

Update Breast Cancer 2020 Part 4 – Advanced Breast Cancer

Update Mammakarzinom 2020 Teil 4 – fortgeschrittenes Mammakarzinom



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ABSTRACT

Substances with good effectiveness that intervene in specific signalling pathways have been used increasingly in recent years in the treatment of patients with advanced breast cancer, and new therapies and approaches have now been added, which actually relate to quite specific changes, such as the treatment of patients with HR+/HER2 tumours with a *PIK3CA*

mutation. The treatment of patients with a *BRCA1* or *BRCA2* mutation has also been improved by the introduction of PARP inhibitors. Attempts are now being made increasingly to extend treatment indications based on molecular patterns, to identify other patients who could benefit from a treatment and to integrate the newly established treatment methods in existing therapy sequences. This review articles summarises the latest information in this connection.

ZUSAMMENFASSUNG

Nachdem in den letzten Jahren bei der Behandlung von Patientinnen mit fortgeschrittenem Mammakarzinom zunehmend Substanzen mit einer guten Effektivität zum Einsatz

kommen, welche spezifische Signalwege angreifen, sind nun neue Therapien und Ansätze hinzugekommen, die sich tatsächlich auf ganz spezifische Veränderungen beziehen wie die Behandlung von Patientinnen mit HR+/HER2- Tumoren mit einer *PIK3CA*-Mutation. Ebenso ist die Behandlung von Patientinnen mit einer *BRCA1*- oder *BRCA2*-Mutation durch die Einführung der PARP-Inhibitoren verbessert worden. Nun wird zunehmend versucht, Therapieindikationen aufgrund molekularer Muster auszudehnen und weitere Patientinnen zu identifizieren, die von einer Therapie profitieren könnten, und die neu etablierten Therapiemethoden in bestehende Therapiesequenzen einzubinden. Diese Übersichtsarbeit fasst die neuesten Erkenntnisse in diesem Zusammenhang zusammen.

Introduction

In the last few years, a few targeted therapies have been developed for patients with metastatic breast cancer and subsequently introduced into clinical practice [1–4]. Some of these therapies, such as the CDK4/6 inhibitors or pertuzumab and T-DM1, had already been developed for subgroups of patients that could be identified by immunohistochemistry. Other drugs, such as the PI3K inhibitor alpelisib or the PARP inhibitors, require testing for genetic changes in the tumour or in the germline in addition for the indication. This focused approach to ensure that patients are selected for whom effectiveness will be particularly high and that patients who do not have this characteristic are spared the side effects is the optimal procedure when introducing new drugs. This review article summarises the latest developments in advanced breast cancer and in the area of biomarkers based on the latest presentations (e.g., ASCO, AACR 2020) and publications.

Treatment of Patients with Advanced HER2-Positive Breast Cancer

Effective treatment of cerebral metastases

The treatment of patients with HER2-positive advanced breast cancer is characterised by the use of targeted anti-HER2 drugs [5]. Trastuzumab, pertuzumab and T-DM1 are very effective anti-HER2 drugs used in the treatment of HER2-positive breast cancer. The tyrosine kinase inhibitors lapatinib and neratinib also have their place. Just in the past year, the tyrosine kinase inhibitor tucatinib was presented through the prospective randomised phase III study HER2CLIMB [6]. In patients with advanced breast cancer, who all had pretreatment with trastuzumab, pertuzumab and T-DM1, a comparison between therapy with trastuzumab + capecitabine and tucatinib + trastuzumab + capecitabine showed that progression-free survival and overall survival were improved. A new analysis has now been presented, which focussed on the 291 patients who already had cerebral metastases at the start of the study. In these patients, a clinically significant advantage was seen for the triple combination. In patients who were treated with tucatinib + trastuzumab + capecitabine, the median CNS-related

progression-free survival was prolonged from 4.2 to 9.9 months. The hazard ratio was 0.32 (95% CI: 0.22–0.48) [7]. The median overall survival was prolonged from 12.0 to 18.1 months. The hazard ratio was 0.58 (79% CI: 0.40–0.85). Similar differences between the treatment arms were also seen in groups of patients who had either active or stable brain metastases. It can be concluded that the addition of tucatinib to treatment with capecitabine and trastuzumab is also associated with a marked improvement of the clinical treatment situation in patients with cerebral metastases.

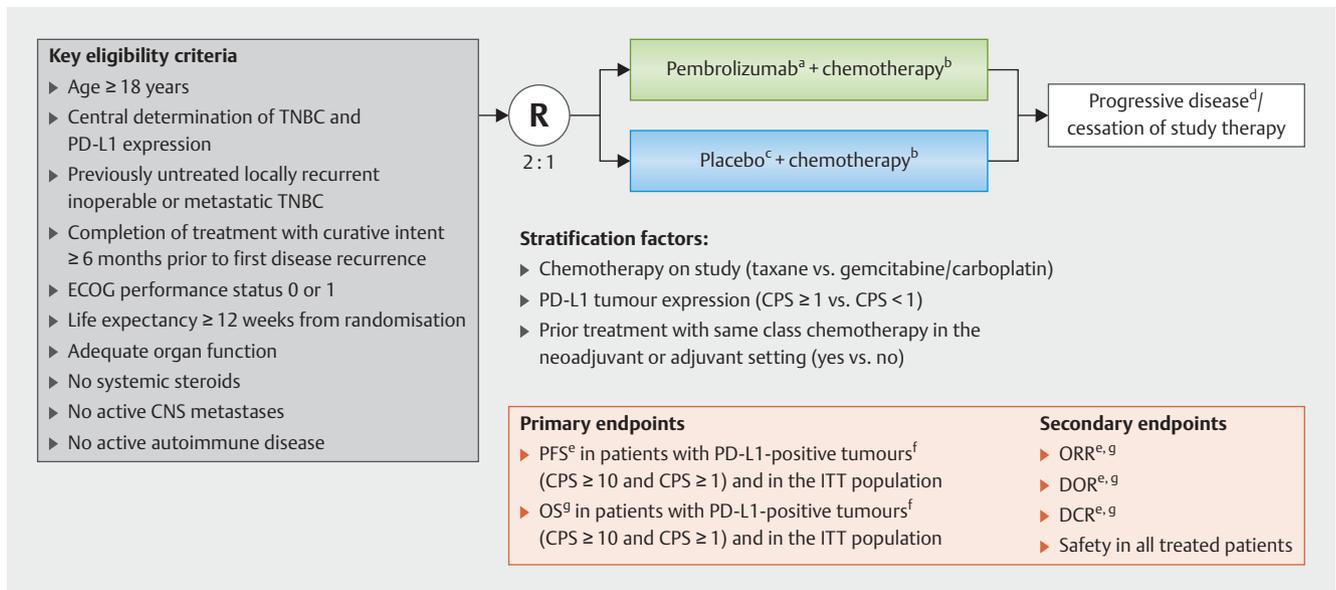
High activity in the area of treatment development for HER2-positive patients

Other anti-HER2 drugs, which are currently being developed for clinical use, include, for example, pyrotinib, margetuximab and trastuzumab-deruxtecan.

Slightly improved progression-free survival was shown for margetuximab, which is an anti-HER2 antibody optimised for ADCC (antibody-dependent cell-mediated cytotoxicity) [8]. In the case of this antibody, the ADCC is dependent on a germline variant of genes CD16 and CD32; patients who will benefit most from such therapy can possibly be identified with this.

An improvement in progression-free survival was found for treatment with pyrotinib and capecitabine compared with treatment with lapatinib and capecitabine [9]. This was confirmed in the PHOEBE phase III study [10]. In the study, after pretreatment with trastuzumab and taxanes, patients were treated either with lapatinib and capecitabine or with pyrotinib and capecitabine. The median progression-free survival was prolonged from 6.8 to 12.5 months (hazard ratio: 0.39; 95% CI: 0.56).

Many studies are currently being conducted with the antibody-drug conjugate (ADC) trastuzumab-deruxtecan. In a single-arm early phase I/II study, this anti-HER2 ADC produced a median progression-free survival of 14.8 months (95% CI: 13.8–16.9), even after several previous treatment lines [11]. This drug could also be effective in patients with low expression of HER2 (score 1+ or 2+). It is therefore being tested not only in HER2-positive patients (e.g., in the post-neoadjuvant therapy setting, in the metastatic situation after T-DM1 and in comparison with T-DM1, and others), but also in patients with an expression of HER2 that suffices to bind the antibody but without classic overexpression of HER2.



▶ **Fig. 1** KEYNOTE-355 study design. ^a Pembrolizumab 200 mg intravenous (i. v.) every 3 weeks (Q3W); ^b Chemotherapy dosing regimens are as follows: nab-paclitaxel 100 mg/m² i. v. on days 1, 8, and 15 every 28 days, paclitaxel 90 mg/m² i. v. on days 1, 8, and 15 every 28 days, gemcitabine 1000 mg/m²/carboplatin AUC 2 on days 1 and 8 every 21 days; ^c Normal saline; ^d Treatment may be continued until confirmation of progressive disease; ^e Based on RECIST v 1.1 assessed by a central imaging vendor; ^f PD-L1 assessed at a central laboratory using PD-L1 ICH 22C3 pharmDx assay and measured using the combined positive score (CPS; number of PD-L1-positive tumour cells, lymphocytes, and macrophages divided by total number of tumour cells \times 100); ^g To be presented at a later date. CNS: central nervous system; ECOG: Eastern Cooperative Oncology Group; PD-L1: programmed death ligand 1; R: randomized; TNBC: triple-negative breast cancer. Modified after: [45].

Treatment of Patients with Advanced TNBC or BRCA-Associated Breast Cancer

Immunotherapies

Since atezolizumab in combination with nab-paclitaxel is already licensed in the first treatment line for patients with metastatic breast cancer, the results of the KEYNOTE-355 study, which tests the PD-1 antibody pembrolizumab also in the first treatment line, have also been published [45].

The KEYNOTE-355 study included patients with advanced TNBC who had not yet had any pretreatment in the metastatic stage. The study compared a combination of chemotherapy and pembrolizumab with chemotherapy alone. The permitted chemotherapy included nab-paclitaxel, paclitaxel or gemcitabine/carboplatin. The study design is shown in ▶ **Fig. 1**. The primary study aim was the progression-free survival, for which a hierarchical procedure was chosen with regard to PD-L1 testing (for a summary of PD-L1 testing see [12]). This means that the population that has a CPS score \geq 10 is tested primarily and if significance is reached, the greater population with a CPS score of \geq 1 was tested. A total of 847 patients were randomised, of whom 566 were to be treated with pembrolizumab + chemotherapy and 281 with chemotherapy alone (2:1 randomisation).

Of the 847 patients, 323 had a CPS score of \geq 10 (38.1%) and 636 patients had a CPS score $>$ 1 (75.1%).

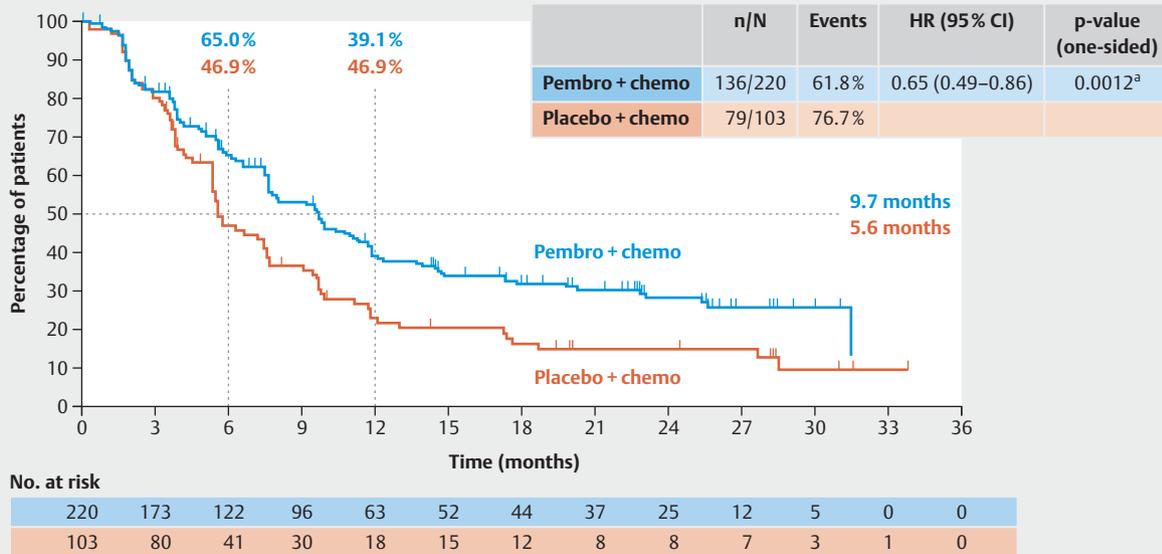
The primary study aim was reached when the CPS \geq 10 tumours were analysed. In this TNBC cohort the addition of pem-

brolizumab to the chemotherapy prolonged the median PFS from 5.6 to 9.7 months. The hazard ratio was 0.65 (95% CI: 0.49–0.86, $p = 0.0012$). The population with CPS \geq 1 could therefore be examined. Here the median PFS was 5.6 vs. 7.6 months and the hazard ratio was 0.74 (95% CI: 0.61–0.90, $p = 0.0014$). Since the required p -value in these multiple consecutively planned tests was 0.0011, this result was not formally statistically significant. The Kaplan-Meier curves of these analyses are shown in ▶ **Fig. 2** and **3**. Analyses of overall survival are not yet available. There was no new information about the side effect profile. Thus, data are now available showing that pembrolizumab can be combined with different chemotherapy drugs in the KEYNOTE-355 treatment situation.

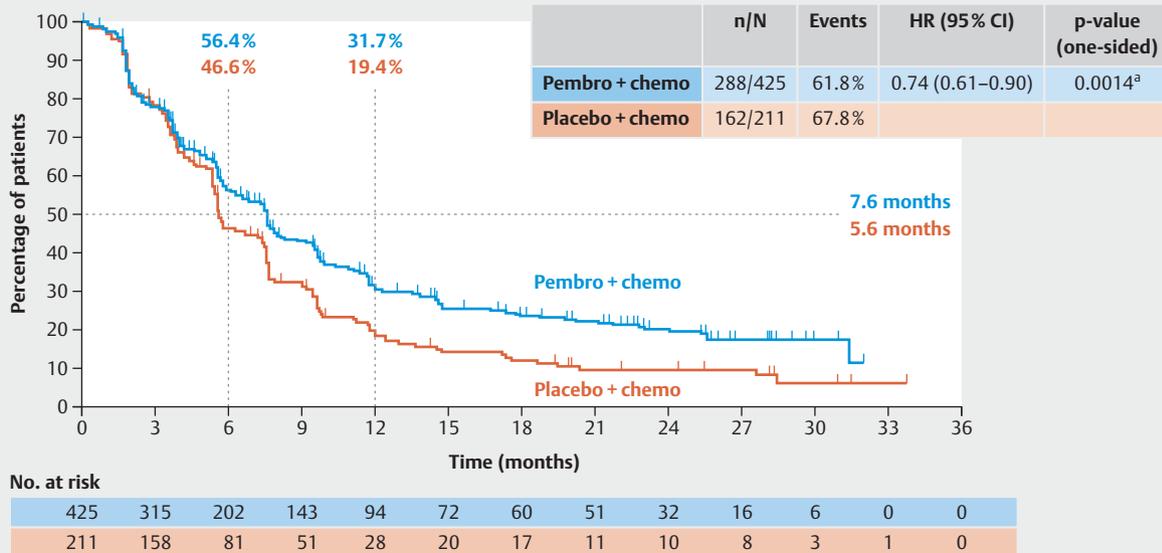
Chemotherapy as a trigger of an immune response

For some chemotherapy agents and certain dosing schedules it is already known that modulation of the immune system can take place [13]. Eribulin and vinorelbine are two of these drugs for which it is suspected that they can have an immunological effect in this way. In a preclinical study, for instance, triple-negative breast cancer cell lines were incubated together with immune cells of the innate immune defence system with eribulin, vinorelbine, docetaxel, paclitaxel and ixabepilone and the immune reaction was measured using the gene expression profile of cytokines and immune checkpoint genes. This showed that eribulin and vinorelbine but not the taxanes can stimulate interferon expression in the immune cells [14].

Against this background, combinations of checkpoint inhibitors with these chemotherapy drugs would be of particular inter-



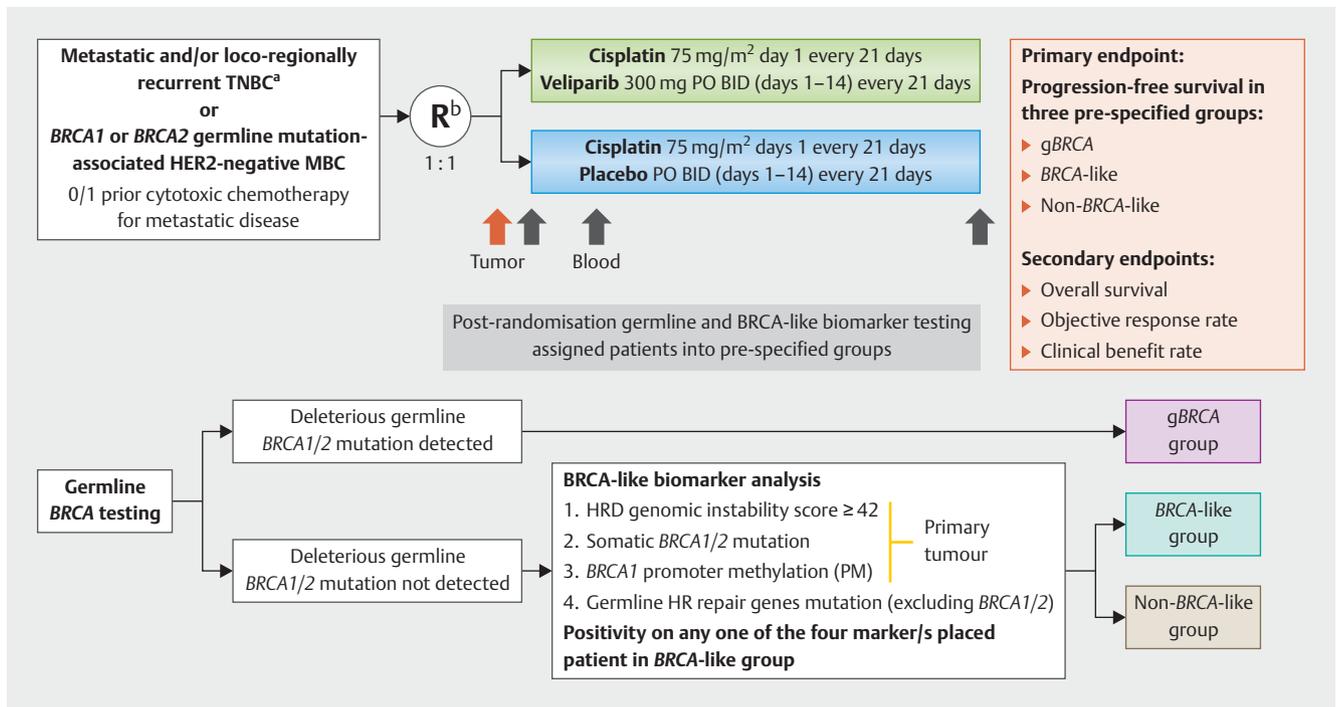
► **Fig. 2** Progression-free survival in the KEYNOTE-355 study in the population of patients with a tumour CPS score of ≥ 10 (primary analysis). ^a Prespecified p-value boundary of 0.00411 not met. Hazard ratio (CI) analysed based on a Cox regression model with treatment as a covariate stratified by the randomization stratification factors. Data cut-off December 11, 2019. HR: hazard ratio; CI: confidence interval. Modified after: [45].



► **Fig. 3** Progression-free survival in the KEYNOTE-355 study in the population of patients with a tumour and CPS score of ≥ 1 . ^a Prespecified p-value boundary of 0.00411 not met. Hazard ratio (CI) analysed based on a Cox regression model with treatment as a covariate stratified by the randomization stratification factors. Data cut-off December 11, 2019. HR: hazard ratio; CI: confidence interval. Modified after: [45].

est. In the phase-I/II ENHANCE1 study a combination of eribulin and pembrolizumab was tested for toxicity and efficacy [15]. This study included 167 patients with advanced TNBC with 0–2 previous treatments. No new unexpected toxicities were seen in addition to those that were expected because of the eribulin therapy or pembrolizumab therapy. A response rate of 25.8% was seen in

patients in the first treatment line and in 21.8% in higher treatment lines [15]. These response rates are promising and thus this combination could be further developed in further phase III studies.



► **Fig. 4** SWOG-S1416 study design. ^a TNBC defined as oestrogen receptor (ER) and progesterone receptor (PgR) immunohistochemical (IHC) nuclear staining of ≤ 1% and HER2 negative per ASCO/CAP guidelines; ^b Randomization stratified by number of prior cytotoxic regimens for metastatic disease (0 vs. 1). BID: bis in die; MBC: metastatic breast cancer; TNBC: triple-negative breast cancer. Modified after: [46].

PARP inhibitors in patients with HRD markers other than BRCA1 and BRCA2

The PARP inhibitors olaparib and talazoparib are licensed for the treatment of HER2-negative patients with advanced breast cancer if a germline BRCA1/2 mutation has been found [16, 17], which is the case in ca. 10% of cases of TNBC and in ca. 4–5% of HER2-negative HR-positive patients [18–22]. For veliparib, which can be combined with chemotherapy in a nearly regular dose, it was shown that the addition of veliparib to chemotherapy with carboplatin and paclitaxel can improve the prognosis of patients with HER2-negative advanced breast cancer if a BRCA1/2 germline mutation had been found [23] (BROCADE study).

A small phase II study has now been reported (SWOG S1416), which treated HER2-negative patients either with veliparib and cisplatin or with cisplatin alone. Patients were included if they were treated in the first or second treatment line and could be assigned to one of the following groups [46].

- Group 1 (germline BRCA group): germline mutation in BRCA1/2
- Group 2 (BRCA-like group): tumour mutation in BRCA1/2, germline mutation in one of 36 DNA repair genes (BROCA-HR), BRCA1 promoter hypermethylation, myChoice score of ≥ 42
- Group 3 (BRCA-unlike): patients could not be assigned to either of the other two groups.

The study design is shown in ► **Fig. 4**. The addition of veliparib did not confer any benefit in the group of BRCA-unlike patients, and also not in the group of patients with a BRCA1/2 germline mutation. The absence of a difference in the group of patients with the

BRCA1/2 germline mutation was initially surprising, but it must be considered that this group of 37 patients was small and that olaparib and talazoparib had been licensed during the study for the treatment of patients with a BRCA1/2 germline mutation. In the BRCA-like group (group 2), however, a statistically significant difference was seen with a median progression-free survival of 4.2 months in patients treated with cisplatin and 5.9 months in patients who had been treated with cisplatin + veliparib (hazard ratio: 0.53; 95% CI: 0.34–0.83). This shows that apart from the group of patients with a germline mutation in BRCA1/2 there are other BRCA-like characteristics (HRD score, mutations in other genes, BRCA1 hypermethylation) that could define efficacy of PARP inhibitors.

The TBCRC-048 study (Olaparib Extended Study) is another small phase II study, which addressed a similar question [24]. Patients were included in this study who had a germline or tumour mutation in one of the following genes: *ATM*, *ATR*, *BARD1*, *BRIP1*, *CHEK2*, *FANCA*, *FANCC*, *FANCD2*, *FANCE*, *FANCF*, *FANCM*, *MRE11A*, *NBN*, *PALB2*, *PTEN*, *RAD50*, *RAD51C*, *RAD51D* and other unnamed genes or a somatic tumour mutation in BRCA1/2. The patients were treated with olaparib monotherapy. Most germline mutations (87% of the patients) were found in *ATM*, *CHEK2*, *PALB2* or tumour mutations in BRCA1/2. The response rate was 33% in the group of patients who had a germline mutation outside BRCA1/2. It was interesting that all 11 patients in whom a germline PALB2 mutation was present benefited from the olaparib therapy (ORR 82%, CBR 100%). In patients with a tumour mutation in BRCA1 or BRCA2 31% had a response to the olaparib therapy [24].

Treatment of Patients with Advanced HER2-Negative, Hormone Receptor-Positive Breast Cancer

Aromatase inhibitor or fulvestrant as combination partner in the hormone-sensitive situation

The therapy sequence in patients with advanced HER2-negative hormone receptor-positive breast cancer is becoming ever more important given the increasing treatment options [25–27]. Not only the sequence in the metastatic situation is of importance but also the way anti-hormone therapies are used in the adjuvant setting. Treatment with CDK4/6 inhibitors has become established as standard in the first treatment line of advanced breast cancer. The efficacy of this treatment has been confirmed both in combination with aromatase inhibitors and with fulvestrant. The choice of endocrine combination partner is particularly important, however, because treatments after the CDK4/6 inhibitors could possibly use fulvestrant as combination partner. The efficacy of the PI3K inhibitor alpelisib was already established some time ago in the SOLAR-1 study. In this study, a combination of fulvestrant with alpelisib was compared with fulvestrant therapy alone [28]. Progression-free survival was prolonged from 5.7 months to 11.0 months in patients with *PIK3CA* mutations. The combination partner fulvestrant could thus be of benefit in the second therapy line after CDK4/6 inhibitors for possible treatment with the PI3K inhibitor alpelisib. The CDK4/6 inhibitors are effective in different treatment situations both in combination with fulvestrant or aromatase inhibitors [29–37]. The 3 studies that recruited hormone-sensitive patients and tested a combination with an aromatase inhibitor (MONALEESA-2, MONARCH-3 and PALOMA-2) all had as a requirement that the patients had no progression on (neo-) adjuvant therapy and that the conclusion of the (neo-) adjuvant therapy had to be at least 12 months previously [32, 34, 36]. Against this background, these studies showed a clear benefit for disease-free survival even when an aromatase inhibitor was again combined with a CDK4/6 inhibitor in the metastatic situation. Nevertheless, real-world data suggest that fulvestrant is often preferred as anti-hormonal therapy in the first palliative treatment line for recurrence [25]. In this connection, the PARSIFAL study published at ASCO 2020 is of particular importance [38]. This study compared treatment with palbociclib + fulvestrant in this described hormone-sensitive situation (similar to MONALEESA-2, MONARCH-3, PALOMA-2) with treatment with palbociclib-letrozole. The primary study aim was progression-free survival. 486 patients in total were included and randomised 1:1. A statistically significant difference was not found between the two arms with regard to progression-free survival (hazard ratio = 1.13 [95% CI: 0.89–1.45]). There was also no difference with regard to overall survival, where the hazard ratio was 1.0 (95% CI: 0.68–1.48) [38]. When interpreting these data, it must be borne in mind that this study initially investigated fulvestrant for superiority, which was not demonstrated. This study then looked at non-inferiority, which likewise was not confirmed. A treatment decision should always therefore depend on the overall view of the disease and the planned therapy sequences.

Alpelisib after CDK4/6 inhibitor treatment

In the Solar-1 study, which showed an improvement in PFS by addition of alpelisib in patients with a *PIK3CA* mutation of the tumour, only a few patients had received previous treatment with a CDK4/6 inhibitor. Only 7 patients received treatment with alpelisib and fulvestrant and 10 patients received placebo and fulvestrant. The median progression-free survival was 5.5 months in patients treated with alpelisib and 1.8 months in those who had been treated with fulvestrant alone [28]. It is therefore clear that better evidence was needed for this group of patients. This evidence was delivered by the recently presented BYLIEVE study in which patients were included who were to be treated again with anti-hormonal therapy following treatment with a CDK4/6 inhibitor [39]. This non-randomised study consisted of several cohorts, of which only cohort A has been presented to date. Cohort A included 112 patients who had previously received treatment with a CDK4/6 inhibitor and an aromatase inhibitor. In the BYLIEVE study all patients received the combination of alpelisib and fulvestrant. Naturally, a tumour mutation in the *PIK3CA* gene had to be found in all patients. The primary end point was the number of patients who had no breast cancer disease progression after 6 months. This number was 50.4% (95% CI: 41.2–59.6). The median progression-free survival (secondary end point) was 7.3 months (95% CI: 5.6–8.3) [39]. It should be noted critically, however, that the BYLIEVE study is not a prospective randomised study that compares the combined treatment consisting of alpelisib and anti-hormonal therapy with a different therapy. Overall, treatment with alpelisib and fulvestrant could represent the preferred treatment option after therapy with a CDK4/6 inhibitor based on the available data for patients with a *PIK3CA* mutation in the tumour. With regard to the side effects, it must be noted that clinically significant hyperglycaemic episodes and skin rashes occur in approximately one third of the patients, often necessitating interdisciplinary management.

Biomarkers

Tumour mutational burden and pembrolizumab

The KEYNOTE-119 study is a study in which patients with advanced TNBC in later treatment lines were treated either with pembrolizumab alone or with chemotherapy [40]. Even though the primary study aim, namely, superiority of pembrolizumab compared with chemotherapy, was not reached, the study showed clearly that pembrolizumab was all the more effective the higher the CPS score was (PD-L1 positivity in immune cells and tumour) [40]. The median overall survival was 14.9 months in patients with a CPS ≥ 20 and 12.7 months in patients with a CPS ≥ 10 , 10.7 and 9.9 months with CPS ≥ 1 , when no limitations were made with regard to the CPS scores [40].

The tumour mutational burden (TMB) was also discussed in this context as a biomarker for the response to immunotherapy [41–44]. The TMB status of 253 of the 601 patients in the KEYNOTE-119 study was determined. 26 patients (10.3%) had a TMB ≥ 10 mutations per megabase pair (mut/Mb). The response rate with pembrolizumab was numerically higher (14.3%) in patients with a high TMB than in patients with a low TMB (12.7%). The dif-

ference between the two treatment arms (pembrolizumab vs. chemotherapy) with regard to overall survival also appeared to be greater in patients with a high TMB (hazard ratio: 0.58; 95% CI: 0.21–1.57) than in patients with a low TMB (hazard ratio: 0.81; 95% CI: 0.61–1.07).

Whether and how TMB can be established as a biomarker in patients with breast cancer remains to be seen.

Outlook

Tucatinib and trastuzumab-deruxtecan are two substances that are entering clinical practice for HER2-positive advanced breast cancer. This could further markedly improve the treatment situation of patients with a HER2-positive tumour. In patients with TNBC, a therapy advantage was shown with pembrolizumab for a second checkpoint inhibitor (after atezolizumab) in first-line therapy. With regard to treatment with PARP inhibitors an attempt is being made to expand the treatment indication to other mutations or HRD signals. For HER2-negative HR-positive tumours, following CDK4/6 inhibitor therapy, a further targeted therapy (PI3K inhibition) has entered clinical practice with alpelisib. The trend of the last few years is thus confirmed, showing that drug development is progressing at high speed and hardly a year passes in which new substances are not presented for all subtypes of metastatic breast cancer with promising new data from clinical studies.

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Conflict of Interest

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References

- [1] Schutz F, Fasching PA, Welslau M et al. Update Breast Cancer 2019 Part 4 – Diagnostic and Therapeutic Challenges of New, Personalised Therapies for Patients with Early Breast Cancer. *Geburtshilfe Frauenheilkd* 2019; 79: 1079–1089
- [2] Welslau M, Hartkopf AD, Muller V et al. Update Breast Cancer 2019 Part 5 – Diagnostic and Therapeutic Challenges of New, Personalised Therapies in Patients with Advanced Breast Cancer. *Geburtshilfe Frauenheilkd* 2019; 79: 1090–1099
- [3] Hartkopf AD, Muller V, Wockel A et al. Update Breast Cancer 2019 Part 1 – Implementation of Study Results of Novel Study Designs in Clinical Practice in Patients with Early Breast Cancer. *Geburtshilfe Frauenheilkd* 2019; 79: 256–267
- [4] Janni W, Schneeweiss A, Muller V et al. Update Breast Cancer 2019 Part 2 – Implementation of Novel Diagnostics and Therapeutics in Advanced Breast Cancer Patients in Clinical Practice. *Geburtshilfe Frauenheilkd* 2019; 79: 268–280
- [5] Lux MP, Nabieva N, Hartkopf AD et al. Therapy Landscape in Patients with Metastatic HER2-Positive Breast Cancer: Data from the PRAEGNANT Real-World Breast Cancer Registry. *Cancers (Basel)* 2019; 11: 10
- [6] Murthy RK, Loi S, Okines A et al. Tucatinib, Trastuzumab, and Capecitabine for HER2-Positive Metastatic Breast Cancer. *N Engl J Med* 2020; 382: 597–609
- [7] Lin NU, Borges V, Anders C et al. Intracranial Efficacy and Survival With Tucatinib Plus Trastuzumab and Capecitabine for Previously Treated HER2-Positive Breast Cancer With Brain Metastases in the HER2CLIMB Trial. *J Clin Oncol* 2020. doi:10.1200/JCO.20.00775
- [8] Rugo HS, Im SA, Wright GLS et al. SOPHIA primary analysis: A phase 3 (P3) study of margetuximab (M) + chemotherapy (C) versus trastuzumab (T) + C in patients (pts) with HER2+ metastatic (met) breast cancer (MBC) after prior anti-HER2 therapies (Tx). *J Clin Oncol* 2019; 37: 1000–1000
- [9] Ma F, Ouyang Q, Li W et al. Pyrotinib or Lapatinib Combined With Capecitabine in HER2-Positive Metastatic Breast Cancer With Prior Taxanes, Anthracyclines, and/or Trastuzumab: A Randomized, Phase II Study. *J Clin Oncol* 2019; 37: 2610–2619
- [10] Xu B, Yan M, Ma F et al. Pyrotinib or lapatinib plus capecitabine for HER2 + metastatic breast cancer (PHOEBE): A randomized phase III trial. *J Clin Oncol* 2020; 38: 1003–1003

- [11] Modi S, Saura C, Yamashita T et al. Trastuzumab Deruxtecan in Previously Treated HER2-Positive Breast Cancer. *N Engl J Med* 2019. doi:10.1056/NEJMoa1914510
- [12] Hartkopf AD, Muller V, Wockel A et al. Translational Highlights in Breast and Ovarian Cancer 2019 – Immunotherapy, DNA Repair, PI3K Inhibition and CDK4/6 Therapy. *Geburtshilfe Frauenheilkd* 2019; 79: 1309–1319
- [13] Shurin MR, Naiditch H, Gutkin DW et al. ChemolmmunoModulation: immune regulation by the antineoplastic chemotherapeutic agents. *Curr Med Chem* 2012; 19: 1792–1803
- [14] Fermaintt CS, Mooberry SL, Risinger AL. Eribulin promotes a distinct immunogenic gene expression signature as compared with paclitaxel. *AACR Annual Meeting 2020*; Abstr. 4896
- [15] Tolaney SM, Kalinsky K, Kaklamani VG et al. A phase Ib/II study of eribulin (ERI) plus pembrolizumab (PEMBRO) in metastatic triple-negative breast cancer (mTNBC) (ENHANCE 1). *J Clin Oncol* 2020; 38: 1015–1015
- [16] Litton JK, Rugo HS, Ettl J et al. Talazoparib in Patients with Advanced Breast Cancer and a Germline BRCA Mutation. *N Engl J Med* 2018; 379: 753–763
- [17] Robson M, Im S-A, Senkus E et al. Olaparib for Metastatic Breast Cancer in Patients with a Germline BRCA Mutation. *N Engl J Med* 2017; 377: 523–533
- [18] Fasching PA, Hu C, Hart SN et al. Cancer predisposition genes in metastatic breast cancer – Association with metastatic pattern, prognosis, patient and tumor characteristics [abstract]. In: *Proceedings of the 2017 San Antonio Breast Cancer Symposium*; 2017 Dec 5–9; San Antonio, TX. Philadelphia (PA): AACR. *Cancer Res* 2018; 78: Abstr. PD1-02
- [19] Couch FJ, Hart SN, Sharma P et al. Inherited mutations in 17 breast cancer susceptibility genes among a large triple-negative breast cancer cohort unselected for family history of breast cancer. *J Clin Oncol* 2015; 33: 304–311
- [20] Fasching PA, Loibl S, Hu C et al. BRCA1/2 Mutations and Bevacizumab in the Neoadjuvant Treatment of Breast Cancer: Response and Prognosis Results in Patients With Triple-Negative Breast Cancer From the GeparQuinto Study. *J Clin Oncol* 2018; 36: 2281–2287
- [21] Pohl-Rescigno E, Hauke J, Loibl S et al. Association of Germline Variant Status With Therapy Response in High-risk Early-Stage Breast Cancer: A Secondary Analysis of the GeparOcto Randomized Clinical Trial. *JAMA Oncol* 2020. doi:10.1001/jamaoncol.2020.0007
- [22] Hahnen E, Lederer B, Hauke J et al. Germline Mutation Status, Pathological Complete Response, and Disease-Free Survival in Triple-Negative Breast Cancer: Secondary Analysis of the GeparSixto Randomized Clinical Trial. *JAMA Oncol* 2017; 3: 1378–1385
- [23] Diéras V, Han HS, Kaufman B et al. Phase 3 study of veliparib with carboplatin and paclitaxel in HER2-negative advanced/metastatic gBRCA-associated breast cancer: BROCADE3. *Ann Oncol* 2019; 30 (Suppl. 05): v851–v934. doi:810.1093/annonc/mdz1394
- [24] Tung NM, Robson ME, Ventz S et al. TBCRC048: A phase II study of olaparib monotherapy in metastatic breast cancer patients with germline or somatic mutations in DNA damage response (DDR) pathway genes (Olaparib Expanded). *J Clin Oncol* 2020; 38: 1002–1002
- [25] Hartkopf AD, Huober J, Volz B et al. Treatment landscape of advanced breast cancer patients with hormone receptor positive HER2 negative tumors – Data from the German PRAEGNANT breast cancer registry. *Breast* 2018; 37: 42–51
- [26] Hartkopf AD, Emons J, Lux MP et al. Clinical endpoints in real-world registry studies PRAEGNANT network for women with advanced breast cancer. *Onkologie* 2020; 26: 530–541
- [27] Fasching PA, Brucker SY, Fehm TN et al. Biomarkers in Patients with Metastatic Breast Cancer and the PRAEGNANT Study Network. *Geburtshilfe Frauenheilkd* 2015; 75: 41–50
- [28] Andre F, Ciruelos E, Rubovszky G et al. Alpelisib for PIK3CA-Mutated, Hormone Receptor-Positive Advanced Breast Cancer. *N Engl J Med* 2019; 380: 1929–1940
- [29] Slamon DJ, Neven P, Chia S et al. Overall Survival with Ribociclib plus Fulvestrant in Advanced Breast Cancer. *N Engl J Med* 2019. doi:10.1056/NEJMoa1911149
- [30] Sledge GW Jr., Toi M, Neven P et al. The Effect of Abemaciclib Plus Fulvestrant on Overall Survival in Hormone Receptor-Positive, ERBB2-Negative Breast Cancer That Progressed on Endocrine Therapy-MONARCH 2: A Randomized Clinical Trial. *JAMA Oncol* 2019. doi:10.1001/jamaoncol.2019.4782
- [31] Turner NC, Ro J, Andre F et al. Palbociclib in Hormone-Receptor-Positive Advanced Breast Cancer. *N Engl J Med* 2015; 373: 209–219
- [32] Goetz MP, Toi M, Campone M et al. MONARCH 3: Abemaciclib As Initial Therapy for Advanced Breast Cancer. *J Clin Oncol* 2017; 35: 3638–3646
- [33] Im SA, Lu YS, Bardia A et al. Overall Survival with Ribociclib plus Endocrine Therapy in Breast Cancer. *N Engl J Med* 2019. doi:10.1056/NEJMoa1903765
- [34] Hortobagyi GN, Stemmer SM, Burris HA et al. Ribociclib as First-Line Therapy for HR-Positive, Advanced Breast Cancer. *N Engl J Med* 2016; 375: 1738–1748
- [35] Finn RS, Crown JP, Lang I et al. The cyclin-dependent kinase 4/6 inhibitor palbociclib in combination with letrozole versus letrozole alone as first-line treatment of oestrogen receptor-positive, HER2-negative, advanced breast cancer (PALOMA-1/TRIO-18): a randomised phase 2 study. *Lancet Oncol* 2015; 16: 25–35
- [36] Finn RS, Martin M, Rugo HS et al. Palbociclib and Letrozole in Advanced Breast Cancer. *N Engl J Med* 2016; 375: 1925–1936
- [37] Turner NC, Slamon DJ, Ro J et al. Overall Survival with Palbociclib and Fulvestrant in Advanced Breast Cancer. *N Engl J Med* 2018; 379: 1926–1936
- [38] Llombart-Cussac A, Pérez-García JM, Bellet M et al. PARSIFAL: A randomized, multicenter, open-label, phase II trial to evaluate palbociclib in combination with fulvestrant or letrozole in endocrine-sensitive patients with estrogen receptor (ER)[+]/HER2[-] metastatic breast cancer. *J Clin Oncol* 2020; 38: 1007–1007
- [39] Rugo HS, Lerebours F, Ciruelos E et al. Alpelisib (ALP) + fulvestrant (FUL) in patients (pts) with PIK3CA-mutated (mut) hormone receptor-positive (HR+), human epidermal growth factor receptor 2-negative (HER2-) advanced breast cancer (ABC) previously treated with cyclin-dependent kinase 4/6 inhibitor (CDKi) + aromatase inhibitor (AI): BYLieve study results. *J Clin Oncol* 2020; 38: 1006–1006
- [40] Cortes J, Lipatov O, Im SA et al. KEYNOTE-119: Phase 3 Study of Pembrolizumab versus Single-Agent Chemotherapy for Metastatic Triple-Negative Breast Cancer (mTNBC). *Ann Oncol* 2019; 30 (Suppl. 05): v851–v934. doi:810.1093/annonc/mdz1394
- [41] Yarchoan M, Hopkins A, Jaffee EM. Tumor Mutational Burden and Response Rate to PD-1 Inhibition. *N Engl J Med* 2017; 377: 2500–2501
- [42] Hellmann MD, Ciuleanu TE, Pluzanski A et al. Nivolumab plus Ipilimumab in Lung Cancer with a High Tumor Mutational Burden. *N Engl J Med* 2018; 378: 2093–2104
- [43] Waqar SN, Govindan R. The Mystic Role of Tumor Mutational Burden in Selecting Patients With Lung Cancer for First-Line Immunotherapy. *JAMA Oncol* 2020. doi:10.1001/jamaoncol.2020.0264
- [44] Chumsri S, Sokol ES, Soyano-Muller AE et al. Durable Complete Response With Immune Checkpoint Inhibitor in Breast Cancer With High Tumor Mutational Burden and APOBEC Signature. *J Natl Compr Canc Netw* 2020; 18: 517–521
- [45] Cortes J, Cescon DW, Rugo HS et al. KEYNOTE-355: Randomized, double-blind, phase III study of pembrolizumab + chemotherapy versus placebo + chemotherapy for previously untreated locally recurrent inoperable or metastatic triple-negative breast cancer. *J Clin Oncol* 2020; 38: 1000–1000
- [46] Sharma P, Rodler E, Barlow WE et al. Results of a phase II randomized trial of cisplatin +/- veliparib in metastatic triple-negative breast cancer (TNBC) and/or germline BRCA-associated breast cancer (SWOG S1416). *J Clin Oncol* 2020; 38: 1001–1001