (and which arm would be the control) or equivalence should be demonstrated. It should be noted that, with the use of non-informative priors, the Bayesian design is entirely equivalent to a frequentist one, with one minus the posterior probability being the one-sided p-value – i.e. 1 – Prob(trueHR< 1.0|data) = 1p.[17] Given the 80% decision guideline, it was considered that a Phase III trial with a two-sided alpha of 0.4 might be deemed unacceptable to funders and regulators. We also believe that Bayesian presentation of the results as probabilities that one arm is better than the other is more intuitive and easier for clinicians and patients to understand than p-values, which are often misinterpreted. It transpired that a relaxed decision criterion was not relevant, given that the posterior probabilities for both EFS and OS were 100% – i.e., equivalent to a one-sided p<0.01 – thereby providing very strong evidence that VDC/IE is superior to VIDE. Another advantage of a Bayesian design is that alternative probabilities can be generated, not just the probability that one arm is better than the other. In this case, there is a 94% chance that the true HR for OS is <0.8, i.e., a

94% chance that there is a reduction in the risk of death with VDC/IE compared with VIDE. Advancements in the utilisation of Bayesian methodology since the design of EE2012 means that if the trial were to be designed again, using a minimally (or weakly) informative prior rather than a non-informative prior would preferable to exclude unrealistic values for the log(HR). However, this would not have altered the conclusion of our trial given the large sample size and event rate.

There appears to be little difference in toxicity between the two chemotherapy arms from evaluation of any grade 3-5 events, in both induction and consolidation. However, on review of specific events, there is less overall haematological toxicity in VDC/IE arm B and hence reduced requirement for blood product transfusions, more blood transfusions were required in the VDC/IE arm, but even more platelet transfusions were required in the VIDE arm. This difference is also apparent in infection events, with admissions for both fever alone and episodes associated with neutropenia less in the VDC/IE arm. Overall, there were more unscheduled visits for VIDE arm A. Gastrointestinal events, however, were similar. These findings are not unexpected, as the toxicity of the two arms had been previously described in publications.[2,11] In terms of the feasibility of delivering the different chemotherapy arms only 58 % of the VIDE arm A received all 8 consolidation courses but for VDC/IE arm B, 75% of patients received all 5 consolidation courses. The 12-week average reduction in total time to complete treatment with VDC/IE is also very important factor supporting this as standard of care.

The success of the VDC/IE arm B and the lower toxicity allows us to think about adding in other non-chemotherapy targeted therapies; in combination, these may have tolerable toxicity and they are certainly needed in the poor prognostic ES such as those with metastatic disease, to hopefully improve outcomes.[5,6,18] Early clinical data suggest that strategies adding a multiple tyrosine kinase inhibiter (MTKI) with anti-angiogenic activities may be beneficial in ES.[19-21] These drugs have been combined with chemotherapy in ARST1321 trial (ifosfamide/doxorubicin) which included younger patients and reported no major toxicities.[22]

In summary, dose intensive chemotherapy with VDC/IE is more effective, less toxic and more convenient for all stages of newly diagnosed ES and should now be the standard of first line care for all patients with ES.

Contributors

BB, PMB, NG, VL, JMB, AS, HG, CO, NF, SS, JW, and KW contributed to the study design, data collection, and interpretation, management of the clinical trial, writing and review of the paper, and approval of the final version. LK contributed to the data collection, and interpretation, management of the clinical trial, writing and

review of the paper, and approval of the final version. VM contributed to the study design, data collection, and interpretation, management of the clinical trial, review of the paper, and approval of the final version. BB acted as chief investigator and was part of the TMG, along with PMB, NG, VL, JMB, AS, HG, NF, SS, JW, LK, VM and KW, wrote the protocol and organised the data management. BB, PMB, JMB, HG and CO coordinated the protocol in participating countries. NF coordinated the data centre and LK, VM and KW did the statistical analysis.

Declaration of interests

SS has received honoraria and consulting fees from GSK, Lilly and Ceridwen Oncology.

JMB has the following interests

Institutional Grants from Adaptimmune, Amgen, AROG,

Bayer, Blueprint, BMS, Celgene, Daichii-Sankyo,

Deciphera, Eisai, FORMA, GSK, IMMIX Biopharma, Karyopharm, Lilly, Nektar, Novartis, Pfizer, PharmaMar

Honoraria from PharmaMar, Tecnofarma

Payment for expert testimony from Bayer, Eisai, Lilly, PharmaMar

Support for attending meetings and/or travel from PharmaMar, Asofarma

Participation on a Data Safety Monitoring Board or Advisory Boards for Asofarma; PharmaMar; Boheringer, Tecnofarma, Roche, Bayer.

We declare no other competing interests.

Data sharing

Individual participant data are not publicly available as this was not anticipated in the study protocol

The link to the protocol:

https://www.birmingham.ac.uk/Documents/college-mds/trials/crctu/ee2012/EE2012-Protocol-version-5.0-02Jun2017.pdf

Acknowledgements

We would like to acknowledge all the patients who agreed to take part in this study, as well as the EE2012 investigators and trial staff at participating trial centres. We also acknowledge other colleagues at partner organisations (University of Birmingham, Centre Léon Bérard, Grupo Español de Investigación en Sarcomas, Our Lady's Children's Hospital, European Organisation for Research and Treatment of Cancer (EORTC-1402-STBSG) who supported the trial within their institution.

Funding

This project has received funding from the European Union's Seventh Framework Programme for research, technological development, and demonstration under grant agreement n°602856. The National Coordinating Centre in France, Centre Léon Bérard, receives additional funding from SFCE and Ligue contre le cancer. The Coordinating Sponsor, United Kingdom is funded by Cancer Research UK (grant award reference C5952/A14745). Funding allowed set up of the study in each country, sponsorship, data collection and analysis.

References

1. de Alava E, Ewing sarcoma, in World Health Organization Classification of Tumours; Pathology and Genetics of Tumours of Soft Tissue and Bone 2013 *IARC*; 305-309.
2. Womer R.B, West DC, Krailo MD et al. Randomized controlled trial of interval-compressed chemotherapy for the treatment of localized Ewing sarcoma: a report from the Children's Oncology Group. *J Clin Oncol* 2012;**30**:4148-54.
3. Le Deley M.C, Paulussen M, Lewis I et al. Cyclophosphamide compared with ifosfamide in consolidation treatment of standard-risk Ewing sarcoma: results of the randomized noninferiority Euro-EWING99-R1 trial. *J Clin Oncol* 2014; **32**: 2440-8.
4. Ladenstein R., Potschager U, Le Deley MC et al. Primary disseminated multifocal Ewing sarcoma: results of the Euro-EWING 99 trial. *J Clin Oncol* 2010; **28**: 3284-91.
5. Luksch R., Tienghi A, Sundby Hall K et al. Primary metastatic Ewing's family tumors: results of the Italian Sarcoma Group and Scandinavian Sarcoma Group ISG/SSG IV Study including myeloablative chemotherapy and total-lung irradiation. *Ann Oncol* 2012; **23**: 2970-2976.
6. Dirksen U, Brennan B, Le Deley MC et al. Efficacy of busulfan-melphalan high dose chemotherapy consolidation (BuMel) compared to conventional chemotherapy combined with lung irradiation in ewing sarcoma (ES) with primary lung metastases: Results of EURO-EWING 99-R2pulm randomized trial (EE99R2pul). *Journal of Clinical Oncology* 2016; **34**: 11001-11001.
7. Paulussen M, Ahrens S, Craft AW et al. Ewing's tumors with primary lung metastases: survival analysis of 114 (European Intergroup) Cooperative Ewing's Sarcoma Studies patients. *J Clin Oncol* 1998; **16**: 3044-52.
8. Tanguturi SK, George S, Marcus KJ et al. Whole Lung Irradiation in Adults with Metastatic Ewing Sarcoma: Practice Patterns and Implications for Treatment. *Sarcoma* 2015; **2015**: 591698.
9. Casey DL, Alektiar KM, Gerber NK et al., Whole lung irradiation for adults with pulmonary metastases from Ewing sarcoma. *Int J Radiat Oncol Biol Phys* 2014; **89**: 1069-1075.
10. Bölling T, Schuck A, Paulussen M et al. Whole lung irradiation in patients with exclusively pulmonary metastases of Ewing tumors. Toxicity analysis and treatment results of the EICESS-92 trial. *Strahlenther Onkol* 2008; **184**: 193-7.

11. Juergens C.,Weston C, Lewis I et al. Safety assessment of intensive induction with vincristine, ifosfamide, doxorubicin, and etoposide (VIDE) in the treatment of Ewing tumors in the EURO-E.W.I.N.G. 99 clinical trial. *Pediatr Blood Cancer*,2006; **47**: 22-9.
12. Anderton J, Moroz V, Marec-Berard P et al. International randomised controlled trial for the treatment of newly diagnosed EWING sarcoma family of tumours - EURO EWING 2012 Protocol. *Trials* 2020; **21**: 96.
13. TSIATIS A.A.. The asymptotic joint distribution of the efficient scores test for the proportional hazards model calculated over time. *Biometrika* 1981; **68**: 311-315.
14. Norton L. Evolving concepts in the systemic drug therapy of breast cancer. *Semin Oncol* 1997; **24**: S10-3-s10-10.
15. Cancer Prevalence UK Data, in Macmillan Cancer Support and National Cancer Registration and Analysis Service 2015; *NCRAS*: London.
16. Sposto R. and D.O. Stram. A strategic view of randomized trial design in low-incidence paediatric cancer. *Stat Med* 1999; **18**: 1183-97.
17. Shi, H. and G. Yin. Reconnecting p-Value and Posterior Probability Under One- and Two-Sided Tests. *The American Statistician* 2021; **75**: 265-275.
18. Whelan J, Le Deley M-C, Dirksen U, et al. High-Dose Chemotherapy and Blood Autologous Stem-Cell Rescue Compared With Standard Chemotherapy in Localized High-Risk Ewing Sarcoma: Results of Euro-E.W.I.N.G.99 and Ewing-2008. *J Clin Oncol* 2018; **36**: 3110-19.
19. Attia S, Bolejack V, Ganjoo KN et al. A phase II trial of regorafenib (REGO) in patients (pts) with advanced Ewing sarcoma and related tumors (EWS) of soft tissue and bone: SARC024 trial results. *J Clin Oncol* 2017; **35**: 11005-11005.
20. Italiano A, Mir O, Mathoulin-Pelisser S et al. Cabozantinib in patients with advanced Ewing sarcoma or osteosarcoma (CABONE): a multicentre, single-arm, phase 2 trial. *Lancet Oncol* 2020; **21**: 446-455.
21. Duffaud F, Blay J-Y, Mir O et al. Results of randomized, placebo (PL)-controlled phase II study evaluating efficacy and safety of regorafenib (REG) in patients (pts) with metastatic osteosarcoma (metOS), on behalf of the French Sarcoma Group (FSG) and Unicancer. *J Clin Oncol* 2018; **36**: 11504-11504.
22. Chen, Y.-L, Weiss AR, Scharschmidt T et al. Results of the dose-finding phase of ARST 1321 from the Children's Oncology Group and NRG Oncology: Neoadjuvant chemoradiation or radiation therapy +/- pazopanib in non-rhabdomyosarcoma soft tissue sarcomas. *J Clin Oncol* 2019; **37**: 11070-11070.

481