

Current perspectives on CHEK2 mutations in breast cancer

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Abstract: Checkpoint kinase 2 (CHEK2) is a serine/threonine kinase which is activated upon DNA damage and is implicated in pathways that govern DNA repair, cell cycle arrest or apoptosis in response to the initial damage. Loss of kinase function has been correlated with different types of cancer, mainly breast cancer. CHEK2 functionality is affected by different missense or deleterious mutations. CHEK2*1100delC and I157T are most studied in populations all over the world. Although these variants have been identified in patients with breast cancer, their frequency raises doubts about their importance as risk factors. The present article reviews the recent advances in research on CHEK2 mutations, focusing on breast cancer, based on the latest experimental data.

Keywords: CHEK2, breast cancer

Introduction

Breast cancer is one of the leading causes of death among women worldwide, and it has been reported as the topmost cause of mortality among female cancer patients in the US in 2016.¹ According to recent estimations, by the year 2026, the number of breast cancer patients will be more than 4.5 million in the US, compared to 3.5 million recorded in 2016.² Management and treatment of cancer are correlated with the diagnosis and specific characteristics of the tumor, such as hormone production and genetic mutations.³ The most well-studied genes that correlate with risk susceptibility are BRCA1/2, while other genes that correlate with an increased risk for breast cancer have been identified as well; one of these genes is *CHEK2*, a tumor suppressor gene that encodes a serine/threonine kinase, the CHK2. This gene is involved in pathways such as DNA repair, cell cycle regulation and apoptosis in response to DNA damage. Mutations of *CHEK2* have been implicated in various types of cancer including breast cancer. The present article reviews the most recent advances in research on *CHEK2* and breast cancer, focusing on mutations and how they could be correlated with diagnosis or prognosis of the disease.

CHEK2 gene

CHEK2 gene is activated by phosphorylation of Thr68 by *ATM*, which causes the dimerization of the gene enabling it to acquire kinase activity. CHEK2 then reacts with downstream phosphatase CDC25, serine/threonine protein kinase NEK6, transcription factor FOXM1, p53 protein and BRCA1 or BRCA2.⁴ CHEK2 regulates cell division by

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preventing cells from entering mitosis or arresting cell cycle in gap 1 phase (G1), in response to DNA damage (Figure 1). Therefore, CHEK2 is essential for cell cycle regulation, and its abnormal expression could lead to cancer. Besides gene and/or protein expression of CHK2, mutations in genomic DNA have been implicated in abnormal functioning of the CHK2 protein. Various aberrations in *CHEK2* gene have been recorded, including 1100delC, I157T, R117G, I160M, G167R, G167A and so on.⁵ Among them, 1100delC and I157T are the most well-studied and have been correlated with risk susceptibility to cancer.

CHEK2 in cancer

CHEK2 germline mutations had been implicated in inherited cancer susceptibility a few years ago. Different mutations of *CHEK2* were detected among patients with Li–Fraumeni syndrome.⁶ Furthermore, mutations of this gene were correlated with other types of cancer. Male carriers have a higher risk for prostate cancer, as *CHEK2* overexpression decreases cell growth while its downregulation affects androgen receptor activity.^{7,8} The I157T variant is associated with other types of cancer, including breast (odds ratio [OR] 1.4; $p=0.02$), prostate (OR 1.7; $p=0.002$), kidney (OR 2.1; $p=0.0006$), colon (OR 2.0; $p=0.001$) and thyroid (OR 1.9; $p=0.04$) cancer.⁹ Results from a study by

Havranek et al confirmed that truncated or missense variants of *CHEK2* gene correlated with an increased risk of non-solid tumor types, because mutations were associated with a higher risk of developing non-Hodgkin lymphoma (OR 2.86; $p=0.003$).¹⁰ Table 1 represents the different mutations according to region.

CHEK2*1100delC

CHEK2*1100delC allele was first correlated with the Li–Fraumeni and Cowden syndromes. However, the above mutation cannot be associated with the risk for these syndromes because, in a study among women in Brazil, neither the mutation carriers nor their family members were reported to have these syndromes.¹¹

According to Schmidt et al, who compared different studies that included more than 40,000 patients, carriers of the CHEK2*1100delC allele have a higher risk of developing breast cancer; however, this risk is lower in higher age groups. In addition, carriers acquire higher probability to develop estrogen receptor-positive breast cancer than noncarriers; however, there is no evidence that this risk is dependent on the status of progesterone receptor (PR) or human epidermal growth factor receptor 2.¹²

In a study of healthy volunteers and breast cancer patients in North America, the frequency of CHEK2*1100delC allele

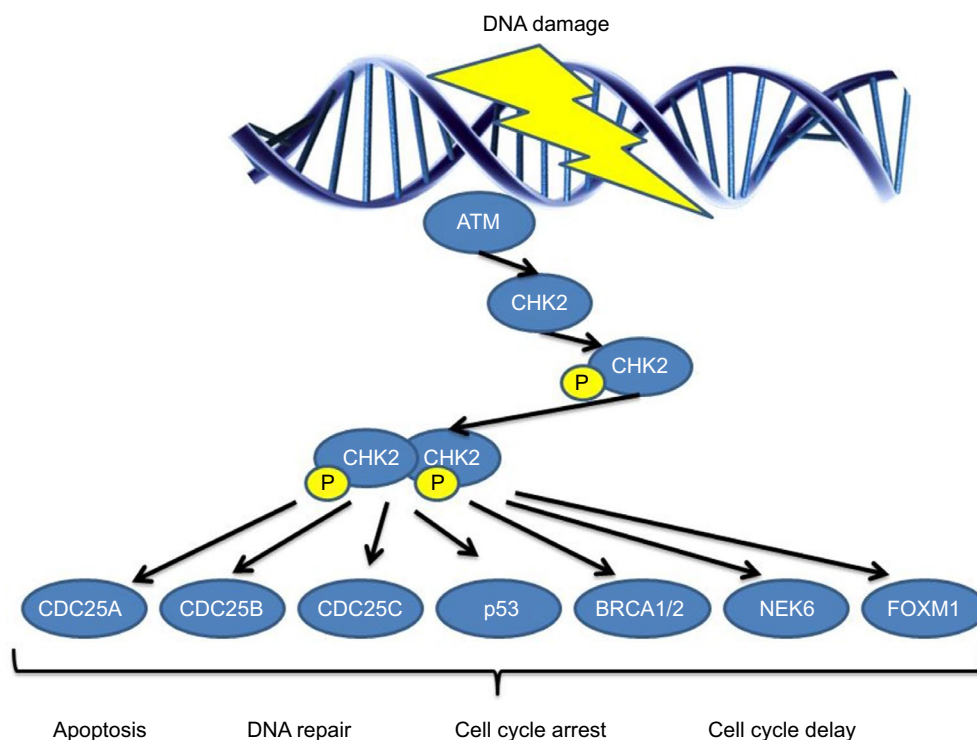


Figure 1 CHEK2 pathway. CHEK2 is activated upon DNA damage. It is phosphorylated followed by homodimerization. In this form, it interacts with other genes affecting specific cellular activities in response to the initial damage.

Abbreviations: CHEK2, checkpoint kinase 2; P, phosphorylated protein.

Table 1 CHEK2 mutations according to region

Region	No. of samples	Sample type (n)	Mutation	Frequency	Family history
New York ¹³	1965	Breast cancer (300)	1100delC	1.0%	192
		Control (1665)		0.3%	N/A
US ¹⁴	1688	Breast cancer (829)	1100delC	1.1%	362
		Control (859)		0.5%	287
Brazil ¹⁵	59	Breast cancer (29)	1100delC	1.7%	N/A
Malaysia ¹⁶	668	Breast cancer (668)	1100delC	0%	165
Ashkenazi Jewish ¹⁷	172	Breast cancer (75)	R3V	1.2%	N/A
			I157T	1.2%	N/A
			R180C	0.6%	N/A
			S428F	5%	N/A
Australia ¹⁸	300	Breast cancer (300)	1100delC	0.6%	139
Russia ¹⁹	1636	Breast cancer (815)	1100delC	2.7%	22
		Control (821)		0.2%	N/A
Spain ²⁰	856	Breast cancer (456)	1100delC	0%	N/A
			IVS10-129a/t	<1%	
			Arg406Cys	<1%	
		Control (400)		0%	
Germany ²¹	2048	Breast cancer (797)	1100delC	1.4%	N/A
		Control (1251)		0.48%	
Sweden ²²	1523	Breast cancer (763)	1100delC	1.44%	N/A
		Control (760)		0.7%	

Note: N/A: data unavailable.

Abbreviation: CHEK2, checkpoint kinase 2.

was lower (0.3%) than the respective frequency observed in European populations.¹³ Another study in the US confirmed the rare frequency of this allele in America (1.1%); however, this allele has been correlated with a risk of breast cancer.¹⁴ Similar results were obtained in South America, as the allele was also rarely observed in Brazil.¹⁵ In addition to America, the CHEK2*1100delC allele was rarely detected in breast cancer patients from Malaysia.¹⁶ The above aberration was found to be rare in Jewish Ashkenazi women with breast cancer as well as in an Australian population (0.68%).^{17,18} In contrast, a higher frequency (2.7%) of 1100delC allele was observed among women suffering from breast cancer in Russia.¹⁹ Among European populations, the frequency rates vary by country. In Spain, this variant is almost absent;²⁰ however, in Germany, the frequency ranges from 1.4% to 2.3%, while in Sweden, the frequency of CHEK2*1100delC was found to range between 1.4% and 2.9%.^{21,22} Most recent experimental data demonstrated that this allele is also associated with an increased risk for other types of cancer apart from breast cancer.²³

CHEK2*I157T

The substitution of isoleucine 157 by threonine affects several interactions at the interface of forkhead-associated and kinase domains, leading to problems in the homodimerization

of CHEK2 which is required for its activation.²⁴ Although I157T decreases protein activity, it cannot be considered as a risk factor for cancer in general populations because significant differences among the alleles concerning prognosis, metastasis, relapse and estrogen receptor or PR expression have not been recorded.²⁵ According to Kilpivaara et al, the I157T variant may be associated with susceptibility to breast cancer, but in a lower frequency than the CHEK2*1100delC allele.²⁶ However, the I157T allele may be associated with an increased risk for lobular breast cancer.²⁷ In addition, the missense variant increases the risk for breast cancer if carriers already have a deleterious CHEK2 mutation.²⁸

Other mutations

Besides the well-known and most studied mutations described previously, others have been reported, such as Q20X and E85X mutations at exons 1 and 2, respectively, which are novel and have been identified in breast cancer patients from Pakistan.²⁹ Previous experimental data on the same area suggested that two additional missense mutations (H371Y and D438Y) are also associated with breast cancer in women.³⁰ H371Y has been associated with moderate risk of breast cancer in Chinese women.³¹ In the UACC812 cell line, derived from the mammary gland, another nonsense truncating mutation, L303X, was detected.³²

CHEK2 and therapy

CHEK2 mutations are not only correlated with risk for breast cancer but have also been involved in response to therapy. Mutations of *CHEK2* or *TP53* have been associated with resistance to anthracycline-based chemotherapy in patients with breast cancer.³³ Another study in Chinese women with breast cancer demonstrated that H371Y carriers may have better response to neoadjuvant chemotherapy ($p=0.031$).³⁴ In contrast, there was no difference observed in response to adjuvant chemotherapy or endocrine therapy.^{35,36} Furthermore, *CHEK2* variants have been associated with response to epirubicin, because different allele carriers respond differently to this chemotherapeutic drug.³⁷ On comparing healthy controls with CHEK2*1100delC carriers, there was no difference observed with regard to chromosomal radiosensitivity.³⁸

CHEK2 and breast cancer risk

Although *CHEK2* mutations are rare, the risk of developing breast cancer is higher in carriers of truncating mutations. This risk is correlated with family history and increases when the carriers have first- and second-degree relatives who are affected. In carriers with no affected relative, the risk is approximately 20%, and it increases up to 44% when both first- and second-degree relatives are affected.³⁹ In an earlier study where 2000 samples were screened, it was found that only the 1100delC allele could contribute to breast cancer susceptibility.⁴⁰

According to Meijers-Heijboer et al, the same mutation results in an increased risk of breast cancer both in women and men; however, the risk does not alter when these individuals are carriers of *BRCA1* or *BRCA2* mutations. The last may be caused due to interactions among *BRCA1*, *BRCA2*, and *CHEK2* because they are involved in the same signaling pathways.⁴¹ Another study, which included a large number of samples (more than 50,000 individuals) also demonstrated that 1100delC heterozygotes have a higher risk of breast cancer.⁴²

Conclusion

CHEK2 gene is activated upon DNA damage, and also activates specific genes related to basic cellular activities, such as apoptosis, repair, cell cycle arrest and so on. Although different mutations have been associated with increased risk for breast cancer and response to chemotherapy, the low frequency rate of the allele is a complicating factor. Experimental data until now are encouraging; however, studies evaluating the function of *CHEK2* along with other genes might be more useful in providing more accurate and reliable data.

Disclosure

The authors report no conflicts of interests in this work.

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