

Capecitabine in combination with bendamustine in pretreated women with HER2-negative metastatic breast cancer: results of a phase II trial (AGMT MBC-6)

Gabriel Rinnerthaler*, Simon Peter Gampenrieder* , Andreas Petzer, Michael Hubalek, Edgar Petru, Margit Sandholzer, Johannes Anedel, Marija Balic, Thomas Melchardt, Cornelia Hauser-Kronberger, Clemens A. Schmitt, Hanno Ulmer and Richard Greil

Abstract

Background: Bendamustine, a medication approved for the treatment of indolent non-Hodgkin lymphoma, has already shown anticancer activity in metastatic breast cancer (MBC). Here, we present the results of a phase II trial of bendamustine in combination with capecitabine in pretreated patients with MBC.

Patients and methods: AGMT MBC-6 is a multicentre, open-label, single-arm phase II study in HER2-negative MBC. All patients were pre-treated with anthracyclines and/or taxans and had measurable disease. Patients received per os 1000 mg/m² capecitabine twice daily on days 1 to 14 in combination with 80 mg/m² bendamustine intravenously on days 1 and 8 of a 3-week cycle for a maximum of eight cycles, followed by a capecitabine maintenance therapy. The primary endpoint was overall response rate (ORR).

Results: From September 2013 to May 2015, 40 patients were recruited in eight Austrian centres. The median age was 60 years (range 29–77). Twenty-five per cent of patients had triple-negative breast cancer (TNBC) and 93% showed visceral involvement. With 17 partial and one complete remission, ORR was 46%. Median progression-free survival (PFS) was 7.5 months [95% confidence interval (CI) 6.1–10.7]. The most common non-haematological adverse events (AEs) of grade 3 were hand-foot syndrome (13%), fatigue (10%), nausea (8%), and dyspnoea (8%). One grade 4 non-haematological AE (hepatic failure) and three grade 4 haematological AEs (neutropenia) were observed. One patient died of restrictive cardiomyopathy, in which a relationship to capecitabine cannot be excluded, but seems unlikely.

Conclusion: The combination of capecitabine and bendamustine shows promising efficacy and moderate toxicity. Further evaluation of this drug combination is warranted.

The clinical trial AGMT MBC-6 was registered at ClinicalTrials.gov, (<https://clinicaltrials.gov/>; identifier: NCT01891227).

Keywords: advanced breast cancer, chemotherapy, combination therapy

Received: 29 March 2021; revised manuscript accepted: 9 August 2021.

Introduction

By the introduction of novel endocrine agents and targeted drugs, substantial progress has been made especially in hormone receptor (HR)-positive and

human epidermal growth factor receptor 2 (HER2)-positive metastatic breast cancer (MBC). Recently, the approval of immunotherapy for triple-negative MBC has aroused considerable attention.¹ However,

Ther Adv Med Oncol

2021, Vol. 13: 1–10

DOI: 10.1177/
17588359211042301

© The Author(s), 2021.
Article reuse guidelines:
[sagepub.com/journals-](https://sagepub.com/journals-permissions)
permissions

Correspondence to:

Richard Greil
IIIrd Medical Department
with Hematology and
Medical Oncology,
Hemostaseology,
Rheumatology and
Infectious Diseases,
Oncologic Center,
Paracelsus Medical
University Salzburg,
Müllner Hauptstraße 48,
Salzburg 5020, Austria

Salzburg Cancer Research
Institute with Laboratory
of Immunological and
Molecular Cancer
Research and Center
for Clinical Cancer and
Immunology Trials,
Salzburg, Austria

Cancer Cluster Salzburg,
Salzburg, Austria
r.greil@salk.at

Gabriel Rinnerthaler
Simon Peter
Gampenrieder

IIIrd Medical Department
with Hematology and
Medical Oncology,
Hemostaseology,
Rheumatology and
Infectious Diseases,
Oncologic Center,
Paracelsus Medical
University Salzburg,
Salzburg, Austria

Salzburg Cancer Research
Institute with Laboratory
of Immunological and
Molecular Cancer
Research and Center
for Clinical Cancer and
Immunology Trials,
Salzburg, Austria

Cancer Cluster Salzburg,
Salzburg, Austria

Andreas Petzer
Internal Department I for
Medical Oncology and
Hematology, Barmherzige
Schwestern Hospital/Linz,
Linz, Austria

Michael Hubalek
Department of Obstetrics
and Gynaecology,
Innsbruck Medical
University, Innsbruck,
Austria



Edgar Petru

Department of Obstetrics and Gynaecology, Medical University Graz, Graz, Austria

Margit Sandholzer

Department of Oncology, Hematology and Gastroenterology, Infectiology, Academic Teaching Hospital Feldkirch, Austria

Johannes Andel

Department of Internal Medicine II, Pyhrn-Eisenwurzen Klinikum Steyr, Steyr, Austria

Marija Balic

Division of Oncology, Department of Internal Medicine, Medical University Graz, Graz, Austria

Thomas Melchardt

IIIrd Medical Department with Hematology and Medical Oncology, Hemostaseology, Rheumatology and Infectious Diseases, Oncologic Center, Paracelsus Medical University Salzburg, Salzburg, Austria

Salzburg Cancer Research Institute with Laboratory of Immunological and Molecular Cancer Research and Center for Clinical Cancer and Immunology Trials, Salzburg, Austria

Cornelia Hauser-

Kronberger

Department of Pathology, Paracelsus Medical University Salzburg, Salzburg, Austria

Clemens A. Schmitt

Department of Internal Medicine 3 – Hematology and Oncology, Kepler University Hospital, Johannes Kepler University, Linz, Austria

Hanno Ulmer

Department of Medical Statistics and Informatics, Medical University Innsbruck, Innsbruck, Austria

*These authors contributed equally to this work.

chemotherapy remains a mainstay of MBC treatment, as several new agents are combined with chemotherapy and resistance might either exist primarily or develop during therapy.

Anthracycline or taxane-based chemotherapy regimens are the preferred agents in the first-line chemotherapy setting in HER2-negative MBC patients.² In second line, or in case of early relapse after adjuvant anthracycline and/or taxane pre-treatment, capecitabine is well established.² Bendamustine is also a well-tolerated agent that has already shown anticancer activity in breast cancer.³

Bendamustine is a hybrid cytotoxic drug because of its structural similarity to alkylating agents and purine analogues. Like other alkylating agents, bendamustine causes DNA breaks by DNA cross-linking. It is currently approved by the US Food and Drug Administration (FDA) as well as the European Medicine Agency (EMA) for the treatment of chronic lymphocytic leukaemia (CLL) and indolent B-cell non-Hodgkin's lymphoma (NHL). The evidence of bendamustine in the treatment of MBC has previously been reviewed by Pirvulescu *et al.*³ published in *Breast Care* in 2008. As monotherapy for pre-treated patients (one pilot trial⁴ and three phase II trials),^{5–7} bendamustine revealed an overall response rate (ORR) ranging from 20% up to 48%, accompanied by a moderate toxicity profile. In a first-line phase III trial in MBC, a combination of bendamustine, methotrexate and 5-fluorouracil (5-FU) (BMF) was compared to cyclophosphamide, methotrexate and 5-FU (CMF).⁸ ORRs of 44% (BMF) and 40% (CMF) were similar in both groups, but myelotoxicities were more frequent in the BMF group (leukopenia 62.7 *versus* 40%). A significantly longer time to progression (TTP), 8.2 *versus* 6.7 months, was seen in the BMF group.

The fluoropyrimidine 5-FU has been used for over 40 years as monotherapy or in combination with other cytostatic drugs in breast cancer treatment. The optimal administration mode of 5-FU for the treatment of MBC has not been defined yet. As reviewed by Cameron *et al.*,⁹ continuous 5-FU in combination with leucovorin seems to be more effective than 5-FU bolus administration, but prospective data on that topic are missing. Based on promising efficacy rates of continuous 5-FU in numerous tumour entities but with the inconvenience of intravenous access devices, several oral formulations of 5-FU have been developed.¹⁰

Capecitabine is an orally administered prodrug of 5-FU with confirmed efficacy as monotherapy in MBC in three phase III trials.^{11–13} In contrast to colorectal cancer in which capecitabine has been shown to be as effective as continuous 5-FU, a head-to-head comparison in MBC is missing. One of the enzymes involved in the conversion of capecitabine to 5-FU is thymidine phosphorylase (TP), which plays an important role in pyrimidine metabolism.^{14,15} TP expression has been linked to capecitabine sensitivity.¹⁶

Based on these findings, we investigated the combination of bendamustine plus capecitabine in pre-treated MBC patients within the MBC-6 trial of the Austrian Group Medical Tumour Therapy (AGMT).

Patients and methods

Study design and participants

The AGMT MBC-6 trial is a non-randomised, multicentre, open-label, single-arm phase II study in pre-treated patients with HER2-negative advanced breast cancer. Eight centres in Austria recruited 40 patients following a two-stage design. Efficacy and safety of bendamustine and capecitabine was evaluated after recruitment of the first 20 patients. On favourable results, a further 20 patients were recruited to reach the target population of 40 evaluable patients.

HER2 negativity was defined as immunohistochemically (IHC) 0–1, or IHC 2+ and HER2 gene amplification measured by *in-situ* hybridisation (ISH) ratio of <2.0 between HER2 gene copy number and centromere of chromosome 17 or a copy number of 4 or less. Hormone receptor positivity was defined as positive staining for estrogen receptor (IHC ≥1%) and/or progesterone receptor (IHC ≥1%). Receptor status assessment was performed by local pathology, without central confirmation. If available, assessment had to be performed from biopsies of metastatic sites, otherwise tissue from primary tumour was analysed.

Patient selection

Patients with metastatic histologically confirmed HER2-negative adenocarcinoma of the breast with documented disease progression after an anthracycline and/or taxane treatment (neoadjuvant, adjuvant or palliative) with at least one measurable lesion according to response

evaluation criteria in solid tumours (RECIST) version 1.1 were eligible for participation (for detailed inclusion and exclusion criteria see Supplemental Table 1).

Dosage selection

Bendamustine has been investigated in different dosages and schedules: in monotherapy regimes bendamustine 120 mg/m² or 150 mg/m² was given on days 1 and 2 of a 3 or 4-week cycle.⁷ In another phase II trial, bendamustine monotherapy was evaluated in a weekly schedule with 60 mg/m² on days 1, 8 and 15, followed by a week of rest, showing the same efficacy but less toxicity.⁴ Furthermore, bendamustine was investigated in combination with methotrexate plus 5-FU (BMF *versus* CMF), anthracyclines,^{17,18} vincristine,¹⁷ or paclitaxel.¹⁹ In the latter trial, bendamustine 70 mg/m² was given in combination with paclitaxel 90 mg/m², both administered on days 1, 8 and 15 of a 4-week cycle, showing a remarkable efficacy. In accordance with that dose intensity, we selected bendamustine 80 mg/m² on days 1 and 8 of a 3-week cycle to be investigated in the MBC-6 trial.

Capecitabine is taken orally twice daily (BID) on days 1 to 14 of a 3-week cycle. The recommended start dosages are 1250 mg/m² BID as a single agent.^{11–13} In pretreated MBC patients capecitabine has been investigated with dosages between 825 mg/m² BID and 1250 mg/m² BID in combination with other cytotoxic drugs.²⁰ It has been demonstrated that the capecitabine dosage can be reduced, either in mono or in combination therapy, to minimise adverse events without compromising efficacy in terms of TTP or overall survival (OS). Results of retrospective analyses support a starting dose of capecitabine 1000 mg/m² BID.²¹ Therefore, in our trial capecitabine 1000 mg/m² was administered for 2 weeks of a 3-week cycle.

Study treatment

Patients received per os 1000 mg/m² capecitabine BID on days 1 to 14 in combination with 80 mg/m² bendamustine intravenously on days 1 and 8 of a 3-week cycle. Capecitabine in combination with bendamustine was administered for a maximum of eight cycles. Afterwards, capecitabine maintenance therapy was continued until disease progression or unacceptable toxic effects.

Endpoints

The primary endpoint of the trial was to determine the efficacy of a capecitabine plus bendamustine combination regimen represented by the ORR [complete response (CR) or partial response (PR)]. ORR was determined by radiological evaluation according to RECIST version 1.1.²² Secondary endpoints included progression-free survival (PFS); time from start of therapy until progression or death from any cause, including follow-up data), clinical benefit rate [CBR; CR, PR or stable disease (SD) for at least 24 weeks], safety, and quality of life (QoL). Adverse events (AEs) were reported according to the common terminology criteria for adverse events (CTCAE) version 4.03.²³ After discontinuation from study treatment, AE assessment was stopped for the corresponding patient. QoL was assessed using the validated European Organization for the Research and Treatment of Cancer (EORTC) QLQ-C30 and EORTC QLQ-BR23 questionnaires.^{24,25} Subgroup analyses of patients with triple-negative and HR-positive tumours were pre-planned.

Response was assessed by computed tomography (CT) or magnetic resonance imaging (MRI) every 9 weeks throughout therapy. A CR or PR had to be certified by a confirmatory scan no less than 4 weeks following the initial assessment. A central review of CT or MRI scans was established for participating sites which could not provide assessments according to RECIST 1.1. Treatment decisions were made according to local CT/MRI reports.

Expression levels of thymidine phosphorylase

Immunohistochemical thymidylate phosphatase expression analysis was performed by an experienced breast cancer pathologist (CHK) on archival formalin-fixed paraffin-embedded (FFPE) breast cancer tissue using the monoclonal antibody TP (clone P-GF.44C; Thermo Fisher) at a final dilution of 1/100. The immunohistochemical staining was automatically performed on a Ventana Benchmark Ultra platform. Scoring was performed according to the method previously described by Tsuda *et al.*²⁶ TP staining intensities of 2+ or 3+ were defined as positive.

Statistical methods

A single-arm two-stage Green–Dahlberg design with a total of 40 patients, testing a null proportion

of 0.2 *versus* an alternative proportion of 0.4 with $\alpha=0.05$ and $1-\beta=0.85$, was used to allow for early termination in case of unsatisfactory efficacy results. In the first stage of the study, 20 subjects were accrued and treated. The study was pre-defined to be stopped if there were fewer than four subjects with a complete response or a partial response. If there were at least four responses, an additional 20 subjects were planned be enrolled for a maximum of 40 subjects. The regimen was pre-defined as effective if 13 or more responses in 40 patients ($\text{ORR} \geq 32.5\%$) were observed at the end of the trial. All analyses were based on the safety population, defined as subjects who received at least one dose of the study medication and had at least one post-treatment safety assessment available. Statistical analysis included descriptive statistics together with Kaplan–Meier survival estimates. Calculations and graphs were performed with MedCalc 19.1 and SPSS 24.

Data availability

This academic clinical trial was sponsored, designed, and monitored by the AGMT, which had exclusive rights to the data and their handling. Mundipharma supported the trial financially, but had no input into the statistical analysis, data interpretation, or writing of the report. The corresponding authors RG, GR and SG had full access to all the study data.

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics

The study was conducted under the principles of the Declaration of Helsinki and International Conference on Harmonisation E6 Good Clinical Practice guidelines. The trial was approved by the ethics committee of the state of Salzburg on 13 May 2013 (protocol number: 415-E/2067/16-2016), by the ethics committee of each participating centre, and by the Austrian regulatory authority. (ClinicalTrials.gov-identifier NCT01891227, EudraCT-number 2012-005593-64.) All patients gave their written informed consent.

Results

From September 2013 to May 2015, 40 patients with pre-treated HER2-negative MBC were enrolled. Twenty-seven patients were treated until disease progression, 13 patients discontinued prematurely for reasons other than disease progression (Figure 1). In March 2018, the last patient discontinued study treatment. No continuous follow-up was planned in the study protocol, but a final assessment of the survival status was performed in February 2020 for the preplanned exploratory overall survival (OS) analysis.

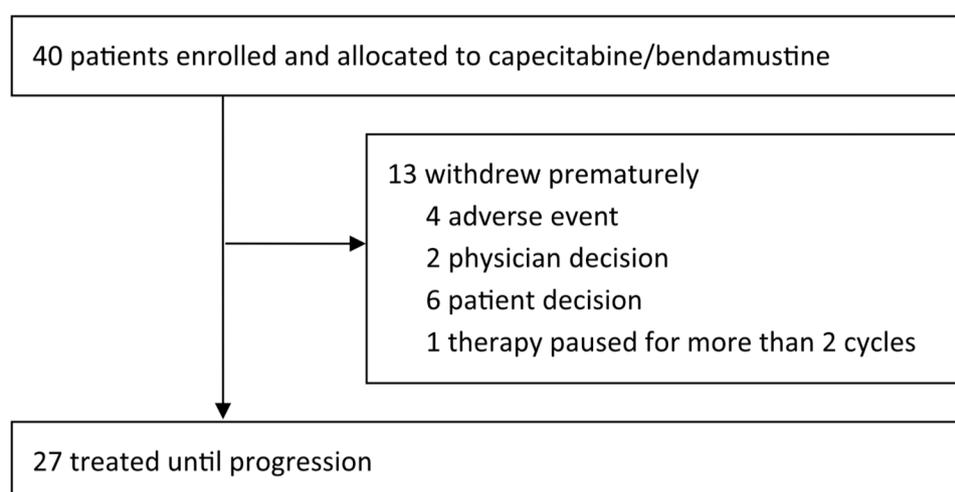


Figure 1. CONSORT diagram.

Response was assessed by computed tomography (CT) or magnetic resonance imaging (MRI) every 9 weeks throughout therapy. A central review of CT or MRI scans was established for participating sites which could not provide assessments according to response evaluation criteria in solid tumours (RECIST) 1.1. Treatment decisions were made according to local CT/MRI reports.

Baseline characteristics are outlined in Table 1.

The median number of treatment cycles was eight (range 1–57), and eight patients received capecitabine monotherapy after completion of the combination treatment period (Supplemental Table 2).

Adverse events

Eighteen patients (45%) experienced at least one drug-related non-haematological AE grade ≥ 3 or a haematological AE grade ≥ 4 . The most common non-haematological AEs grade ≥ 3 were hand-foot syndrome, fatigue, diarrhoea, and dyspnoea. The most common haematological AE grade 4 was leukopenia (Table 2 and Supplemental Tables 3 and 4). Alopecia was uncommon, with only two patients (5%) experiencing grade 1 hair loss.

One patient died as a result of restrictive cardiomyopathy, in which a relationship to capecitabine cannot be fully excluded, but seems unlikely.

Efficacy

With 17 confirmed PR and one confirmed CR, ORR was 45%; 47% (14/30) in HR-positive and 40% (4/10) in TNBC patients, respectively (Table 3). The CBR was 53% (21/40). Median PFS was 7.5 months [95% confidence interval (CI) 6.1–10.7] in the overall population, 8.4 months (95% CI 6.1–12.8) in HR-positive and 4.1 months (95% CI 1.4–8.9) in TNBC patients, respectively (Figure 2). In an unplanned subgroup analysis regarding TP expression, no difference between TP-positive and TP-negative patients was observed [hazard ratio 0.86, 95% CI 0.36 to 2.05; $p=0.73$; Figure 2(c), Supplemental Figure 1].

The median OS, an exploratory endpoint of this trial, was 19.2 months (95% CI 14.4–34.8; Supplemental Figure 2).

Quality of life

Thirty-two patients were included in the QoL analysis. Three patients were excluded due to missing QLQC30 measurements, and in five patients only a baseline assessment was available.

The median time to 10% deterioration of QLQC30 global health status was 4.6 months (95% CI

Table 1. Baseline characteristics.

Characteristic	Patients <i>n</i> (%), <i>N</i> =40
Median age	60 years (range 29–77)
Performance score (%)	
ECOG 0	30 (75)
ECOG 1	10 (25)
HR-positive	30 (75)
TNBC	10 (25)
Previous (neo-)adjuvant chemotherapy	26 (65)
Previous (neo-)adjuvant endocrine treatment in patients HR-positive disease; <i>n</i> =30	30 (100)
Pretreatment chemo-therapy lines for MBC (%)	
0	15 (37)
1	17 (43)
2	6 (15)
3	2 (5)
Visceral disease	37 (93)
ECOG, Eastern Cooperative Oncology Group; HR, hormone-receptor; TNBC, triple negative breast cancer.	

0.9–8.1). In patients with a clinical benefit (PR, CR, or SD ≥ 24 weeks), the time to 10% deterioration was 8.1 months (95% CI 1.4–14.7), compared to 4.4 months (95% CI 0–9.4) in patients without a clinical benefit (Supplemental Figure 3).

Linear mixed effects modelling was applied to evaluate whether the two variables (baseline *versus* week 9) and (clinical benefit yes/no) had a significant effect on the different QLQ. For physical function, there was a significant decline from baseline to week 9 ($p=0.027$). For dyspnoea, average values were higher in the clinical benefit group ($p=0.013$). Interestingly, for diarrhoea, significant improvements were observed in the clinical benefit group ($p=0.035$ and interaction week \times clinical benefit $p=0.03$). All other comparisons resulted in (non-significant) p -values >0.05 .

Discussion

To our knowledge, the AGMT MBC-6 trial is the only clinical trial investigating a capecitabine plus bendamustine combination treatment of breast

Table 2. Adverse events.

N=40	Number of patients with maximal grading				
	Non-haematological AEs	All grades (%)	Grade 2 (%)	Grade 3 (%)	Grade 4 (%)
Fatigue	29 (73)	13 (33)	4 (10)	-	-
Hand-foot syndrome*	23 (58)	6 (15)	5 (13)	-	-
Nausea	19 (48)	9 (23)	<5	-	-
Musculoskeletal pain*	15 (38)	4 (10)	<5	-	-
Diarrhoea*	14 (35)	6 (15)	3 (8)	-	-
Dyspnoea*	10 (25)	3 (8)	3 (8)	-	-
Abdominal pain*	8 (20)	5 (13)	-	-	-
Headache*	7 (18)	5 (13)	-	-	-
Upper respiratory tract infection*	7 (18)	<10	2 (5)	-	-
Constipation	6 (15)	5 (13)	-	-	-
Vomiting	6 (15)	<10	2 (5)	-	-
Pulmonary embolism*	4 (10)	<10	3 (8)	-	-
Device-related infection	2 (5)	-	2 (5)	-	-
Cardiomyopathy	1 (3)	-	-	-	1 (3)
Hepatic failure	1 (3)	-	-	1 (3)	-
Haematological AEs	All grades (%)	Grade 2 (%)	Grade 3 (%)	Grade 4 (%)	Grade 5
Leukopenia	17 (43)	10 (25)	4 (10)	2 (5)	-
Neutropenia	17 (43)	6 (15)	9 (23)	1 (3)	-
Anaemia	10 (25)	4 (10)	-	-	-
Lymphopenia	2 (5)	-	2 (5)	-	-

Adverse events (AEs) grade ≥ 2 and number of patients with maximum grading per event are listed. 'All grades' includes patients with maximum grade 1. AEs grade ≥ 2 with occurrence in $\geq 10\%$ of patients, grade 3 in $\geq 5\%$ of patients and all grade 4/5 AEs are shown.
*AE terms are summarised MedDRA preferred terms.

cancer patients. According to the prespecified threshold, the regimen was found to be effective seeing as 18 responses were observed in the study, exceeding the efficacy criterion of 13 responses or more in 40 patients. With an ORR of 45% and a median PFS of 7.5 months, this investigational treatment combination seems to be more effective than capecitabine monotherapy.

Five multicentre phase II trials evaluated capecitabine monotherapy in patients with advanced or MBC that were pre-treated with taxane and/or anthracycline. The reported ORRs lay between

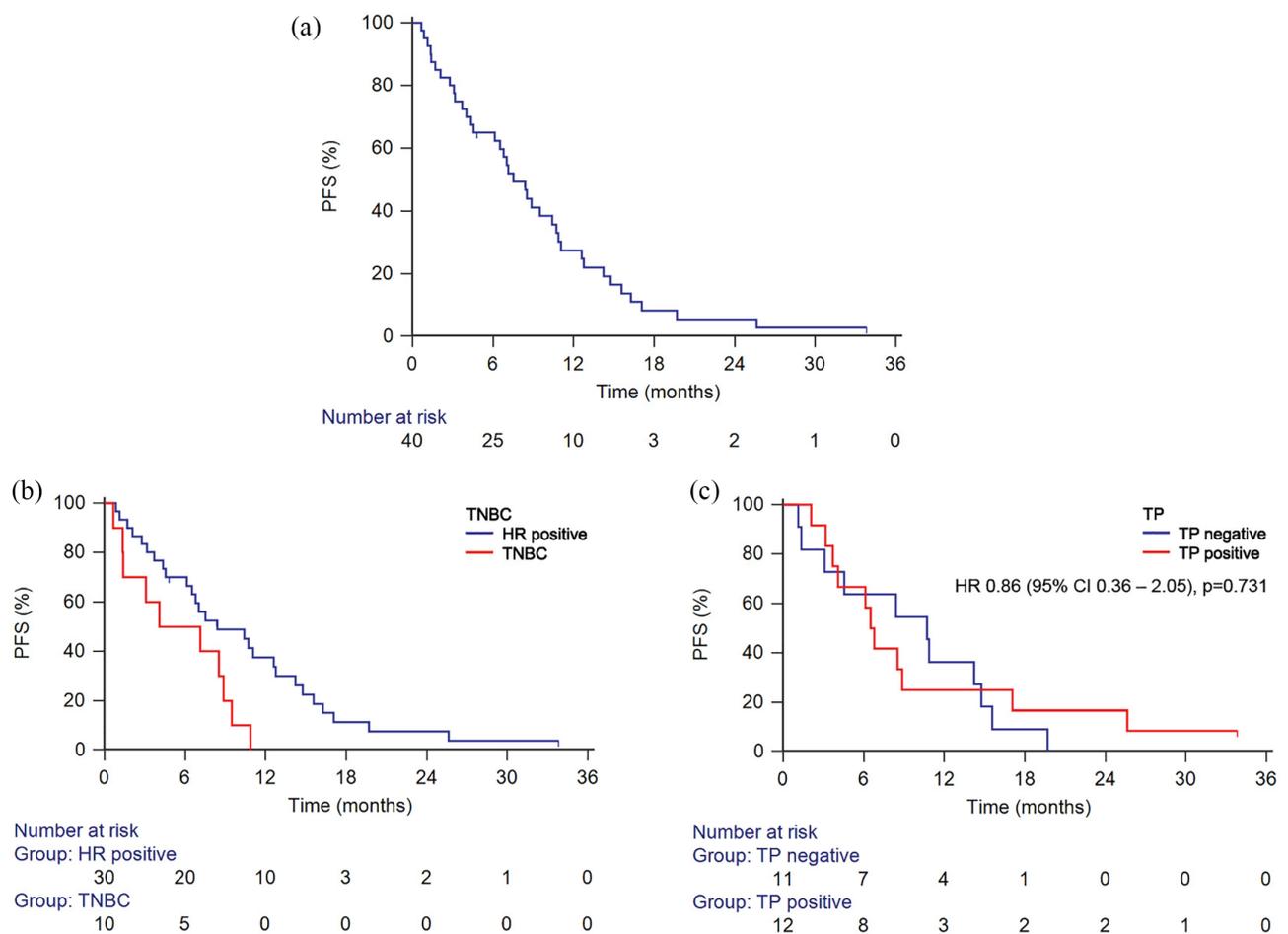
20% and 36%.²⁷⁻³¹ The median TTP was 3.0–8.1 months.²⁷⁻³¹ In three phase III trials in patients with MBC that were pre-treated with anthracycline and taxane, capecitabine monotherapy showed similar results to the phase II studies with ORRs from 9% to 29%.¹¹⁻¹³ TTP was 4.1 to 4.4 months.

For the treatment of MBC, the role of combination chemotherapy is still controversial. In a Cochrane Database systemic review, sequential treatment was beneficial in terms of PFS.³² In contrast, response rates, but also the rate of febrile

Table 3. Response rates in MBC patients following capecitabine and bendamustine combination therapy.

Best overall response	Overall, n (%), N= 40	TNBC, n (%), N= 10	HR-positive, n (%), N= 30
Complete response* (CR)	1 (3)	1 (10)	0 (0)
Partial response* (PR)	17 (43)	3 (30)	14 (47)
Stable disease (SD)	11 (28)	2 (20)	9 (30)
<24 Weeks**	8 (20)	2 (20)	6 (20)
≥24 Weeks	3 (8)	0 (0)	3 (10)
Progressive disease (PD)	8 (20)	3 (30)	5 (17)
Not evaluable (NE)	3 (7.5)	1 (10)	2 (6)
Overall response rate (ORR)	18 (45)	4 (40)	14 (47)
Clinical benefit rate (CBR)	21 (53)	4 (40)	17 (57)

*Responses had to be confirmed after ≥4 weeks.
**Including one not confirmed PR.

**Figure 2.** Progression free survival.

Progression free survival (a) in the overall population, (b) by receptor status, (c) and by thymidylate phosphatase expression in patients who received capecitabine and bendamustine combination therapy.

HR, hormone receptor; TNBC, triple negative breast cancer; TP, thymidine phosphatase.

neutropenia, were higher with combination regimens. No difference in OS was seen. Therefore, international guidelines recommend sequential treatment as the first option.² Combination chemotherapy regimens should be preserved for patients with ‘rapid clinical progression, life-threatening visceral metastases, or a need for rapid symptom and/or disease control’.² Within the MBC-6 trial, a moderate toxicity profile was observed, with no toxicity-induced worsening of the overall QoL. The median time to 10% deterioration of QLQC30 global health status was longer in patients with a clinical benefit compared to patients who did not benefit from treatment (8.1 *versus* 4.4 months).

A major advantage of this combination regimen is the low incidence of alopecia (grade 1 was observed in two patients =5%). Since chemotherapy-induced alopecia can be psychosocially devastating,³³ this regimen might be preferable to patients who are frightened by the idea of losing their hair. A further interesting aspect is the fact that both are available as generics, making it a cheap treatment option which could even be applied in low-income countries.

TP expression, a potential biomarker for capecitabine efficacy, had no effect on PFS in our trial. This could imply that the combination of bendamustine plus capecitabine overcomes the intrinsic resistance to the 5-FU pro-drug in case of missing or low expression of TP in the tumour.

In our opinion, further development of the bendamustine–capecitabine combination in a randomised phase III trial, for example in comparison with capecitabine monotherapy, would be justified. The generic availability of both drugs and the resulting lack of financial support from industry, however, make it very difficult for an academic study group to carry out such a large trial.

Conclusion

The combination of capecitabine and bendamustine shows promising efficacy and a moderate toxicity profile. Further evaluation of this drug combination is warranted.

Acknowledgements

The authors gratefully acknowledge the support from the AGMT office (particularly Daniela

Wolkersdorfer, Judith Schuster, and Alexandra Keuschnig) and all trial coordinators and study nurses at the contributing centres.

Authors' contributions

Gabriel Rinnerthaler: Conceptualisation, methodology, writing – original draft, project administration; **Simon Peter Gampenrieder:** Conceptualisation, methodology, writing – original draft; **Andreas Petzer:** Investigation, resources, writing – review and editing; **Michael Hubalek:** Investigation, writing – review and editing; **Edgar Petru:** Investigation, resources, writing – review and editing; **Margit Sandholzer:** Investigation, resources, writing – review and editing; **Johannes Anzel:** Investigation, resources, writing – review and editing; **Marija Balic:** Investigation, resources, writing – review and editing; **Thomas Melchardt:** Writing – review and editing; **Cornelia Hauser-Kronberger:** Formal analysis, writing – review and editing; **Clemens A Schmitt:** Resources, writing – review and editing; **Hanno Ulmer:** Data curation, formal analysis, visualisation, writing – review and editing; **Richard Greil:** Conceptualisation, methodology, writing – review and editing, supervision, funding acquisition.

Conflict of interest statement

Conflicts of interest with Mundipharma: Employment or leadership position: none; Consultant or advisory role: Andreas Petzer, Richard Greil; Fees for non-CME services received directly from commercial interest or their agents: none; Contracted research: Richard Greil; Ownership interest: none; Traveler grants: none.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This trial was supported by an unrestricted grant of Mundipharma. Mundipharma had no role in the study design, data collection, data analysis, data interpretation and writing the paper. The corresponding author (RG) had full access to all the study data.

ORCID iD

Simon Peter Gampenrieder  <https://orcid.org/0000-0002-3966-1071>

Supplemental material

Supplemental material for this article is available online.

References

- Corona SP, Sobhani N, Ianza A, *et al.* Advances in systemic therapy for metastatic breast cancer: future perspectives. *Med Oncol* 2017; 34: 119.
- Cardoso F, Senkus E, Costa A, *et al.* 4th ESO–ESMO international consensus guidelines for advanced breast cancer (ABC 4). *Ann Oncol* 2018; 29: 1634–1657.
- Pirvulescu C, von Minckwitz G and Loibl S. Bendamustine in metastatic breast cancer: an old drug in new design. *Breast Care* 2008; 3: 333–339.
- Jamitzky T and Lange O. Third-line chemotherapy with bendamustin for metastatic breast cancer – a prospective pilot study. *Eur J Cancer* 1996; 32: 47–47.
- Eichbaum MH, Schuetz F, Khbeis T, *et al.* Weekly administration of bendamustine as salvage therapy in metastatic breast cancer: final results of a phase II study. *Anticancer Drugs* 2007; 18: 963–968.
- Höffken K, Merkle K, Schönfelder M, *et al.* Bendamustine as salvage treatment in patients with advanced progressive breast cancer: a phase II study. *J Cancer Res Clin Oncol* 1998; 124: 627–632.
- Reichmann U, Bokemeyer C, Wallwiener D, *et al.* Salvage chemotherapy for metastatic breast cancer: results of a phase II study with bendamustine. *Ann Oncol* 2007; 18: 1981–1984.
- von Minckwitz G, Chernozemsky I, Sirakova L, *et al.* Bendamustine prolongs progression-free survival in metastatic breast cancer (MBC): a phase III prospective, randomized, multicenter trial of bendamustine hydrochloride, methotrexate and 5-fluorouracil (BMF) versus cyclophosphamide, methotrexate and 5-fluorouracil (CMF) as first-line treatment of MBC. *Anticancer Drugs* 2005; 16: 871–877.
- Cameron DA, Gabra H and Leonard RC. Continuous 5-fluorouracil in the treatment of breast cancer. *Br J Cancer* 1994; 70: 120–124.
- Bunnell CA and Winer EP. Oral 5-FU analogues in the treatment of breast cancer. *Oncology (Williston Park)* 1998; 12: 39–43.
- Lechleider RJ, Kaminskas E, Jiang X, *et al.* Ixabepilone in combination with capecitabine and as monotherapy for treatment of advanced breast cancer refractory to previous chemotherapies. *Clin Cancer Res* 2008; 14: 4378–4384.
- Sparano JA, Vrdoljak E, Rixe O, *et al.* Randomized phase III trial of ixabepilone plus capecitabine versus capecitabine in patients with metastatic breast cancer previously treated with an anthracycline and a taxane. *J Clin Oncol* 2010; 28: 3256–3263.
- Miller KD, Chap LI, Holmes FA, *et al.* Randomized phase III trial of capecitabine compared with bevacizumab plus capecitabine in patients with previously treated metastatic breast cancer. *J Clin Oncol* 2005; 23: 792–799.
- Friedkin M and Roberts D. The enzymatic synthesis of nucleosides. I. Thymidine phosphorylase in mammalian tissue. *J Biol Chem* 1954; 207: 245–256.
- Toi M, Atiqur Rahman M, Bando H, *et al.* Thymidine phosphorylase (platelet-derived endothelial-cell growth factor) in cancer biology and treatment. *Lancet Oncol* 2005; 6: 158–166.
- Andreetta C, Puppin C, Minisini A, *et al.* Thymidine phosphorylase expression and benefit from capecitabine in patients with advanced breast cancer. *Ann Oncol* 2009; 20: 265–271.
- Brockmann B, Kirchoff I, Geschke E, *et al.* [Therapeutic results and toxic side effects of the combination cytosatan, adriamycin and vincristine as second-line therapy of metastatic breast cancer]. *Arch Geschwulstforsch* 1989; 59: 341–346.
- Schmidt P, Heck HK and Preiss J. Bendamustine/mitoxantrone in the treatment of advanced breast cancer. *ECCO* 1999; 35: S324.
- Loibl S, Doering G, Müller L, *et al.* Multicenter phase II study with weekly bendamustine and paclitaxel as first- or later-line therapy in patients with metastatic breast cancer: RiTa II trial. *Breast Care* 2011; 6: 457–461.
- Alsalmoumi L, Shawagfeh S, Abdi A, *et al.* Efficacy and safety of capecitabine alone or in combination in advanced metastatic breast cancer patients previously treated with anthracycline and taxane: a systematic review and meta-analysis. *Oncol Res Treat* 2020; 43: 694–702.
- Bajetta E, Procopio G, Celio L, *et al.* Safety and efficacy of two different doses of capecitabine in the treatment of advanced breast cancer in older women. *J Clin Oncol* 2005; 23: 2155–2161.
- Eisenhauer EA, Therasse P, Bogaerts J, *et al.* New response evaluation criteria in solid tumours: revised RECIST guideline (version 1.1). *Eur J Cancer* 2009; 45: 228–247.

23. NCI. *CTCAE version 4.03*. <http://evs.nci.nih.gov/ftp1/CTCAE/About.html> (accessed 16 May 2017).
24. Fayers P, Aaronson N and Bjordal K. *EORTC QLQ-C30 scoring manual*, 3rd ed. Brussels: European Organisation for Research and Treatment of Cancer, 2001.
25. Sprangers MA, Groenvold M, Arraras JJ, *et al*. The European Organization for Research and Treatment of Cancer breast cancer-specific quality-of-life questionnaire module: first results from a three-country field study. *J Clin Oncol* 1996; 14: 2756–2768.
26. Tsuda H, Akiyama F, Kurosumi M, *et al*. Reproducible immunohistochemical criteria based on multiple raters' judgments for expression of thymidine phosphorylase in breast cancer tissue. *Breast Cancer Res Treat* 2004; 86: 215–223.
27. Blum JL, Jones SE, Buzdar AU, *et al*. Multicenter phase II study of capecitabine in paclitaxel-refractory metastatic breast cancer. *J Clin Oncol* 1999; 17: 485–485.
28. Blum JL, Dieras V, Lo Russo PM, *et al*. Multicenter, phase II study of capecitabine in taxane-pretreated metastatic breast carcinoma patients. *Cancer* 2001; 92: 1759–1768.
29. Talbot DC, Moiseyenko V, Van Belle S, *et al*. Randomised, phase II trial comparing oral capecitabine (Xeloda) with paclitaxel in patients with metastatic/advanced breast cancer pretreated with anthracyclines. *Br J Cancer* 2002; 86: 1367–1372.
30. Reichardt P, Von Minckwitz G, Thuss-Patience PC, *et al*. Multicenter phase II study of oral capecitabine (Xeloda) in patients with metastatic breast cancer relapsing after treatment with a taxane-containing therapy. *Ann Oncol* 2003; 14: 1227–1233.
31. Fumoleau P, Largillier R, Clippe C, *et al*. Multicentre, phase II study evaluating capecitabine monotherapy in patients with anthracycline- and taxane-pretreated metastatic breast cancer. *Eur J Cancer* 2004; 40: 536–542.
32. Dear RF, McGeechan K, Jenkins MC, *et al*. Combination versus sequential single agent chemotherapy for metastatic breast cancer. *Cochrane Database Syst Rev* 2013; 2013: CD008792.
33. Choi EK, Kim IR, Chang O, *et al*. Impact of chemotherapy-induced alopecia distress on body image, psychosocial well-being, and depression in breast cancer patients. *Psychooncology* 2014; 23: 1103–1110.