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Involvement of \textit{BAG3} and \textit{HSPB7} loci in various etiologies of systolic heart failure:

Results of a European collaboration assembling more than 2,000 patients

Sophie Garnier, PhD\textsuperscript{1,2,3}; Christian Hengstenberg, MD-PhD\textsuperscript{4}; Nicolas Lamblin, MD-PhD\textsuperscript{5}; Olivier Dubourg, MD-PhD\textsuperscript{6,7}; Pascal De Groote, MD-PhD\textsuperscript{8}; Laurent Fauchier, MD\textsuperscript{8}; Jean-Noël Trochu, MD-PhD\textsuperscript{9}; Eloisa Arbustini, MD-PhD\textsuperscript{10}; Ulrike Esslinger, PhD\textsuperscript{1,3,4}; Paul Barton, MD-PhD\textsuperscript{11}; Benjamin Meder, MD\textsuperscript{12}; Hugo Katus, MD-PhD\textsuperscript{12}; Karen Frese, PhD\textsuperscript{12}; Michel Komajda, MD-PhD\textsuperscript{1,3,13}; Stuart SA. Cook, PD-PhD\textsuperscript{14,15,16}; Richard Isnard, MD-PhD\textsuperscript{1,13}; Laurence Tiret, PhD\textsuperscript{1,2,3}; Eric Villard, PhD\textsuperscript{1,2,3,13}; Philippe Charron, MD-PhD\textsuperscript{1,3,6,7}

\textsuperscript{1}INSERM, UMR_S 1166, F-75013, Paris, France; \textsuperscript{2}Sorbonne Universités, UPMC Univ Paris 06, UMR_S 1166, Team Genomics & Pathophysiology of Cardiovascular Diseases, F-75013, Paris, France; \textsuperscript{3}ICAN Institute for Cardiometabolism and Nutrition, F-75013, Paris, France; \textsuperscript{4}University of Regensburg, Department of Internal Medicine II, Regensburg, Germany; \textsuperscript{5}Hôpital Régional Universitaire de Lille - Hôpital Cardiologique, Lille, France; \textsuperscript{6}Hôpital Ambroise Paré AP-HP, Paris, France; \textsuperscript{7}Université de Versailles Saint Quentin en Yvelines, Versailles, France; \textsuperscript{8}Hôpital Régional Universitaire de Tours, Tours, France; \textsuperscript{9}INSERM UMR 1087, Nantes, France; \textsuperscript{10}IRCCS Foundation Policlinico San Matteo, Center for Genetic Cardiovascular Diseases, Pavia, Italy; \textsuperscript{11}Royal Brompton & Harefield NHS Foundation Trust's NIHR Cardiovascular biomedical research unit, London, United Kingdom; \textsuperscript{12}University Hospital Heidelberg, Heidelberg, Germany; \textsuperscript{13}Université Paris 6 & AP-HP, Hôpital de la Pitié-Salpêtrière, Paris, France; \textsuperscript{14}National Heart and Lung Institute, Imperial College London, London, United Kingdom; \textsuperscript{15}National Heart Centre Singapore, Singapore; \textsuperscript{16}Duke-NUS, Singapore
Corresponding author: Dr. Sophie Garnier

INSERM UMR S 1166 - Team Genomics & Pathophysiology of Cardiovascular Diseases

Faculté de médecine Pierre et Marie Curie 6ème étage,
91 Boulevard De l'Hôpital, 75634 Paris Cedex 13, France

Tel: +33 1 40 77 81 40
Fax: +33 1 40 77 96 25
e-mail: sophie.garnier@upmc.fr

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Heart failure (HF), a major public health burden affecting 2% of industrialized populations, is a syndrome resulting from structural or functional myocardial impairment leading to inadequate cardiac output to meet the body’s metabolic demands (1). Half of HF patients present systolic dysfunction (systolic-HF), also called reduced ejection fraction (HF-REF), a disease related to various causes including idiopathic Dilated Cardiomyopathy (DCM) and Coronary Artery Diseases (CAD) (ischemic-HF). HF is usually a multifactorial disease but the genetic variants contributing to its susceptibility or its severity may be different according to its underlying causes (2) and their identification is only beginning.

A previous genome wide association study (GWAS) (3) identified two single nucleotide polymorphisms (SNPs) associated with DCM: rs2234962 within BAG3 gene (B-cell lymphoma 2-associated athanogene 3) and rs10927875 within a locus encompassing five genes including HSPB7 (heat shock 27 kDa protein family, member 7) (further called HSPB7 locus). Other studies also reported associations between polymorphisms in the HSPB7 locus and HF (4-6), two of them assessing the implication of the locus in the subgroup of ischemic-HF patients (4, 5), but none addressed the role of BAG3 in ischemic-HF nor the potential impact of HSPB7 and BAG3 loci on HF severity. We hypothesized that these two loci could be involved in susceptibility to syst-HF due to CAD (ischemic-HF) and/or in severity of syst-HF due to CAD or DCM.

All participants were of European origin, had a diagnosis of systolic-HF (Left Ventricle Ejection Fraction, LVEF, < 45%) and gave written informed consent. The study complies with the principles of the Declaration of Helsinki and was approved by local ethics committees. In total, 1160 ischemic-HF patients and 1612 controls and 1141 DCM patients were studied. Genotyping of rs2234962-BAG3 and rs10927875-HSPB7 was performed with TaqMan technology. Disease severity was assessed in patients with Ischemic-HF or DCM as
following: LVEF, Left Ventricle End Diastolic Diameter (LVEDD), NYHA dyspnea at inclusion and Age at diagnosis.

We analyzed the data following this summarized methodology. After quality controls and Hardy-Weinberg equilibrium testing in controls (p<0.05), the association between Ischemic-HF and individual genotypes was tested using a logistic regression model adjusting on age, gender, and study population in the R statistical environment (7). We assumed an additive mode of inheritance and decided to adjust the p-value threshold following Bonferroni correction for two independent tests (p-value <0.025 considered significant). Severity assessment in patients was performed via linear regression analyses adjusted for age, sex, and origin depending on the SNP genotype exposure.

Considering the allelic odds ratios for rs10927875-\textit{HSPB7} and rs2234962-\textit{BAG3} associations with DCM (0.71 and 0.54 respectively) (3) and the p-value threshold of 0.025, our study had a 95% and 99% power to detect similar associations.

We observed that rs10927875-\textit{HSPB7} is significantly associated with Ischemic-HF (Table 1), with a MAF lower in patients than in controls (0.29 vs. 0.33, p=0.0017, odds ratio 0.96 [0.94-0.98]), which is consistent with a protective effect of the T minor variant against Ischemic-HF. No significant association was detected between rs2234962-\textit{BAG3} and Ischemic-HF (Table 1), even though a trend was detected.

Regarding severity, rs2234962-\textit{BAG3} was significantly associated with LVEDD both in DCM (adjusted-p: 0.0056, Table 2, N=1076 patients) and ischemic-HF patients (adjusted-p: 0.01, N=359 patients). In the ischemic-HF population, the major allele T of rs2234962-\textit{BAG3} was associated with enlarged LVEDD (TT: 64.0 ±8.7 mm; TC: 62.7 ±8.0 mm and CC: 61.8 ±9.8 mm) and thus with a greater severity of the disease. Results are less clear in DCM.
patients although the same trend could be observed between major homozygous and heterozygous alleles (TT: 70.9 ±9.6 mm and TC: 69.1 ±9.2 mm respectively).

No other association could be revealed between the two SNPs and any of the other severity criteria.

The protective effect of the T minor allele of rs10927875-HSPB7 against ischemic-HF is consistent with previous findings in DCM patients (3). Matkovich and Cappola also described SNPs in HSPB7 locus, rs1739840 and rs1739843 respectively, which exhibited a lower MAF in Ischemic-HF cases than in controls (0.4126 vs. 0.4735 and 0.367 vs 0.436 respectively) (5, 6).

Finding an association between ischemic-HF and HSPB7 locus but not with BAG3 locus suggests that the genetic background of multifactorial systolic-HF is different according to its underlying causes. This is meaningful since the pathophysiological pathways of these two diseases are different. DCM resulting from a primary myocardial defect whereas ischemic-HF is due to ischemia and necrosis. Since HSPB7 locus appears involved in both causes, this may reflect a pivotal role of gene(s) in the locus as a poorly adaptive process to various triggers. The restricted association of BAG3 locus with DCM suggests a more specific role in the context of a primary myocardial defect.

rs10927875-HSPB7 locates in an intron of ZBTB17 on chromosome 1p36, but the locus encompasses several other genes—SPEN, HSPB7, CLCNKA and CLCNKB—exhibiting strong linkage disequilibrium. HSPB7 is considered as a strong candidate because it exhibits cardiac-specific expression and some of its variants have been independently associated with advanced HF, systolic-HF (8) or with DCM (4-6). A recent study found that HSPB7 is early expressed in embryonic heart and have a major role in heart embryogenesis (9).
BAG3 is mainly expressed in striated muscle and is involved in anti-apoptosis and anti-proteotoxicity pathways (10). rs2234962-BAG3, a non-synonymous SNP (c.T757C, p.C151R) predicted as probably damaging by Polyphen, is associated in our study with LVEDD in both ischemic-HF and CMD populations. The number of T alleles appears related with enlarged LVEDD in ischemic-HF patients but this was less clear for DCM patients, possibly due to the very low T homozygous DCM patients (9 out of the 1141). A less efficient BAG3 activity may favour HF severity but the hypothesis is speculative.

Out of the two loci previously associated with DCM, we observed that HSPB7 locus was also associated with ischemic-HF whereas BAG3 locus was not. Conversely, BAG3 locus was associated with LVEDD in both DCM and syst-HF patients. Our results suggest investigating further the role of these two loci in the pathophysiology of HF of various causes.
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CONFLICT OF INTEREST

The authors report no relationships that could be construed as a conflict of interest
REFERENCES


Table 1: Genotypic repartition of cases (ischemic-HF), controls and allelic comparison test assuming an additive allele effect

<table>
<thead>
<tr>
<th>SNP</th>
<th>Population</th>
<th>Patients Genotype</th>
<th>MAF</th>
<th>Controls Genotypes</th>
<th>MAF</th>
<th>p-adj*</th>
<th>OR [CI 95%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>rs10927875-HSPB7 (TT/TC/CC)</td>
<td>Germany</td>
<td>18/133/147</td>
<td>0.28</td>
<td>32/127/115</td>
<td>0.35</td>
<td>0.06</td>
<td>0.95 [0.90-1.00]</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>28/153/173</td>
<td>0.29</td>
<td>84/310/312</td>
<td>0.34</td>
<td>0.17</td>
<td>0.97 [0.94-1.01]</td>
</tr>
<tr>
<td></td>
<td>UK</td>
<td>33/221/235</td>
<td>0.29</td>
<td>47/271/256</td>
<td>0.32</td>
<td>0.30</td>
<td>0.98 [0.96-1.01]</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>79/507/555</td>
<td>0.29</td>
<td>163/708/683</td>
<td>0.33</td>
<td>1.7E-3</td>
<td>0.96 [0.94-0.98]</td>
</tr>
<tr>
<td>rs2234962-BAG3 (CC/TC/TT)</td>
<td>Germany</td>
<td>12/92/192</td>
<td>0.20</td>
<td>12/90/171</td>
<td>0.21</td>
<td>0.75</td>
<td>0.99 [0.93-1.05]</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>13/103/241</td>
<td>0.18</td>
<td>32/232/433</td>
<td>0.21</td>
<td>0.13</td>
<td>0.96 [0.92-1.00]</td>
</tr>
<tr>
<td></td>
<td>UK</td>
<td>13/151/323</td>
<td>0.18</td>
<td>18/199/346</td>
<td>0.21</td>
<td>0.43</td>
<td>0.99 [0.95-1.02]</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>38/346/756</td>
<td>0.18</td>
<td>62/521/960</td>
<td>0.21</td>
<td>0.07</td>
<td>0.97 [0.94-1.00]</td>
</tr>
</tbody>
</table>

This table gives the genotypic repartition for the three SNPs in the corresponding population. The deducted Minor Allele Frequency (MAF) is also given. *p-adj, p-value adjusted for age, gender and population. OR calculation was done on the row genotypes data thus no adjustment was performed.
Table 2: Association with severity sub-phenotypes for French, German and Italian DCM patients.

<table>
<thead>
<tr>
<th>SNP</th>
<th>Severity criteria</th>
<th>France (N=749)</th>
<th>Germany (N=278)</th>
<th>Italy (N=114)</th>
<th>Total (N=1141)</th>
</tr>
</thead>
<tbody>
<tr>
<td>rs10927875-HSPB7</td>
<td>LVEF (N=1004)</td>
<td>0.14</td>
<td>0.24</td>
<td>0.05</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>LVEDD (1076)</td>
<td>0.47</td>
<td>0.82</td>
<td>0.79</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>NYHA (738)</td>
<td>0.79</td>
<td>0.02</td>
<td>0.35</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Age at diagnosis (1141)</td>
<td>0.66</td>
<td>0.07</td>
<td>0.95</td>
<td>0.2</td>
</tr>
<tr>
<td>rs2234962-BAG3</td>
<td>LVEF (1004)</td>
<td>0.13</td>
<td>0.40</td>
<td>0.10</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>LVEDD (1076)</td>
<td>4.1E⁻³</td>
<td>0.37</td>
<td>0.78</td>
<td>5.6E⁻³</td>
</tr>
<tr>
<td></td>
<td>NYHA (738)</td>
<td>0.59</td>
<td>0.09</td>
<td>0.02</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>Age at diagnosis (1141)</td>
<td>0.57</td>
<td>0.74</td>
<td>0.27</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The phenotypic information was not always available for the 1141 DCM cases. The exact number of tested individuals is given for each sub-phenotype. *p-adj, p-value of the test adjusted on age, gender and population.