

# GNAS Gene Variants Affect $\beta$ -blocker–related Survival after Coronary Artery Bypass Grafting

Ulrich H. Frey, M.D., Jochen D. Muehlschlegel, M.D., M.M.Sc., Christoph Ochterbeck, Ph.D., Amanda A. Fox, M.D., M.P.H., Stanton K. Shernan, M.D., Charles D. Collard, M.D., Peter Lichtner, Ph.D., Jürgen Peters, M.D., Simon Body, M.B.Ch.B., M.P.H.

## ABSTRACT

**Background:** Cardiac overexpression of the  $\beta$ -adrenoreceptor ( $\beta$ AR)–coupled stimulatory G-protein subunit  $G_{\alpha s}$  enhances inotropic responses to adrenergic stimulation and improves survival in mice under  $\beta$ AR blockade. The authors recently identified three common haplotypes in the *GNAS* gene encoding  $G_{\alpha s}$ , with the greatest  $G_{\alpha s}$  protein expression and signal transduction in haplotype \*3 carriers and less in haplotype \*2 and \*1 carriers. The authors tested the hypothesis that these *GNAS* variants result in altered mortality in patients after coronary artery bypass graft surgery, particularly in those receiving  $\beta$ AR blockade.

**Methods:** This prospective analysis included 1,627 European ancestry patients undergoing primary coronary artery bypass graft surgery. Patients were genotyped for two *GNAS* haplotype tagging single-nucleotide polymorphisms defining three major haplotypes. Up to 5-yr all-cause mortality was estimated using a Cox proportional hazard model; hazard ratios and 95% CIs were calculated while adjusting for demographics, clinical covariates, and the new EuroSCORE II.

**Results:** Univariate analysis revealed haplotype-dependent 5-yr mortality rates (\*1/\*1: 18.9%, \*2/\*1: 13.7%, \*2/\*2: 9.3%, \*3/\*1: 10.6%, \*3/\*2: 9.1%, and \*3/\*3: 9.6%;  $P = 0.0006$ ). After adjustment for other predictors of death, homozygote haplotype \*1 carriers showed a doubled risk for death (hazard ratio, 2.2; 95% CI, 1.2 to 3.8;  $P = 0.006$ ). Considering only patients receiving  $\beta$ AR blockers ( $n = 1,267$ ), the adjusted risk of death even tripled (hazard ratio, 3.0; 95% CI, 1.5 to 6.1;  $P = 0.002$ ).

**Conclusions:** *GNAS* haplotypes independently associate with an increased risk of death after primary coronary artery bypass graft surgery. These results are most pronounced in patients receiving  $\beta$ AR blockers, strengthening the rationale for personalized treatment, to decrease medication side effects and improve outcomes. (**ANESTHESIOLOGY 2014; 120:1109-17**)

THE cardiac  $\beta$ -adrenergic receptor ( $\beta$ AR) signal transduction pathway regulates inotropy and chronotropy.  $\beta$ AR stimulation results in activation of the  $\alpha$  subunit of the stimulatory G-protein ( $G_{\alpha s}$ ), which is coupled to adenylyl cyclase and increases cyclic adenosine monophosphate production. In coronary artery disease–associated ischemic heart failure, chronic stimulation of  $\beta$ ARs by increased concentrations of circulating catecholamines evokes  $\beta$ AR desensitization through uncoupling of downstream signaling effectors.<sup>1,2</sup>  $\beta$ AR blocker use results in a restoration of  $\beta$ AR sensitivity and has been associated with slightly increased survival in patients after coronary artery bypass graft (CABG) surgery.<sup>3</sup> However, substantial heterogeneity of individual responses to  $\beta$ AR blocker therapy exists and appear related in part to variation in the adrenergic pathway genes.<sup>4</sup> Yet, results of studies addressing the association of genetic variation in the  $\beta$ AR with cardiac outcomes have been disappointing, and most presumptive associations have not been consistently replicated in later studies.<sup>5-9</sup>

### What We Already Know about This Topic

- In animals, overexpression of the G-protein subunit  $G_{\alpha s}$  enhances inotropy from adrenergic stimulation and improves survival in the face of  $\beta$ -adrenoreceptor blockade
- There is genomic variability in the *GNAS* gene for this protein in humans, which may impart risk to surgery and  $\beta$ -blockade

### What This Article Tells Us That Is New

- In 1,627 patients undergoing coronary artery bypass graft surgery, those with a *GNAS* haplotype resulting in low expression and function of  $G_{\alpha s}$  showed double the risk of death compared with other haplotypes
- In this high-risk group, those who also received  $\beta$ -blockers showed triple the risk of death

Due to the direct signal transduction from  $\beta$ ARs to the G-protein  $G_{\alpha s}$ ,  $G_{\alpha s}$  might play a role in  $\beta$ AR blocker–related outcomes in patients undergoing CABG. Supporting

This article is featured in “This Month in Anesthesiology,” page 1A. Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are available in both the HTML and PDF versions of this article. Links to the digital files are provided in the HTML text of this article on the Journal’s Web site ([www.anesthesiology.org](http://www.anesthesiology.org)). This article is based on an Abstract for the 2013 American Society of Anesthesiologists (ASA) Best Abstracts session and Annual Meeting of the ASA 2013, San Francisco, California, October 12–16, 2013. The first two (U.H.F. and J.D.M.) and last two authors (J.P. and S.B.) contributed equally to this study.

Submitted for publication June 20, 2013. Accepted for publication January 16, 2014. From the Klinik für Anästhesiologie und Intensivmedizin, Universität Duisburg-Essen and Universitätsklinikum Essen, Essen, Germany (U.H.F., C.O., J.P.); Department of Anesthesiology, Perioperative, and Pain Medicine, Brigham and Women’s Hospital, Harvard Medical School, Boston, Massachusetts (J.D.M., S.K.S., S.B.); Department of Anesthesiology and Pain Management, Southwestern Medical Center, Dallas, Texas (A.A.F.); Division of Cardiovascular Anesthesiology, Texas Heart Institute, St. Luke’s Episcopal Hospital, Houston Texas (C.D.C.); and Helmholtz Zentrum München, Deutsches Forschungszentrum für Gesundheit und Umwelt, Neuherberg, Germany (P.L.).

Copyright © 2014, the American Society of Anesthesiologists, Inc. Lippincott Williams & Wilkins. Anesthesiology 2014; 120:1109-17

this, in transgenic mice, overexpression of *G $\alpha$ s* using a rat  $\alpha$ -myosin heavy chain promoter<sup>10</sup> increases heart rate and cardiac contractility in young transgenic animals but is associated with dilated cardiomyopathy at old age.<sup>11</sup> By contrast, chronic  $\beta$ AR blockade completely prevents the decrease in ejection fraction, cardiac dilation, and premature mortality, characteristic of older transgenic mice overexpressing *G $\alpha$ s*.<sup>12</sup> These data indicate significant physiological effects of increased *G $\alpha$ s* expression. In humans, however, genetic overexpression experiments are difficult to perform and, therefore, it remains unknown whether altered *G $\alpha$ s* expression affects the prognosis of humans with cardiac disease.

*G $\alpha$ s* is imprinted in a tissue-specific manner. Although it is expressed primarily from the maternal allele in some select hormone-active tissues, it is biallelically expressed with an almost equal contribution of the maternal and paternal allele in most tissues.<sup>13</sup> Although heterozygous *GNAS* mutations in specific tissues result in different kinds of endocrine disorders,<sup>14</sup> germline variations affecting *G $\alpha$ s* expression have not hitherto been identified. By sequencing the human *GNAS* gene, we recently identified two haplotype tagging single-nucleotide polymorphisms (SNPs), G(-1211)A and T2291C, which are located in regulatory regions and form three common haplotypes in the *GNAS* gene.<sup>15,16</sup> Haplotype \*3 (A(-1211)/C2291) carriers showed altered transcription factor binding, increased *G $\alpha$ s* expression, and enhanced *G $\alpha$ s*-stimulated adenylyl cyclase activity. This was associated with a higher stroke volume and cardiac index as well as a lower N-terminal pro-brain natriuretic peptide concentration,<sup>15,16</sup> indicating that germline variants in regulatory regions of the *G $\alpha$ s* gene serve as markers to investigate functional and clinical consequences of altered *G $\alpha$ s* expression. These observations along with a pilot study of short-term mortality after CABG surgery<sup>17</sup> led us to the hypothesis that *GNAS* variants associate with mortality during the 5 yr after CABG surgery and that this association is modified by the presence or absence of  $\beta$ AR blockade.<sup>11</sup> We further hypothesized that genetic variants would add additional predictive value over the EuroSCORE II surgical risk index, a validated and commonly used method for predicting mortality after CABG surgery.<sup>18,19</sup>

## Materials and Methods

### Study Sample

Patients aged 20 to 80 yr undergoing nonemergent primary CABG surgery using cardiopulmonary bypass without other concurrent surgery were prospectively enrolled (<http://clinicaltrials.gov/show/NCT01258231>) at two institutions (Brigham and Women's Hospital, Boston, Massachusetts, and Texas Heart Institute, St. Luke's Episcopal Hospital, Houston, Texas) between August 2001 and January 2009. Patients with a preoperative hematocrit of less than 25% or those having received a transfusion of leukocyte-rich blood products within 30 days before surgery were not enrolled.

To avoid potential population stratification, analysis was restricted to subjects who self-reported four generations of grandparental European ancestry. Study protocols were approved by the respective Institutional Review Boards, and participants were enrolled after providing informed written consent. At each site, patient demographics, perioperative risk factors, medications, and postoperative outcomes were recorded using study-specific case report forms. Mortality was assessed by accessing hospital records and the Social Security Death Index.<sup>†</sup> Death status was queried at 5 yr of follow-up or earlier in patients who had not completed 5 yr of follow-up at the time this analysis was performed.

### Genotyping

DNA was extracted from leukocytes using standard protocols. Two *GNAS* gene SNPs (Chr. 20): G(-1211)A (rs6123837) and T2291C (rs6026584) and two *ADRB2* gene SNPs (Chr. 5), Arg16Gly (nucleotide 46 A/G, rs1042713), and Gln-27Glu (nucleotide 79 C/G, rs1042714) were genotyped. The method of "slowdown polymerase chain reaction"<sup>20</sup> was used to amplify promoter and intron 1 fragments comprising *GNAS* SNPs as previously described.<sup>16</sup> *GNAS* and *ADRB2* SNPs were genotyped using genotyping assays from Applied Biosystems (Carlsbad, CA). *GNAS* haplotypes were inferred using the Bayesian statistical-based program PHASE, version 2.1,<sup>21</sup> resulting in three common haplotypes (\*1, \*2, and \*3). Individual diplotypes (*i.e.*, haplotype pairs) were constructed from the respective genotypes (see table, Supplemental Digital Content 1, <http://links.lww.com/ALN/B35>). All SNPs were in Hardy–Weinberg equilibrium.

### Statistical Analysis

Data are presented as mean  $\pm$  SD unless stated otherwise. Univariate comparisons of 5-yr genotype- or diplotype-related mortality were performed using Cox proportional hazard statistics. Kaplan–Meier plots were used to show the relation between genotypes or diplotypes and cumulative mortality. Log-rank tests for trend were performed for genotype- or diplotype-dependent survival using an additive model due to a gene-dose effect. After demonstrating a significant  $\beta$ AR blocker  $\times$  diplotype interaction on the univariate ( $P = 0.018$ ) as well as the multivariate level ( $P = 0.015$ ), we generated two multivariable (Cox proportional hazards) predictor models of mortality in patients receiving  $\beta$ AR blockers. The first model was generated using clinical and demographic variables that were associated ( $P < 0.1$ ) in univariate analysis as well as covariates being part of the EuroSCORE II with time to death during the first 5 yr after surgery. The second multivariable model incorporated the EuroSCORE II score. Patients who did not die during the 5 yr after CABG were censored at 5 yr or at the last date of follow-up if that was less than 5 yr after surgery.

Proportional hazards assumptions were obtained by computing correlations between time and partial residuals, which are calculated separately for each genetic predictor. Partial residuals were plotted against survival time to test the proportional hazards assumption by adding a smoother to the residual plots.

<sup>†</sup> Available at: <http://searches.rootsweb.ancestry.com/ssdi.html>. Accessed December 16, 2013.

In addition, general linear regression analysis was performed for partial residuals against time. A nonzero correlation was regarded as evidence against the proportionality assumption.

This study takes the advantage of an ongoing registry and longitudinally updated data set, CABG Genomics, which has been used for previous analyses of genetic associations. We are aware of potential problems of multiplicity in a data set over time, but adjusting the  $\alpha$  error for previous analyses is difficult and has traditionally not been done. Hence, neither attempts were made to adjust the error rate for past or future analyses of these data, nor did we consider multiple genotype predictors.

Data were analyzed using the SPSS software package, version 19.0 (IBM, New York, NY). A two-tailed *P* value of less than 0.05 was considered statistically significant.

**Results**

Patient characteristics stratified by *GNAS* genotypes are shown in table 1. Whereas only a significant association of T2291C and sex could be detected, no association of *GNAS* genotypes and variables of cardiovascular disease prevalence were identified.

During the up to 5-yr postoperative follow-up period, 10.9% of subjects died. Median follow-up time of surviving

**Table 1.** Demographic Variables and Statistics as Related to *GNAS* Genotypes

	G(-1211)A				T2291C			
	AA (n = 216)	AG (n = 719)	GG (n = 692)	<i>P</i> Value	CC (n = 729)	CT (n = 697)	TT (n = 201)	<i>P</i> Value
<b>Demographics</b>								
Sex, N (% male)	173 (80.1)	564 (78.4)	565 (81.6)	0.322	569 (78.1)	578 (82.9)	155 (77.1)	0.039
Age, yr (range)	65 (35–86)	64 (25–89)	65 (35–89)	0.568	65 (25–89)	64 (28–89)	65 (41–89)	0.136
BMI (kg/m <sup>2</sup> )	29.4±5.2	29.6±5.7	30.0±5.7	0.318	29.7±5.7	29.6±5.6	30.1±5.9	0.642
Euroscore II	3.6±4.0	3.8±5.3	4.0±5.2	0.578	3.8±5.0	3.8±5.1	4.4±5.4	0.231
<b>Medical history</b>								
Preoperative LVEF, (%)	52±12	51±12	52±11	0.411	52±12	52±12	51±13	0.963
Diabetes mellitus, N (%)	82 (38)	252 (35)	218 (32)	0.151	255 (35)	222 (32)	75 (37)	0.256
Pulmonary disease, N (%)	29 (13)	118 (16)	126 (18)	0.244	110 (15)	123 (18)	40 (20)	0.195
Creatinine concentration, (mg/dl)	1.1±0.4	1.1±0.3	1.1±0.3	0.460	1.1±0.3	1.1±0.3	1.1±0.3	0.383
Hematocrit, (%)	41±4	41±4	40±4	0.942	40±4	41±4	40±4	0.382
Hypertension, N (%)	157 (73)	543 (76)	527 (76)	0.583	557 (76)	524 (75)	147 (73)	0.537
Hypercholesterolemia, N (%)	169 (78)	532 (74)	547 (79)	0.068	562 (77)	521 (75)	165 (82)	0.090
Coronary stenosis (>50%) regions, N (%)								
≤2	37 (18)	175 (25)	172 (26)		170 (24)	167 (25)	47 (24)	
3	118 (56)	352 (51)	343 (52)		371 (53)	344 (51)	98 (50)	
≥4	56 (27)	170 (24)	151 (23)	0.147	165 (23)	161 (24)	51 (26)	0.940
Previous myocardial infarction, N (%)	89 (41)	285 (40)	283 (41)	0.860	300 (41)	272 (39)	85 (42)	0.601
<b>NYHA, N (%)</b>								
I	71 (33)	218 (30)	224 (32)		239 (33)	212 (30)	62 (31)	
II	86 (40)	304 (42)	291 (42)		287 (39)	304 (44)	90 (45)	
III	46 (21)	164 (23)	142 (21)		167 (23)	148 (21)	37 (18)	
IV	13 (6)	33 (5)	35 (5)	0.876	36 (5)	33 (5)	12 (6)	0.580
<b>Medications: preoperative, N (%)</b>								
β-Blocker	176 (81)	563 (78)	528 (76)	0.259	583 (80)	533 (77)	151 (75)	0.170
Aspirin	171 (79)	563 (79)	533 (77)	0.746	585 (81)	528 (76)	154 (77)	0.093
HMG-CoA reductase inhibitor	168 (78)	537 (75)	515 (75)	0.655	562 (78)	503 (73)	155 (78)	0.057
<b>Surgery</b>								
<b>No. of grafts, N (%)</b>								
≤2	26 (12)	128 (18)	115 (17)		113 (16)	122 (18)	34 (17)	
3	93 (43)	338 (47)	316 (46)		342 (47)	302 (43)	102 (51)	
≥4	97 (45)	253 (35)	261 (38)	0.088	274 (38)	273 (39)	64 (32)	0.237
CPB duration, min	101±43	100±45	98±41	0.742	99±41	100±46	97±37	0.695
Aortic cross-clamp duration, min	75±35	74±35	72±35	0.458	74±34	74±36	70±35	0.339
Intraoperative β-blocker administration, N (%)	35 (16)	124 (17)	100 (15)	0.350	119 (16)	112 (16)	28 (14)	0.709
Intraoperative IABP, N (%)	5 (2)	12 (2)	15 (2)	0.737	13 (2)	10 (1)	9 (4)	0.098

Data are shown as percentages for dichotomous variables and as means ± SD for continuous variables. Diabetes mellitus was defined as insulin dependent or noninsulin dependent. *P* values refer to univariate Cox regression analysis.

BMI = body mass index; CPB = cardiopulmonary bypass; HMG = 3-hydroxy-3-methyl-glutaryl-CoA reductase; IABP = intraaortic balloon pump; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association.

patients was 5.0 yr (range, 2.4 to 5.0 yr). Univariate analysis demonstrated that *GNAS* variants, but not *ADRB2* variants, had a significant association with all-cause mortality (table 2).

*GNAS* variants showed a significant association with mortality for the G(-1211)A variant (GG: 13.2%, AG: 9.8%, and AA: 9.6%;  $P = 0.012$ ; fig. 1A) and the T2291C variant (TT: 18.9%, CT: 12.1%, and CC: 9.2%;  $P = 0.0003$ ; fig. 1B). Estimation of diplotypes confirmed these results with 5-yr mortality for diplotype \*1/\*1: 18.9%, \*2/\*1: 13.7%, \*2/\*2: 9.3%, \*3/\*1: 10.6%, \*3/\*2: 9.1%, and \*3/\*3: 9.6% (overall  $P = 0.0006$ ; fig. 1C). Consideration of clinical covariates revealed a hazard ratio of 2.2 for homozygous \*1 versus \*3 (95% CI, 1.2 to 3.8;  $P = 0.006$ ).

We next examined *GNAS* genotype association with 5-yr mortality stratified by  $\beta$ AR blocker use. When we analyzed patients without  $\beta$ AR blocker therapy, we observed no genotype effect on 5-yr mortality (fig. 1, D–F). In contrast, there was a strong association with mortality in patients receiving  $\beta$ AR blockers. Five-year mortality was associated with genotypes of the *GNAS* variants G(-1211)A (GG: 14.1%, AG: 9.2%, and AA: 6.9%;  $P = 0.0014$ ; fig. 1G), T2291C (TT: 19.4%, CT: 11.5%, and CC: 8.2%;  $P = 0.0002$ ; fig. 1H), and estimated diplotypes (\*1/\*1: 19.4%, \*2/\*1: 13.5%, \*2/\*2: 9.2%, \*3/\*1: 9.7%, \*3/\*2: 8.6%, and \*3/\*3: 6.9%;  $P < 0.0001$ ; fig. 1I). In multivariable analysis, after verifying proportional hazard assumptions, these findings remained

present after accounting for clinical factors previously found to be associated with mortality and revealed increased mortality for \*2/\*1 and \*1/\*1 patients compared with that for homozygous \*3 patients (table 3). We also estimated the additional value of *GNAS* haplotype data on the widely used EuroSCORE II to predict survival after CABG surgery. As expected, we not only observed strong predictive value of the EuroSCORE II but also observed that *GNAS* haplotypes were prognostic factors for 5-yr survival, independent of the EuroSCORE II. Although the EuroSCORE II resulted in a hazard ratio of 1.07 (95% CI, 1.06 to 1.09;  $P < 0.001$ ), patients homozygous for the \*1 *GNAS* haplotype had a more than three-fold increased 5-yr mortality compared with that for patients homozygous for \*3 (hazard ratio, 3.14; 95% CI, 1.57 to 6.31;  $P = 0.001$ ).

In this cohort,  $\beta$ AR blocker use *per se* was not associated with overall survival (fig. 2A). However, stratification by *GNAS* haplotypes demonstrated marked differences in the effect of  $\beta$ AR blocker use on survival. Significantly better survival was seen for patients using  $\beta$ AR blockers and being \*3 positive (91.3%). In contrast, reduced survival was observed in patients not possessing the \*3 haplotype irrespective of  $\beta$ AR blocker therapy (85.6 to 85.9%) or in haplotype \*3 positive patients without  $\beta$ AR blocker therapy (85.8%; fig. 2B;  $P = 0.0085$ ).

## Discussion

Our data show that *GNAS* haplotypes associate with significantly different rates of death during the 5 yr after CABG surgery. *GNAS* haplotype \*1 or \*2 carriers show an increased risk of death compared with the risk by \*3 haplotypes. Importantly, this effect is more pronounced in patients receiving  $\beta$ AR blockers and is independent of other traditional risk factors.

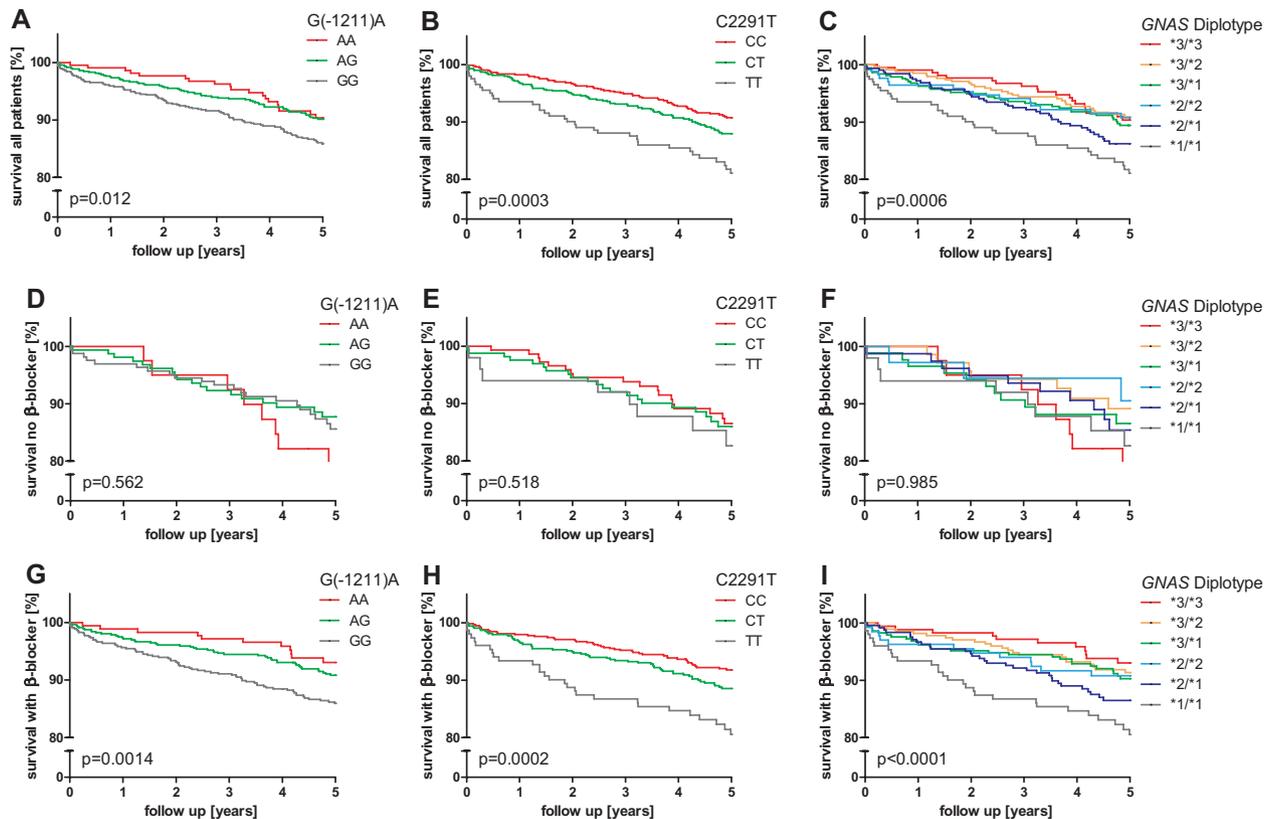
These findings also suggest that routine use of  $\beta$ AR blockers in *GNAS* haplotype \*3 negative patients undergoing cardiac surgery may not provide significant long-term mortality benefit. Furthermore, we observed that the addition of *GNAS* diplotypes to the well-validated EuroSCORE II provides additional predictive value for long-term post-operative mortality. The frequency of homozygosity of the \*1 haplotype, similar to that observed in a different smaller CABG cohort,<sup>17</sup> establishes the *GNAS* haplotype as a common disease-linked haplotype with a novel association to a long-term outcome, whereas an association to cardiovascular disease prevalence has not been detected.

Experiments from transgenic mice indicate the importance of the G $\alpha$ s protein in the maintenance and augmentation of cardiac function.<sup>11,12,22</sup> We recently identified three common haplotypes in the *GNAS* gene encoding G $\alpha$ s<sup>16</sup> with haplotype-specific differences in *GNAS* promoter activity.<sup>16,17</sup> In human myocardium, we could demonstrate the greatest G $\alpha$ s protein expression and signal transduction in haplotype \*3 carriers, followed by haplotypes \*2 and \*1.<sup>17</sup> Interestingly, diminished G $\alpha$ s expression in haplotype

**Table 2.** Genotype-specific Survival

	Alive (N = 1,450)	Died (N = 177)	P Value
Genotype, N (%)			
<i>ADRB2</i> Arg16Gly (n = 1,549)			
Gly/Gly	562 (40)	62 (39)	0.94
Arg/Gly	635 (46)	73 (46)	
Arg/Arg	194 (14)	23 (15)	
<i>ADRB2</i> Glu27Gln (n = 1,550)			
Gln/Gln	483 (35)	47 (30)	0.13
Glu/Gln	639 (46)	87 (55)	
Glu/Glu	269 (19)	25 (16)	
<i>GNAS</i> G(-1211)A			
GG	600 (41)	92 (52)	0.025
AG	653 (45)	66 (37)	
AA	197 (14)	19 (11)	
<i>GNAS</i> T2291C			
TT	165 (11)	36 (20)	0.001
CT	619 (43)	78 (44)	
CC	666 (46)	63 (36)	
<i>GNAS</i> diplotype			
*1/*1	165 (11)	36 (20)	0.008
*2/*1	280 (19)	41 (23)	
*2/*2	155 (11)	15 (9)	
*3/*1	339 (23)	37 (21)	
*3/*2	314 (22)	29 (16)	
*3/*3	197 (14)	19 (11)	

Data are shown as numbers with percentages in brackets.  $P$  values refer to univariate Cox regression analysis.



**Fig. 1.** Kaplan–Meier plots for survival dependent on *GNAS* polymorphisms and respective diplotypes. (A–C) Survival analysis for all patients ( $n = 1,627$ ). (D–F) Survival analysis for patients without  $\beta$ -adrenergic receptor blockade ( $n = 360$ ). (G–I) Survival analysis for patients under  $\beta$ -adrenergic receptor blockade ( $n = 1,267$ );  $P$  values represent log-rank test for trend.

\*1 carriers was associated with a higher  $\beta$ AR density,<sup>16</sup> a feature pathognomonic of  $\beta$ AR up-regulation.<sup>23</sup> However, it has to keep in mind that those experiments were carried out in human atrial tissue and it has been shown that there are differences in the *G $\alpha$ s* expression levels between cardiac atria and ventricular myocardium.<sup>24</sup>

Experiments with transgenic mice overexpressing *G $\alpha$ s* showed increased sensitivity to catecholamines as a result of enhanced  $\beta$ AR coupling to various effector pathways, specifically adenylyl cyclase and L-type calcium channels.<sup>10,11,25</sup> However, the effects of chronically enhanced  $\beta$ -adrenergic signalling over the lifespan of the animal may be deleterious, particularly in the face of ineffective  $\beta$ AR-desensitization mechanisms, as these mice developed cardiomyopathy at older age.<sup>26</sup> These experiments in transgenic animals are in contrast to our findings, where we identified a 30% increase of *G $\alpha$ s* expression in humans in homozygous haplotype \*3 carriers,<sup>16</sup> which was also associated with a survival benefit in patients with enhanced *G $\alpha$ s* expression (haplotype \*3). In transgenic mice, however, *G $\alpha$ s* expression was up-regulated more than three-fold compared with that in wildtype mice.<sup>22</sup> Therefore, we hypothesize that higher *G $\alpha$ s* expression in homozygous haplotype \*3 carriers might result in a sensitization of  $\beta$ AR, resulting in a greater number of  $\beta$ AR in the “high-affinity state” resulting in a survival benefit.<sup>10</sup>

Our findings showing a survival benefit from  $\beta$ AR blockade in patients with haplotype \*3 (increased *G $\alpha$ s* expression), compared with other patients (fig. 2B), are in agreement with chronic  $\beta$ AR blockade in transgenic mice overexpressing *G $\alpha$ s* resulting in protection from evoked heart failure.<sup>10–12,22,25</sup> We, therefore, speculate that resensitization of  $\beta$ AR by  $\beta$ AR blockade in patients with increased *G $\alpha$ s* expression results in a long-term patient benefit.

Another issue that has to be considered is the potential effect of altered *G $\alpha$ s* expression in ischemia–reperfusion damage during CABG surgery. Many pathological processes contribute to ischemia- and reperfusion-associated heart injury. For example, ischemia during extracorporeal circulation is associated with decreased adenylyl cyclase activity and intracellular cyclic adenosine monophosphate concentrations and may result in increased vascular permeability, endothelial cell inflammation, an imbalance between vasodilating and vasoconstricting factors, and the activation of coagulation and the complement system.<sup>27</sup> Therefore, increased cardiac *G $\alpha$ s* concentration with increased intracellular cyclic adenosine monophosphate levels during that period could evoke beneficial effects regarding attenuated reperfusion injury and inflammatory response.

We hypothesized that enhanced *G $\alpha$ s*-mediated signal transduction might yield a more beneficial outcome after

**Table 3.** Multivariable (Cox Proportional Hazards) Predictor Model of Mortality in Patients on  $\beta$ AR Blockade (n = 1,267)

Predictor	HR	95% CI		P Value
		Lower	Upper	
<b>Sex</b>				
Female	1*			
Male	1.27	0.81	2.00	0.308
Age (yr)	1.05	1.03	1.07	<0.001
Preoperative LVEF (%)	0.97	0.96	0.99	<0.001
<b>Diabetes mellitus</b>				
No	1*			
Yes	1.49	1.04	2.13	0.030
<b>Pulmonary disease</b>				
No	1*			
Yes	1.49	0.96	2.18	0.075
Creatinine concentration (mg/dl)	1.68	1.10	2.56	0.015
Hematocrit (%)	0.95	0.90	0.99	0.014
NYHA	1.27	1.04	1.56	0.019
Number of grafts	0.71	0.55	0.92	0.008
<b>GNAS diplotype</b>				
*3/*3	1*			
*3/*2	1.27	0.61	2.62	0.521
*3/*1	1.51	0.74	3.07	0.252
*2/*2	1.33	0.58	3.04	0.502
*2/*1	2.27	1.14	4.53	0.020
*1/*1	3.02	1.50	6.11	0.002

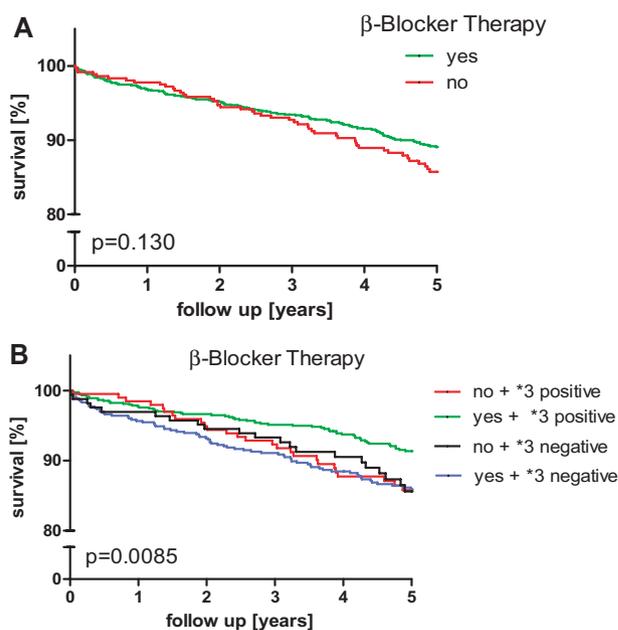
Clinical and demographic variables were selected based on association ( $P < 0.1$ ) in univariate analysis or when part of the EuroSCORE II.

\* Reference.

$\beta$ AR =  $\beta$ -adrenoreceptor; HR = hazard ratio; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association.

CABG, particularly under  $\beta$ AR blockade, and this hypothesis was tested, first in a pilot study,<sup>17</sup> and now in a large multicenter cohort of patients. In the pilot study including 185 patients under chronic  $\beta$ AR blockade, *Gnas* expression was diminished in homozygous haplotype \*1 patients and this was associated with an increased risk of death compared with the risk in homozygous haplotype \*3 carriers, with an independent hazard ratio of 3.1.<sup>17</sup> The current study in 1,627 patients with a 5-yr follow-up now extends these pilot data in a new cohort of well-characterized patients and confirms the primary hypothesis. In a multivariable analysis, homozygous \*1 patients had a doubled risk of death compared with that of homozygous \*3 patients and stratification by the presence or absence of  $\beta$ AR blockade tripled this risk, independently of conventional risk factors.

From a pharmacogenetic point of view, our observations are important as  $\beta$ AR blockers are the cornerstone therapy for patients with coronary artery disease, and the use of  $\beta$ AR blockers in the perioperative period remains a topic of intense research.<sup>28</sup> Although the consistent efficacy of  $\beta$ AR blockers has been questioned, variability of effects was suggested to relate in part to genetic heterogeneity.<sup>29,30</sup> On the basis of our observations in the current study, future studies of  $\beta$ AR blockers should include accounting for genotype structure of genes in the  $\beta$ AR pathway. Importantly, this



**Fig. 2.** Kaplan-Meier survival analysis stratified by  $\beta$ -adrenoreceptor ( $\beta$ AR) blocker therapy. (A) Patients on  $\beta$ AR blockade (n = 1,267) and patients without  $\beta$ -adrenergic receptor blockade (n = 360). (B) Analyses for haplotype \*3 positive patients with (n = 739) and without  $\beta$ -adrenergic receptor blockade (n = 196) and of haplotype negative patients with (n = 528) and without  $\beta$ -adrenergic receptor blockade (n = 164). P values represent log-rank test for comparison of all curves.

study questions the value of routine use of  $\beta$ AR blockers in all patients undergoing cardiac surgery, an issue which was already raised during the early termination of the PeriOperative ISchemic Evaluation trial,<sup>31</sup> in which patients who received  $\beta$ AR blockers had an increased risk of strokes. However, the investigational  $\beta$ AR blocker bucindolol, which in the Beta-Blocker Evaluation of Survival Trial trial<sup>32</sup> did not show an overall survival benefit compared with placebo, was associated with fewer adverse events in patients with a  $\beta$ AR genetic variant.<sup>33</sup> Thus, without pharmacogenetic data, there exists a tradeoff between the benefit of a medication in a minority of patients and the possibly associated risks and costs in the majority of patients.

Finally, despite improved survival in a pilot study of patients with various Gly16Gly genotypes undergoing CABG surgery,<sup>17</sup> we did not find an association of *ADRB2* polymorphisms with long-term survival in the current study. Therefore, we cannot draw a definitive conclusion of whether *ADRB2* genotypes influence outcome after CABG surgery. However, a recent study<sup>34</sup> of patients with acute coronary syndrome does not support a significant impact of *ADRB2* genotypes on outcome in American patients of Caucasian ethnicity.

### Limitations

Our study should be interpreted in the context of some potential limitations. The study of this longitudinal observational

cohort was not designed to investigate  $\beta$ AR blocker-specific effects on long-term survival. Due to a high level of adherence to  $\beta$ AR blocker guideline recommendations, only a small fraction of subjects were left untreated with  $\beta$ AR antagonists. This precluded a formal analysis to investigate the statistical interaction of genotype with  $\beta$ AR antagonist treatment. Nevertheless, we identified genetic subgroups with worse outcomes despite  $\beta$ AR antagonist treatment, in whom more aggressive interventions to improve survival might be warranted. In addition, we had no information on the various  $\beta$ AR blockers used in this cohort and thus cannot ascertain agent-specific effects, if present. Moreover, we were unable to account for changes in medications during follow-up time. Furthermore, classifying patients by discharge medication status is a well-recognized and often-used approach because most patients remain on their discharge regimen after hospital stay.<sup>35</sup>

This is an analysis of an ongoing study in a longitudinal cohort for which we have previously reported associations between genetic variants and atrial fibrillation,<sup>36</sup> myocardial injury,<sup>37–39</sup> ventricular dysfunction,<sup>40,41</sup> inflammation,<sup>42</sup> and up to 5-yr postoperative all-cause mortality.<sup>41,43–45</sup> The current study's assessment of *GNAS* variants associated with 5-yr mortality did not adjust for previous analyses of these other gene-association studies in the CABG Genomics Program cohort. Finally, it may be speculated that one or several yet unidentified functional SNPs in adrenergic or other pathway genes such as the A2B adenosine receptor or the  $\beta$ 1-receptor could influence our results.<sup>6,46</sup> However, due to our hypothesis-driven approach following a pilot study,<sup>17</sup> analysis of those genes was not the aim of our current study but should be considered with future studies. Moreover, besides the  $\beta$ -adrenergic signaling pathway, *G $\alpha$ s* is also activated by several other G-protein-coupled receptors, for example, including the serotonin and adenosine receptors.<sup>47</sup> It is, therefore, conceivable that it is not solely the  $\beta$ -receptor-mediated signal transduction pathway that is responsible for the observed effects but also cumulative or single effects mediated *via* other *G $\alpha$ s*-mediated signaling pathways.

In conclusion, *GNAS* haplotypes independently associate with an increased risk of death after primary CABG surgery. These results are most pronounced in patients receiving  $\beta$ AR blockers and strengthen the rationale for personalized treatment to decrease medication side effects and improve outcomes.

## Acknowledgments

Supported by Harvard Clinical and Translational Science Center, National Center for Research Resources, Boston, Massachusetts; National Institute of Health grants, Bethesda, Maryland; American Heart Association Scientist Development Grant; the Department of Anesthesiology, Perioperative, and Pain Medicine, Brigham and Women's Hospital, Boston, Massachusetts; the Klinik für Anästhesiologie und Intensivmedizin, Universität Duisburg-Essen and University Hospital Essen, Essen, Germany; and Baylor College of Medicine Division of Cardiovascular Anesthesia at the Texas Heart Institute, Saint Luke's Episcopal Hospital, Houston, Texas.

## Competing Interests

The authors declare no competing interests.

## Correspondence

Address correspondence to Dr. Frey: Klinik für Anästhesiologie und Intensivmedizin, Universitätsklinikum Essen, D-45122 Essen, Germany. ulrich.frey@uk-essen.de. This article may be accessed for personal use at no charge through the Journal Web site, [www.anesthesiology.org](http://www.anesthesiology.org).

## References

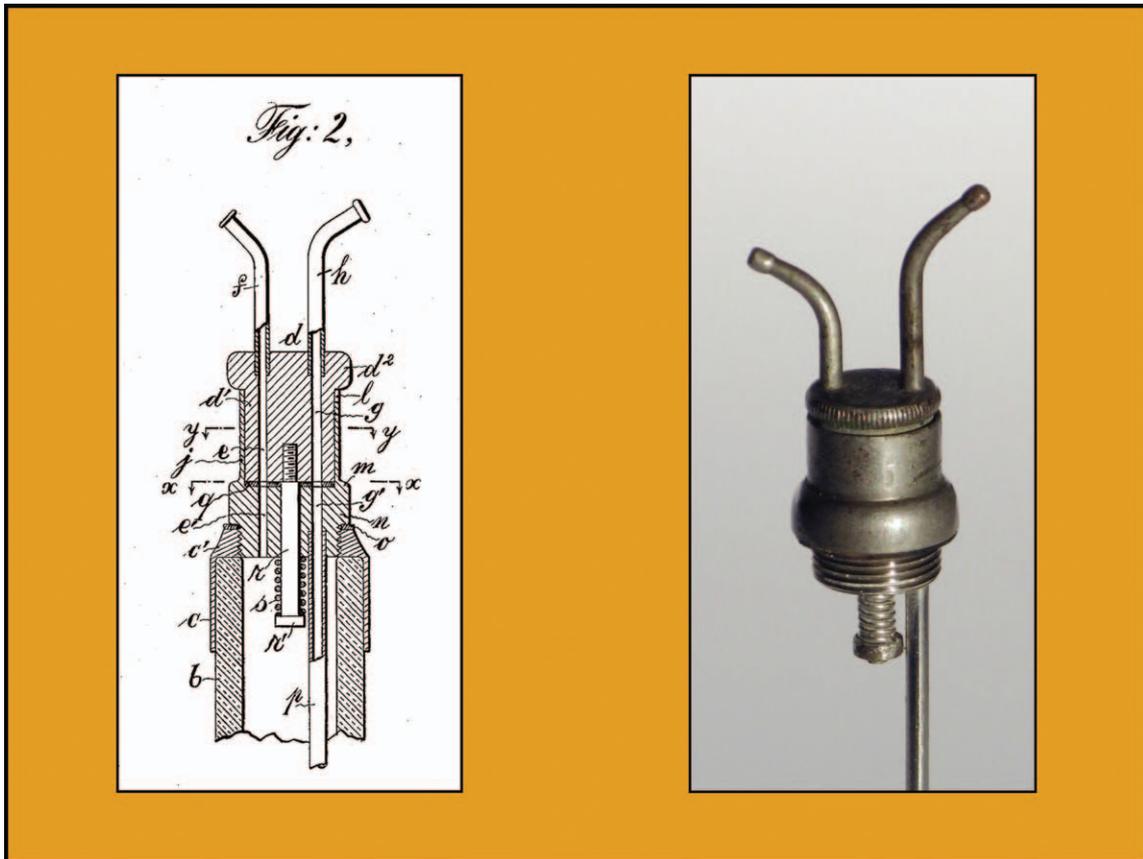
1. Post SR, Hammond HK, Insel PA:  $\beta$ -Adrenergic receptors and receptor signaling in heart failure. *Annu Rev Pharmacol Toxicol* 1999; 39:343–60
2. Engelhardt S:  $\beta$ -Adrenergic receptors in heart failure. *Heart Fail Clin* 2005; 1:183–91
3. Ferguson TB Jr, Coombs LP, Peterson ED; Society of Thoracic Surgeons National Adult Cardiac Surgery Database: Preoperative  $\beta$ -blocker use and mortality and morbidity following CABG surgery in North America. *JAMA* 2002; 287:2221–7
4. Cresci S, Dorn GW II, Jones PG, Beitelshes AL, Li AY, Lenzini PA, Province MA, Spertus JA, Lanfear DE: Adrenergic-pathway gene variants influence  $\beta$ -blocker-related outcomes after acute coronary syndrome in a race-specific manner. *J Am Coll Cardiol* 2012; 60:898–907
5. Muthumala A, Drenos F, Elliott PM, Humphries SE: Role of  $\beta$  adrenergic receptor polymorphisms in heart failure: Systematic review and meta-analysis. *Eur J Heart Fail* 2008; 10:3–13
6. Leineweber K, Heusch G:  $\beta$ 1- and  $\beta$ 2-Adrenoceptor polymorphisms and cardiovascular diseases. *Br J Pharmacol* 2009; 158:61–9
7. Shin J, Lobmeyer MT, Gong Y, Zineh I, Langae TY, Yarandi H, Schofield RS, Aranda JM Jr, Hill JA, Pauly DF, Johnson JA: Relation of  $\beta$ 2-adrenoceptor haplotype to risk of death and heart transplantation in patients with heart failure. *Am J Cardiol* 2007; 99:250–5
8. Lanfear DE, Jones PG, Marsh S, Cresci S, McLeod HL, Spertus JA:  $\beta$ 2-Adrenergic receptor genotype and survival among patients receiving  $\beta$ -blocker therapy after an acute coronary syndrome. *JAMA* 2005; 294:1526–33
9. Sehnert AJ, Daniels SE, Elashoff M, Wingrove JA, Burrow CR, Horne B, Muhlestein JB, Donahue M, Liggett SB, Anderson JL, Kraus WE: Lack of association between adrenergic receptor genotypes and survival in heart failure patients treated with carvedilol or metoprolol. *J Am Coll Cardiol* 2008; 52:644–51
10. Gaudin C, Ishikawa Y, Wight DC, Mahdavi V, Nadal-Ginard B, Wagner TE, Vatner DE, Homcy CJ: Overexpression of Gs alpha protein in the hearts of transgenic mice. *J Clin Invest* 1995; 95:1676–83
11. Iwase M, Uechi M, Vatner DE, Asai K, Shannon RP, Kudej RK, Wagner TE, Wight DC, Patrick TA, Ishikawa Y, Homcy CJ, Vatner SF: Cardiomyopathy induced by cardiac Gs alpha overexpression. *Am J Physiol* 1997; 272(1 Pt 2):H585–9
12. Asai K, Yang GP, Geng YJ, Takagi G, Bishop S, Ishikawa Y, Shannon RP, Wagner TE, Vatner DE, Homcy CJ, Vatner SF:  $\beta$ -Adrenergic receptor blockade arrests myocyte damage and preserves cardiac function in the transgenic G(salpa) mouse. *J Clin Invest* 1999; 104:551–8
13. Klenke S, Siffert W, Frey UH: A novel aspect of *GNAS* imprinting: Higher maternal expression of *G $\alpha$ s* in human lymphoblasts, peripheral blood mononuclear cells, mammary adipose tissue, and heart. *Mol Cell Endocrinol* 2011; 341:63–70

14. Weinstein LS, Chen M, Xie T, Liu J: Genetic diseases associated with heterotrimeric G proteins. *Trends Pharmacol Sci* 2006; 27:260–6
15. Frey UH, Hauner H, Jöckel KH, Manthey I, Brockmeyer N, Siffert W: A novel promoter polymorphism in the human gene GNAS affects binding of transcription factor upstream stimulatory factor 1, Galphas protein expression and body weight regulation. *Pharmacogenet Genomics* 2008; 18:141–51
16. Frey UH, Adamzik M, Kottenberg-Assenmacher E, Jakob H, Manthey I, Broecker-Preuss M, Bergmann L, Heusch G, Siffert W, Peters J, Leineweber K: A novel functional haplotype in the human GNAS gene alters Galphas expression, responsiveness to  $\beta$ -adrenoceptor stimulation, and peri-operative cardiac performance. *Eur Heart J* 2009; 30:1402–10
17. Frey UH, Kottenberg E, Kamler M, Leineweber K, Manthey I, Heusch G, Siffert W, Peters J: Genetic interactions in the  $\beta$ -adrenoceptor/G-protein signal transduction pathway and survival after coronary artery bypass grafting: A pilot study. *Br J Anaesth* 2011; 107:869–78
18. Biancari F, Vasques F, Mikkola R, Martin M, Lahtinen J, Heikkinen J: Validation of EuroSCORE II in patients undergoing coronary artery bypass surgery. *Ann Thorac Surg* 2012; 93:1930–5
19. Chalmers J, Pullan M, Fabri B, McShane J, Shaw M, Mediratta N, Poullis M: Validation of EuroSCORE II in a modern cohort of patients undergoing cardiac surgery. *Eur J Cardiothorac Surg* 2013; 43:688–94
20. Frey UH, Bachmann HS, Peters J, Siffert W: PCR-amplification of GC-rich regions: 'Slowdown PCR'. *Nat Protoc* 2008; 3:1312–7
21. Stephens M, Smith NJ, Donnelly P: A new statistical method for haplotype reconstruction from population data. *Am J Hum Genet* 2001; 68:978–89
22. Vatner DE, Asai K, Iwase M, Ishikawa Y, Wagner TE, Shannon RP, Homcy CJ, Vatner SF: Overexpression of myocardial G $\alpha$  prevents full expression of catecholamine desensitization despite increased  $\beta$ -adrenergic receptor kinase. *J Clin Invest* 1998; 101:1916–22
23. Sibley DR, Lefkowitz RJ: Molecular mechanisms of receptor desensitization using the  $\beta$ -adrenergic receptor-coupled adenylate cyclase system as a model. *Nature* 1985; 317:124–9
24. Ping P, Hammond HK: Diverse G protein and  $\beta$ -adrenergic receptor mRNA expression in normal and failing porcine hearts. *Am J Physiol* 1994; 267(5 Pt 2):H2079–85
25. Iwase M, Bishop SP, Uechi M, Vatner DE, Shannon RP, Kudej RK, Wight DC, Wagner TE, Ishikawa Y, Homcy CJ, Vatner SF: Adverse effects of chronic endogenous sympathetic drive induced by cardiac G $\alpha$  overexpression. *Circ Res* 1996; 78:517–24
26. Vatner SF, Vatner DE, Homcy CJ:  $\beta$ -Adrenergic receptor signaling: An acute compensatory adjustment-inappropriate for the chronic stress of heart failure? Insights from G $\alpha$  overexpression and other genetically engineered animal models. *Circ Res* 2000; 86:502–6
27. Eltzschig HK, Eckle T: Ischemia and reperfusion—From mechanism to translation. *Nat Med* 2011; 17:1391–401
28. Nagele P, Liggett SB: Genetic variation,  $\beta$ -blockers, and perioperative myocardial infarction. *ANESTHESIOLOGY* 2011; 115:1316–27
29. Chen ZM, Pan HC, Chen YP, Peto R, Collins R, Jiang LX, Xie JX, Liu LS; COMMIT (ClopidoGrel and Metoprolol in Myocardial Infarction Trial) Collaborative Group: Early intravenous then oral metoprolol in 45,852 patients with acute myocardial infarction: Randomised placebo-controlled trial. *Lancet* 2005; 366:1622–32
30. Freemantle N, Cleland J, Young P, Mason J, Harrison J:  $\beta$ -Blockade after myocardial infarction: Systematic review and meta regression analysis. *BMJ* 1999; 318:1730–7
31. Devereaux PJ, Yang H, Yusuf S, Guyatt G, Leslie K, Villar JC, Xavier D, Chrolavicius S, Greenspan L, Pogue J, Pais P, Liu L, Xu S, Malaga G, Avezum A, Chan M, Montori VM, Jacka M, Choi P: Effects of extended-release metoprolol succinate in patients undergoing non-cardiac surgery (POISE trial): A randomised controlled trial. *Lancet* 2008; 371:1839–47
32. Beta-Blocker Evaluation of Survival Trial Investigators: A trial of the  $\beta$ -blocker bucindolol in patients with advanced chronic heart failure. *N Engl J Med* 2001; 344:1659–67
33. Liggett SB, Mialet-Perez J, Thaneemit-Chen S, Weber SA, Greene SM, Hodne D, Nelson B, Morrison J, Domanski MJ, Wagoner LE, Abraham WT, Anderson JL, Carlquist JF, Krause-Steinrauf HJ, Lazzeroni LC, Port JD, Lavori PW, Bristow MR: A polymorphism within a conserved  $\beta$ 1-adrenergic receptor motif alters cardiac function and  $\beta$ -blocker response in human heart failure. *Proc Natl Acad Sci U S A* 2006; 103:11288–93
34. Cresci S, Dorn GW II, Jones PG, Beitelshes AL, Li AY, Lenzini PA, Province MA, Spertus JA, Lanfear DE: Adrenergic-pathway gene variants influence  $\beta$ -blocker-related outcomes after acute coronary syndrome in a race-specific manner. *J Am Coll Cardiol* 2012; 60:898–907
35. Muhlestein JB, Horne BD, Bair TL, Li Q, Madsen TE, Pearson RR, Anderson JL: Usefulness of in-hospital prescription of statin agents after angiographic diagnosis of coronary artery disease in improving continued compliance and reduced mortality. *Am J Cardiol* 2001; 87:257–61
36. Body SC, Collard CD, Shernan SK, Fox AA, Liu KY, Ritchie MD, Perry TE, Muehlschlegel JD, Aranki S, Donahue BS, Pretorius M, Estrada JC, Ellinor PT, Newton-Cheh C, Seidman CE, Seidman JG, Herman DS, Lichtner P, Meitinger T, Pfeufer A, Kääh S, Brown NJ, Roden DM, Darbar D: Variation in the 4q25 chromosomal locus predicts atrial fibrillation after coronary artery bypass graft surgery. *Circ Cardiovasc Genet* 2009; 2:499–506
37. Muehlschlegel JD, Perry TE, Liu KY, Fox AA, Smith SA, Lichtner P, Collard CD, Shernan SK, Hartwig JH, Body SC, Hoffmeister KM: Polymorphism in the protease-activated receptor-4 gene region associates with platelet activation and perioperative myocardial injury. *Am J Hematol* 2012; 87:161–6
38. Collard CD, Shernan SK, Fox AA, Bernig T, Chanock SJ, Vaughn WK, Takahashi K, Ezekowitz AB, Jarolim P, Body SC: The MBL2 'LYQA secretor' haplotype is an independent predictor of postoperative myocardial infarction in whites undergoing coronary artery bypass graft surgery. *Circulation* 2007; 116(11 suppl):I106–12
39. Liu KY, Muehlschlegel JD, Perry TE, Fox AA, Collard CD, Body SC, Shernan SK: Common genetic variants on chromosome 9p21 predict perioperative myocardial injury after coronary artery bypass graft surgery. *J Thorac Cardiovasc Surg* 2010; 139:483–8, 488.e1–2
40. Fox AA, Collard CD, Shernan SK, Seidman CE, Seidman JG, Liu KY, Muehlschlegel JD, Perry TE, Aranki SF, Lange C, Herman DS, Meitinger T, Lichtner P, Body SC: Natriuretic peptide system gene variants are associated with ventricular dysfunction after coronary artery bypass grafting. *ANESTHESIOLOGY* 2009; 110:738–47
41. Muehlschlegel JD, Perry TE, Liu KY, Fox AA, Collard CD, Shernan SK, Body SC: Heart-type fatty acid binding protein is an independent predictor of death and ventricular dysfunction after coronary artery bypass graft surgery. *Anesth Analg* 2010; 111:1101–9
42. Perry TE, Muehlschlegel JD, Liu KY, Fox AA, Collard CD, Body SC, Shernan SK; CABG Genomics Investigators: C-Reactive protein gene variants are associated with postoperative C-reactive protein levels after coronary artery bypass surgery. *BMC Med Genet* 2009; 10:38
43. Lipman PJ, Liu KY, Muehlschlegel JD, Body S, Lange C: Inferring genetic causal effects on survival data with associated endo-phenotypes. *Genet Epidemiol* 2011; 35:119–24

44. Perry TE, Muehlschlegel JD, Liu KY, Fox AA, Collard CD, Body SC, Shernan SK; CABG Genomics Investigators: Preoperative C-reactive protein predicts long-term mortality and hospital length of stay after primary, nonemergent coronary artery bypass grafting. *ANESTHESIOLOGY* 2010; 112:607–13
45. Muehlschlegel JD, Liu KY, Perry TE, Fox AA, Collard CD, Shernan SK, Body SC; CABG Genomics Investigators: Chromosome 9p21 variant predicts mortality after coronary artery bypass graft surgery. *Circulation* 2010; 122(11 suppl):S60–5
46. Eckle T, Hartmann K, Bonney S, Reithel S, Mittelbronn M, Walker LA, Lowes BD, Han J, Borchers CH, Buttrick PM, Kominsky DJ, Colgan SP, Eltzschig HK: Adora2b-elicited Per2 stabilization promotes a HIF-dependent metabolic switch crucial for myocardial adaptation to ischemia. *Nat Med* 2012; 18:774–82
47. Wettschureck N, Offermanns S: Mammalian G proteins and their cell type specific functions. *Physiol Rev* 2005; 85:1159–204

## ANESTHESIOLOGY REFLECTIONS FROM THE WOOD LIBRARY-MUSEUM

### The Wachter Chloroform Dropper



An American citizen residing in Jersey City, New Jersey, Frederick Wachter filed on Columbus Day of 1905 for a U.S. patent on his “Chloroform-Dropper.” On the right side of both images, an air-venting tube *h* extends down through the stopper and deep inside the drop bottle as tube *p*. A central screw turns through 90 degrees from *s*[hut] to *o*[pen]. When fully open, with bent tubes pointed downward, chloroform can pass through the left tubing on both images, from *e* to *f*. Granted on June 12, 1906, [U.S.] “PAT No 823233” was inscribed across the dropper top. One of the few examples of dropper bottle technology not designed in Europe, the Wachter Chloroform Dropper was designed, as Europeans will gleefully note, by a German-American who was born in Baden, Germany. (Copyright © the American Society of Anesthesiologists, Inc.)

George S. Bause, M.D., M.P.H., Honorary Curator, ASA’s Wood Library-Museum of Anesthesiology, Park Ridge, Illinois, and Clinical Associate Professor, Case Western Reserve University, Cleveland, Ohio. UJYC@aol.com.