BRCA2 secondary mutation-mediated resistance to platinum and PARP inhibitor-based therapy in pancreatic cancer

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Background: Pancreatic cancer has become the third leading cause of cancer death with minimal improvements in outcome for over 40 years. Recent trials of therapies that target-defective DNA maintenance using poly (ADP-ribose) polymerase (PARP) inhibitors are showing promising results, yet invariably patients recur and succumb to disease. Mechanisms of resistance to platinum-based and PARP inhibitor therapy in other cancer types include secondary mutations, which restore the integrity of DNA repair through an increasing number of different mechanisms.

Methods: Here we present a case of a 63-year-old female patient with a germ line pathogenic BRCA2 mutation (6714 deletion) who developed pancreatic cancer and had an exceptional response to platinum and PARP inhibitor therapy. Through next-generation sequencing and clinical follow-up, we correlated tumour response and resistance to the BRCA2 mutational status in the tumour.

Results: Initially, the patient had an exceptional response to platinum and PARP inhibitor therapy, most likely due to the BRCA2 mutation. However, the primary lesion recurred while on PARP inhibitor therapy and contained a secondary mutation in BRCA2, which mostly likely restored BRCA2 function in PARP inhibitor-resistant tumour cells.

Conclusions: To our knowledge, this is the first report of a BRCA2 reversion mutation that conferred resistance to PARP inhibitor-based therapy in a pancreatic ductal adenocarcinoma patient. Future studies are needed to understand this important mechanism of resistance and how it may impact the choice of therapy for patients with pancreatic cancer.

Emerging data suggest that the subgroup of pancreatic ductal adenocarcinoma (PDA) patients whose tumours harbour defects in genes involved in the homologous recombination pathway, most notably BRCA1 and BRCA2 mutations, may benefit significantly from poly (ADP-ribose) polymerase (PARP) inhibitor-based therapy (Lowery et al, 2011; Pishvaian et al, 2013; O’Reilly et al, 2014; Kaufman et al, 2015). From a personalised therapy perspective, this patient cohort is sizable as previous reports claim a conservative 5–7% of PDAs harbour mutations in the BRCA pathway, whereas more recent sophisticated interrogations of PDA genomes estimate that up to 20% of PDA have defects in DNA damage response, which may confer sensitivity to platinum therapy and drugs that specifically target these mechanisms (PARP, ATR, and Wee1 inhibitors; Waddell et al, 2015; Bailey

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et al, 2016). In fact, ongoing clinical trials have revealed that patients with BRCA-mutated PDAs are experiencing progression-free survival times of 12 months or more, with frank response rates of over 50%. Unfortunately these patients’ tumours eventually develop resistance to PARP inhibitor-based therapy.

Pancreatic ductal adenocarcinoma cells altered in the DNA repair genes, BRCA2, FANCC, and G (labelled as ‘BRCA-deficient’), are all hypersensitive to inter-strand cross-linking agents and platinum-based drugs in in vitro and in vivo models (van der Heijden et al, 2005). Ashworth and colleagues showed that cells deficient in genes involved in homologous recombination repair pathway of double-stranded breaks (including BRCA1, BRCA2, RAD51, RAD54, DSS1, RPA1, NBS1, ATR, ATM, CHK1, CHK2, FANCD2, FANCA, or FANCC) are also hypersensitive to PARP inhibitors (Farmer et al, 2005; McCabe et al, 2006). Hence, PARP inhibitors are being investigated as a therapeutic option for various cancers disrupted in the BRCA pathway, and the PARP inhibitor olaparib (Lynparza, Astra Zeneca, Cambridge, UK) was recently approved for BRCA-mutated ovarian cancer.

Poly (ADP-ribose) polymerase is a nuclear enzyme that plays a critical role in the repair of DNA damage (McCabe et al, 2006; Donawho et al, 2007; Kummer et al, 2009). Thus, PARP inhibition results in less efficient DNA repair following a cytotoxic insult. Consequently, PARP inhibitors act as sensitising agents for a variety of DNA-damaging chemotherapeutic agents and with radiotherapy. Veliparib (ABT-888, Abbvie Inc., Lake Bluff, IL, USA) is a PARP inhibitor that has proven in vivo radiotherapy. The results of which revealed a pathogenic BRCA2 mutation (c.6486_6489delACAA p.K2162fs*5), a four base pair deletion that resulted in a premature STOP codon (Figure 2). Careful review of the BRCA2 mutation identified in the tumour specimen by Foundation Medicine (and discussion with Foundation Medicine) have confirmed that the specific mutation was the same as the patient’s germline BRCA2 mutation identified on the buccal swab. Of note, an assessment of the mutational allele frequency (MAF) revealed that the MAF of the BRCA2 mutation was 61% – thus a higher allele frequency than would be expected for a purely heterozygous state, and suggesting that there was loss of heterozygosity in a portion of the cancer cells. However, because the tested sample was not of isolated tumour cells, adjacent stromal cell contamination may have affected the MAF results, and the MAF purely in the tumour cells may actually have been higher than 61%. The tumour also exhibited a KRAS G12V and a TP53 mutation (P295fs*50) both typical for pancreatic adenocarcinomas.

After recovery from surgery, the patient was seen at Georgetown University for enrolment in an IRB-approved Phase I/II trial of 5-FU, oxaliplatin, and veliparib (NCT01489865). Her pre-treatment CA 19-9 was 31.5, and her baseline imaging revealed a pancreatic head mass 1.7 cm × 1.7 cm, as well as a left lobe liver lesion, 2.3 cm × 2.0 cm (Figure 1A, baseline imaging). The treatment consisted of the standard modified FOLFIRI regimen with oxaliplatin (85 mg m⁻² Day 1, and continuous infusion 5-fluorouracil (2400 mg m⁻²) Days 1–3 but without the 5-fluorouracil bolus. She also received veliparib 200 mg orally twice a day for 7 days, and the cycles were repeated every 2 weeks. Our patient began therapy on 05 June 2014, and had a fair degree of nausea and vomiting, ultimately requiring the dose of veliparib to be reduced by 50%, to 100 mg twice a day. She also had to stop the oxaliplatin after Cycle 13 for neuropathy. Nevertheless, the patient stayed on therapy for 31 cycles, through 10 August 2015 (progression-free survival = 15 months). While on study, she experienced a near complete response, with a virtual radiographic disappearance of the liver lesion and pancreatic head lesion by 23 March 2015 (Figure 1B, near complete response imaging). Then, starting 18 May 2015, her imaging revealed renewed progression of the pancreatic head mass. Interestingly, the re-growth, in retrospect, was eccentric, when compared to the primary pancreatic mass, visually suggesting growth of an independent, resistant clone on the periphery (Figure 1C and D, emerging resistance imaging).

Per RECIST criteria, the patient had developed progressive disease by 10 August 2015, but her disease burden was still minimal, and there was no evidence of extrapancreatic disease. On the basis of the lack of development of additional liver lesions and the response to systemic therapy, the patient underwent surgical exploration on 10 September 2015 at the Johns Hopkins University Hospital with the intent of performing a pancreaticoduodenectomy. The only identifiable liver lesion was resected and found to be scar tissue on intraoperative frozen section. As a result of these intraoperative findings the patient underwent a margin-negative pancreaticoduodenectomy at that time. Final pathology revealed a primary pancreatic adenocarcinoma with 3 out of 24 local lymph nodes positive for disease. Final pathology confirmed only scar within the liver lesion. She had an unremarkable recovery from the operation.

After resection, due to the patient’s reluctance to have additional cytotoxic chemotherapy due to future olaparib as a maintenance strategy in place of cytotoxic adjuvant therapy. She was treated at 400 mg orally twice a day, but quickly needed to reduce the dose to 200 mg twice a day due to nausea and fatigue. During this time, the

METHODS AND RESULTS

Our patient is a 63-year-old female who was diagnosed with pancreatic cancer when she initially presented with nausea, vomiting, abdominal pain, and jaundice in April 2014. She had a strong family history of cancer, with her brother having had breast cancer, and her mother having breast cancer and uterine cancer, and her father having prostate cancer. The patient had previously chosen to undergo germ line testing (from a buccal swab) through Foundation Medicine (and discussion with Foundation Medicine) and was found to have metastatic disease to the liver, which was proven on an intraoperative frozen section. The liver lesion was excised and sent to Foundation Medicine for next-generation sequencing of cancer-related genes (Foundation ONE test), the results of which revealed a pathogenic BRCA2 mutation (c.6486_6489delACAA p.K2162fs*5), a four base pair deletion that resulted in a premature STOP codon (Figure 2). Careful review of the BRCA2 mutation identified in the tumour specimen by Foundation Medicine (and discussion with Foundation Medicine) have confirmed that the specific mutation was the same as the patient’s germline BRCA2 mutation identified on the buccal swab. Of note, an assessment of the mutational allele frequency (MAF) revealed that the MAF of the BRCA2 mutation was 61% – thus a higher allele frequency than would be expected for a purely heterozygous state, and suggesting that there was loss of heterozygosity in a portion of the cancer cells. However, because the tested sample was not of isolated tumour cells, adjacent stromal cell contamination may have affected the MAF results, and the MAF purely in the tumour cells may actually have been higher than 61%. The tumour also exhibited a KRAS G12V and a TP53 mutation (P295fs*50) both typical for pancreatic adenocarcinomas.

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resection specimen was re-sent to Foundation Medicine, which again reported the original mutations (including the identical KRAS and TP53 mutations), but also revealed a new somatic (secondary) BRCA2 mutation (c.6448_6473delAAAGTTTCTCCA TATCTCTCTCAATT p.K2150fs*17). This somatic 26 base deletion in the BRCA2 gene was located 13 bases upstream of the germ line 4 base pair deletion of the same allele. This secondary somatic deletion restored the reading frame of the BRCA2 gene, which contained the four base deletion (Figure 2). Interestingly, the MAF of the secondary mutation from the pancreatic resection specimen was only 8%, whereas the MAF of the germ line BRCA2 mutation was reduced to 52%. These results suggest that only a relatively small portion of the mutated alleles harboured this secondary mutation. Clinically, immediately following the pancreaticoduodenectomy, there was no evidence of recurrent metastatic disease and the functional consequences of this secondary mutation in this context were not known. That is, although the reading frame was restored, there was no knowledge of whether this produced a fully, or even hypo-functional BRCA2. As a consequence, olaparib was continued. Unfortunately, by early January, 2016 the patient was clearly becoming symptomatic, and imaging revealed early peritoneal carcinomatosis, suggesting olaparib offered no control of her disease. Thus, she was taken off therapy, and was able to enrol in an immunotherapy trial of the combination of the CXCR2 antagonist, AZD5069, and durvalumab (NCT02499328). While on study, she developed suppurative cholecystitis, and passed away on 24 May 2016.

CONCLUSIONS

Many PARP inhibitor resistance mechanisms have been proposed (Montoni et al, 2013), but Sakai et al (2008) and Edwards et al (2008) were the first to describe that BRCA2 reversion mutations could confer resistance to PARP inhibitor-based therapy (Ashworth, 2008). They demonstrated that the PDA cell line CAPAN1 that has lost one copy of the BRCA2 gene and harbours a c.6174delT mutation in the other, are exquisitely sensitive to potent PARP inhibitors (McCabe et al, 2005). In the cell line, this mutation was accompanied by a loss of the wild-type copy of the BRCA2 gene, yet made a truncated protein ~2000 amino acids. This study, albeit in just one cell line, demonstrated that PARP inhibitors targeted this BRCA2 genetic lesion by showing that isogenic cells generated to become >1000-fold resistant harboured a secondary mutation, which restored the open reading frame of the BRCA2 sequence, and thus restoring the DNA repair function (i.e., RAD51 binding to the BRCA repeats; Ashworth, 2008).

Subsequently, others also demonstrated the presence of secondary BRCA1/2 mutations that confer resistance to therapy in BRCA1/2-mutated ovarian cancer patients, whose tumours had become resistant to platinum-based therapies (Swisher et al, 2008; Norquist et al, 2011), and may occur through a variety of mechanisms that would not be detected using NGS for selected genes and may require whole-genome sequencing (Patch et al, 2015). Importantly, Sakai et al (2008) demonstrated that the
platinum-resistant, BRCA2 functionally reverted ovarian cancer cell lines also demonstrate resistance to PARP inhibitor therapy. Additional studies in breast and ovarian cancer patients described the development of BRCA reversion and PARP inhibitor resistance (Barber et al, 2013). Of note, Ang et al (2013) assessed response to chemotherapy including platinum-based chemotherapy in patients with PARP inhibitor (olaparib)-resistant ovarian cancer. Surprisingly, these PARP inhibitor-resistant ovarian cancers retained sensitivity to chemotherapies including platinum. However, these observations were confounded by the fact that none of the PARP inhibitor-resistant ovarian cancers were found to have BRCA reversion events, thus providing evidence that other mechanisms may be at play such as defects in drug transport or drug metabolism.

As our patient received several therapies, including those that target similar mechanisms such as platinum and PARP inhibition, it is difficult to be definitive. Yet it is reasonable to suggest that either the platinum and/or the PARP inhibitor induced selection pressure on the tumour to restore defective DNA damage response mechanisms. To our knowledge, this is the first report of a BRCA2 reversion mutation, which conferred resistance to PARP inhibitor-based therapy in a PDA patient. Future studies are needed to understand this important mechanism of resistance and how it may impact the choice of therapy for patients with pancreatic cancer. Central to this approach is the assessment of tumour biopsies pre- and post treatment.

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

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