

SHORT COMMUNICATION

The Role of Connexin 37 Polymorphism in Spontaneous Abortion

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Summary

Among unique cardiovascular risk factors in women are complications during pregnancy, including miscarriage. Important risk factor is also genetic background. One of powerful candidate genes for cardiovascular disease of atherosclerotic origin (aCVD) is gene for connexin 37 (Cx37) with strong gene-environment interaction including smoking status, that is also strong risk factor for complications in pregnancy including spontaneous abortion (SA). We analyzed association between SA and Cx37 gene polymorphism (1019C>T; Pro319Ser) in 547 fetuses and its potential interaction with smoking status of mothers. Using genetic analyses from women from general population as controls, ORs for T allele, found in our previous studies to be protective against aCVD, were calculated. T allele carriers (fetuses), had OR 0.91 (95 % CI 0.72-1.14) and no interaction with smoking was observed. In conclusion, no significant association between Cx37 polymorphism and SA was observed and no modifying effect of smoking status on this association was detected.

Key words

Connexin 37 gene • Gap junctions • Spontaneous abortion • Protective factor • Smoking • Cardiovascular disease • Candidate genes

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Regarding cardiovascular disease of atherosclerotic origin (aCVD) the annual incidence of cardiovascular diseases is age-dependently increasing both in men and women. The prevalence is higher in men until midlife (Kittnar 2020). However, women are affected similarly or more than men in older age. Despite the main cardiovascular factors are shared by both sexes, several unique cardiovascular factors were described in women as is miscarriage and other complications during pregnancy (Horn *et al.* 2019, Oliver-Williams *et al.* 2013) and metabolic disorders as gestational diabetes mellitus (Vejrazkova *et al.* 2017). Therefore, detection of determinants of atherosclerotic disease in women including metabolic ones may help to identify and to prevent atherosclerotic process and its clinical complications (Pithová *et al.* 2016). However, also better understanding of the complications in pregnancy might have similar preventative effect especially when accompanied by genetic analyses. Indeed, genetic studies could help to identify not only inherited causes of early pregnancy loss, extremely serious and emotional problem both for affected women, their partners and their physicians, but also for aCVD. One of powerful candidate genes for aCVD is gene for connexin 37 (C1019>T) (Cx37) with strong gene-environment interaction including smoking status. Connexins are the main proteins in gap junctions. Connexin 37 (Gap junction protein alpha; OMIM ID 121012; Cx37) is the main gap junction representative in the vessel wall

expressed in endothelial cells, smooth muscle cells but also in monocytes (Chanson *et al.* 2007, Wong *et al.* 2006), therefore in the main cells involved in the process of atherosclerosis. Gene polymorphism-association studies have detected a link between the C1019>T single nucleotide polymorphism (SNP) in the human *Cx37* gene and its protective role in cardiovascular disease. This polymorphism results in a non-conservative amino acid change in the regulatory C-terminus of the *Cx37* protein (P319>S). It was recently demonstrated that *Cx37* hemichannels control the initiation of atherosclerotic plaque development by regulating ATP-dependent monocyte adhesion (Deroutte *et al.* 2009).

In addition to cells responsible for atherosclerosis and aCVD, *Cx 37* is also present in ovary, in which gap junctions mediate metabolic cooperation between granulosa cells and oocyte. These interactions are mediated not only by paracrine factors but also by gap junctions including *Cx37* (Fontana *et al.* 2020). Preimplantation embryos express multiple connexins and assemble them into gap junctions. The suppression of connexin expression seems to play an important role in embryo implantation in several species. The gap junction induction is one of the earliest known signs for a blastocyst-derived signal, which may be involved in preparing the endometrium for implantation. It could help to regulate the invasion process by a coordinated cell death of the endometrial cells replaced by the invading trophoblast (Grümmer and Winterhager 1998). However, despite the importance of the different connexin channels expressed in the endometrium this topic was not evaluated.

Based on these facts, we analyzed data from fetuses from women with spontaneous abortion (SA) for *Cx37* gene polymorphism (1019C>T; Pro319Ser) including its potential interaction with smoking, frequent risk factor for early pregnancy loss. In particular, we analyzed if T allele of *Cx37* gene, found to be protective against ischemic heart disease in our previous studies, could be protective also against SA and if this protection could be modified by smoking status.

Women with verified diagnosis of SA participated in the study after giving written informed consent. The study was approved by the Institutional ethics committees and was conducted according to the Good Clinical Practice guidelines. Participating women filled in questionnaire focused on history of SA and physical and ultrasound examination were performed. Samples of aborted fetuses from Caucasian women (n=547) aged 15-44 years (mean age 32.1±4.8 years) collected during

2008-2011 at the Gynecological and Obstetrical Clinic in Prague (Rynekrova *et al.* 2012, Hubacek *et al.* 2015) were examined. Material acquired from surgical revision of uterine cavity was subjected to a cytogenetic and histological examination. Women with anatomic abnormalities of the uterus, primary endocrinopathies (such as thyreopathy, diabetes mellitus, hyperprolactinemia), known immunologic or hematologic disease, febrile infections during the first trimester, drug abuse and abnormal cytogenetic examination of the aborted tissue were excluded from the study.

As a control group we used data from the cohort of 662 women examined from the population sample in Prague (mean age 57.9±2.8 years). Detailed questionnaire about medical history, focused also on gynecological history including history of SA was obtained (Hubacek *et al.* 2009).

Samples from both groups of women (meant fetuses in study group) were stored at -20 °C and DNA was isolated by standard procedures. To genotype the *Cx37* rs1764391 polymorphism, oligonucleotides 5'-CTGGACCCACCCCTCAGAATGGCCAAAGA and 5'-AGGAAGCCGTAGTGCCTGGTGG and the restriction enzyme AasI (Fermentas, Lithuania) were used. T allele is characterized by restriction fragments 240 bp + 35 bp; and C allele with the unrestricted 275 bp fragment. Restriction fragments were separated *via* electrophoresis using 2 % agarose gel (Pitha *et al.* 2016b).

We compared the prevalence of *Cx37* gene variants (TT, CT, CC) between aborted material from women with SA vs. women from general population after stratifying them by smoking status (self-reported). Continuous variables were compared by unpaired Student's *t*-test (between study population and control group), for categorical variables χ^2 Fischer exact test was used.

In women with spontaneous abortion 5.6 % were smokers/past smokers (mean age 27.2±6.5 years) and 94.4 % were non-smokers (mean age 32.3±4.6 years) (difference for age, $p<0.001$). In the population sample 44.8 % women were smokers/past smokers (mean age 57±2.7 years) and 55.2 % non-smokers (mean age 57±2.7 years).

Cx37 T allele was present in 55.2 % (mean age 32.1±4.7 years) of aborted fetuses, and in 57.5 % (mean age 57±2.7 years) of women from general population. In smoking women at least one T allele was present in 53.4 % of the fetuses, and in 56.1 % of women from

general population. In non-smoking women at least one T allele was present in 55.1 % of the fetuses, and in 59.0 % of women from general population. We compared distribution of Cx37 gene polymorphism between fetuses from women older than 32 years with women younger than 32 years (median age). No difference in the prevalence of T allele was detected (56.9 % vs. 54.2 %, $p=0.294$). We also tested difference in prevalence of T allele between fetuses of women with one SA ($n=448$) and fetuses of women with more than 1 SA ($n=115$), but also in this case no significant difference was detected (54.3 % vs. 60.0 %, $p=0.161$). The only difference found was that women with more than one SA were older than women with one SA (34.1 ± 4.7 vs. 31.6 ± 4.8 years, $p<0.001$). In addition, in the control group from general

population, women (after exclusion of diabetics) with the history of one or more SA ($n=51$) were compared to women without history of SA with history of pregnancy ($n=233$) of similar age, no difference in the presence of T allele was observed (66.7 % vs. 60.1 %; $p=0.671$).

Using general population as a control sample, ORs for T allele carriers were calculated for the whole populations under study and for smoking and non-smoking women including similar stratification to smokers/past smokers and non-smokers as in the control group. Fetuses from women suffering from SA with T allele have OR 0.91 (95 % CI 0.72-1.14) and there was no interaction with smoking status of mothers, OR 0.84 (0.64-1.11) for non-smokers vs. OR 0.89 (0.42-1.9) for smokers (Table 1).

Table 1. Cx37 polymorphism in fetuses and population control. Smoking status in fetuses correspond with this characteristics in mothers.

Entire groups						
Cx37	Controls		Abortions		OR	P
	N	%	N	%		
CC	281	42.5	239	44.8	1.00	
CT	300	45.3	239	44.8	0.93 (0.73-1.19)	0.28
TT	81	12.2	55	10.4	0.80 (0.54-1.18)	0.25
+T	381	57.5	294	55.2	0.91 (0.72-1.14)	0.41
Smokers/past smokers						
Cx37	Controls		Abortions		OR	P
	N	%	N	%		
CC	126	43.9	14	46.7	1.00	
CT	121	42.2	14	46.7	1.04 (0.48-2.28)	0.92
TT	40	13.9	2	6.7	0.45 (0.10-2.07)	0.29
+T	161	56.1	16	53.4	0.89 (0.42-1.90)	0.77
Neversmokers						
Cx37	Controls		Abortions		OR	P
	N	%	N	%		
CC	144	40.7	232	44.9	1.00	
CT	172	48.6	231	44.7	0.83 (0.63-1.11)	0.21
TT	38	10.4	54	10.4	0.88 (0.55-1.40)	0.28
+T	210	59.0	285	55.1	0.84 (0.64-1.11)	0.22

In summary, in our study we found no significant differences in Cx37 gene variability between fetuses analyzed after SA and general population of

middle aged women. These results were not modified by smoking status. Therefore, in contrast to our previous findings in women with acute coronary syndrome (Pitha

et al. 2016a) T allele does not seem to be neither protective against SA, nor its effect is strongly modified by smoking status. Therefore, mechanisms leading to cardiovascular disease and complications during pregnancy including SA seems to be different regarding mechanism mediated by gap junctions involved in differentiation processes by mediating exchanges between mother and fetus cells, affecting the maternofetal blood flow interrelationships, trophoblast invasiveness and the formation of a syncytiotrophoblast (Malassiné and Cronier 2005). Expression of some connexins, among them also Cx37, has been shown to reflect maturity of luteinized follicles in animal models and Cx43 expression was associated with better prognosis in *in vitro* fertilization (Tsai *et al.* 2003). Transcription factors of several connexins were detected in human embryos, e.g. Cx43 was indicated in all embryonic developing stages (Bloor *et al.* 2004). He and Chen (2016) demonstrated that the expression of Cx43, together with VEGF, is significantly reduced in chorionic villi and decidua in women with spontaneous abortion. This may be caused by the influence on angiogenesis of placenta and developing embryo. It was reported (Togashi *et al.* 2015), that mouse embryos cultured with some gap junctions inhibitors presented frequent collapses and developmental delay. Functional and structural abnormalities of Cx43 might also play an important role in heart diseases (Pecoraro *et al.* 2015). Because of this finding and possible similarity with Cx43, we focused on Cx37 polymorphism on spontaneous abortion. In addition, Cx37 polymorphism is also supposed to play important role in cardiovascular events. Nevertheless, we did not find an association in the case of Cx37 gene as for other studies describing different connexins polymorphisms and spontaneous abortion (He and Chen 2016).

Regarding the (absence of) effect of smoking in our study, the idea was that adhesion properties of vessels wall caused by Cx37 gene polymorphism could favor not only macrophage accumulation in the atherosclerotic lesions but also endothelial dysfunction induced by smoking initiated by reduced nitric oxide bioavailability and further by the increased expression of adhesion molecules (Messner *et al.* 2014) Therefore protective effect of the Cx37 T allele might be strongly modified by smoking in atherosclerosis. But according to our data the deleterious effect of smoking on pregnancy, particularly on SA seems not to be mediated through Cx37 gene.

The limitations of our study are incomplete data in women with history of SA and focus only on one

polymorphism of one gene from rather large connexin family. On the other hand, the strengths of the study include high number of studied women and numerous representative control group from the population sample in Prague, which could reflect real population background for our findings in contrast to cases and controls usually used for such comparisons. In addition, selecting only Cx37 gene was based on knowledge, that connexin 37 is on one hand the main protein of gap junctions in cells involved in the process of atherosclerosis, but on the other hand it is also present in maternofetal organs. Moreover, data from the Czech Republic, Croatia, Hungary and Romania indicated that the strongest protective effect of the Cx37 T allele was detected in the non-smoking patients without diabetes mellitus and hypertension and that effect could be mediated through stem cells (Pitřha *et al.* 2010, Pitřha *et al.* 2016a). Therefore, we have chosen Cx37 polymorphism as gene potentially covering both cardiovascular and pregnancy complications. Another limitation is the lack of data from mothers/fathers and absence of information regarding other potential modifying factors including diabetes mellitus; however, women with these characteristics were excluded to detect only the effect of this particular gene variability and smoking.

In summary, to the best of our knowledge, only a few studies have demonstrated effect of connexins on spontaneous abortion and no studies analyzed parallel effect of particular connexin gene polymorphism on cardiovascular disease and SA. In our study, no effect of Cx37 polymorphism measured in fetuses was observed on abortion and no interaction with smoking status on this association was proved.

Conflict of Interest

There is no conflict of interest.

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Abbreviations

aCVD – Cardiovascular disease of atherosclerotic origin, CI – Confidence interval, Cx37 – Connexin 37, DNA – Deoxyribonucleic acid, OR – Odds ratio, SA – Spontaneous abortion, VEGF – Vascular endothelial growth factor.

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