Vasodilatory responses of renal interlobular arteries to epoxyeicosatrienoic acids analog are not enhanced in Ren-2 transgenic hypertensive rats: evidence against a role of direct vascular effects of epoxyeicosatrienoic acids in progression of experimental heart failure

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Running head: Epoxyeicosatrienoic acid and congestive heart failure

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Summary

Pathophysiological mechanisms underlying the development of renal dysfunction and progression of congestive heart failure (CHF) remain poorly understood. Recent studies have revealed striking differences in the role of epoxyeicosatrienoic acids (EETs), active products of cytochrome P-450-dependent epoxygenase pathway of arachidonic acid, in the progression of aorto-caval fistula (ACF)-induced CHF between hypertensive Ren-2 renin transgenic rats (TGR) and transgene-negative normotensive Hannover Sprague-Dawley (HanSD) controls. Both ACF TGR and ACF HanSD strains exhibited marked intrarenal EETs deficiency and impairment of renal function, and in both strains chronic pharmacologic inhibition of soluble epoxide hydrolase (sEH) [which normally degrades EETs] normalized EETs levels. However, the treatment improved the survival rate and attenuated renal function impairment in ACF TGR only. Here we aimed to establish if the reported improved renal function and attenuation of progression of CHF in ACF TGR observed after sEH blockade depends on increased vasodilatory responsiveness of renal resistance arteries to EETs. Therefore, we examined the responses of interlobar arteries from kidneys of ACF TGR and ACF HanSD rats to EET-A, a new stable 14,15-EET analog. We found that the arteries from ACF HanSD kidneys rats exhibited greater vasodilator responses when compared to the ACF TGR arteries. Hence, reduced renal vasodilatory responsiveness cannot be responsible for the lack of beneficial effects of chronic sEH inhibition on the development of renal dysfunction and progression of CHF in ACF HanSD rats.

Key words: congestive heart failure; aorto-caval fistula; epoxyeicosatrienoic acids; hypertension.

Introduction

Congestive heart failure (CHF) is a major public health problem affecting currently 4% of the adult population in Europe and the yearly increase in the number of new patients is estimated at 50% (Braunwald 2015a, Maggioni 2015). The patients' survival rate is worse than in most types of cancers, especially in cases associated with impairment of renal hemodynamics and sodium retention (Braam *et al.* 2014, Braunwald 2015a); hypertension and renal dysfunction are independent crucial risk factors for the progression of CHF (Braam *et al.* 2014, Mann and Bohm 2015). Obviously, new treatment strategies are urgently needed (Braam *et al.* 2014, Braunwald 2015b, Iwaz *et al.* 2016). However, the prerequisite for successful treatment is a better understanding of the pathophysiology of renal dysfunction in CHF.

Increased activity of the renin-angiotensin system (RAS) was previously shown to be crucial for the development of renal dysfunction and progression of CHF (Braunwald 2015b, Cohen-Segev *et al.* 2014, Ichikawa *et al.* 1984, Packer 1996, Pfeffer *et al.* 1985), however, it cannot be the sole causative factor. It has been proposed that intrarenal interaction between RAS and other vasoactive system(s) is important (Abassi *et al.* 2011, Braam *et al.* 2014). Attention was focused on epoxyeicosatrienoic acids (EETs), metabolites of cytochrome P-450 (CYP) dependent epoxygenase pathway of arachidonic acid metabolism known to participate in the regulation of cardiovascular and renal function (Capdevila *et al.* 2015, Elmarakby 2012, Fan et al. 2015, Neckář *et al.* 2012, Sporková *et al.* 2011, Walkowska *et al.* 2010). EETs induce arterial dilatation directly through activation of large-conductance calcium-activated potassium channels and reduction of calcium entry into vascular smooth muscle cells, and also by opposing renal vasoconstrictor actions of angiotensin II (ANG II) (Imig and Deichmann 1997, Imig *et al.* 2001, Kohagure *et al.* 2000). EETs also inhibit tubular sodium reabsorption and induce natriuresis (Madhun *et al.* 1991, Sakairi *et al.* 1995,). These results led to a proposal that intrarenal EETs counteract increased RAS activity (Elmarakby 2012, Fan *et al.* 2015, Imig *et al.* 2001). Thus, increasing the tissue bioavailability of EETs could become a new approach to combat renal dysfunction and progression of CHF. This is commonly achieved by blocking soluble epoxide hydrolase (sEH), the enzyme which degrades EETs to biologically inactive dihydroxyeicosatrienoic acids (DHETEs) (Capdevila *et al.* 2015, Elmarakby 2012, Fan *et al.* 2015). Since augmentation of tissue EETs´ bioavailability proved antihypertensive and nephro- and cardioprotective, we reasoned that chronic sEH inhibition would attenuate CHF, especially the

form associated with evident renal dysfunction (Kopkan *et al.* 2012, Kujal *et al.* 2014, Neckář *et al.* 2012, Sporková *et al.* 2011).

The rat with aorto-caval fistula (ACF) presents a well-defined model of CHF due to volume overload. It is characterized by cardiac remodeling, congestion, and marked activation of the intrarenal RAS with impairment of renal function; the model has many features similar to untreated human CHF and is recommended by American Heart Association (Abasi *et al.* 2011, Benes *et al.* 2011, Červenka *et al*. 2015a, Houser *et al.* 2012, Melenovsky *et al.* 2012). The Ren-2 transgenic rat model (TGR) combines endogenous activation of the RAS and hypertension (Jacinto *et al.* 1999, Kopkan *et al.* 2005, Kujal *et al.* 2014, Mullins *et al.* 1990, Neckář *et al.* 2012) and we found recently that both TGR and normotensive Hannover Sprague-Dawley (HanSD) rats (transgene-negative control to TGR) with ACF-induced CHF exhibited tissue EETs deficiency that could be corrected by chronic sEH inhibition (Červenka *et al.* 2015a, Červenka *et al.* 2015b). Surprisingly, chronic sEH inhibition improved the survival rate and attenuated renal dysfunction in ACF TGR but not in ACF HanSD rats (Červenka *et al.* 2015a, Červenka *et al.* 2015b). These data suggested that in contrast to their important role in ACF TGR, EETs are not involved in the development of renal dysfunction in the control strain. It should be noted that while natriuretic actions of EETs have been widely investigated and are shown to underlie hypotensive and organ-protective effects (Elmarakby 2012, Fan *et al.* 2015, Kopkan *et al.* 2012, Kujal *et al.* 2014, Neckář *et al.* 2012), the role of their direct vasodilatory influence is not well known despite the evidence of such effects on the renal vasculature (Fan *et al.* 2015). It was found that EETs elicited markedly greater renal vasodilatation in spontaneously hypertensive rats (SHR) than in normotensive controls (Pomposiello *et al.* 2003). In this context we hypothesized that the vasculature of the kidney of ACF TGR exhibits increased vasodilatory responsiveness to EETs as compared to ACF HanSD rats. Therefore, such enhanced responsiveness of small renal arteries to EETs could account for the beneficial effects of chronic sEH inhibition on the development of renal dysfunction and progression of CHF in ACF TGR.

To test this hypothesis, we examined vasodilatory responses of interlobar arteries from the kidneys of ACF TGR and ACF HanSD rats to the newly developed 14,15-EET analog [disodium (*S*)-2-(13-(3-pentyl)ureido)-tridec-8(Z)-enamido)succinate, EET-A] (Falck *et al.* 2009, Khan *et al.* 2014). Furthermore, to determine whether possible altered renal vasodilatory responses in ACF TGR is specific to EET-A or rather reflects general changes in vascular reactivity, the renal vascular responsiveness to norepinephrine and to acetylcholine were also examined.

Methods

Ethical approval and animals.

The studies were performed in accordance with guidelines and practices established by the *Animal Care and Use Committee of the Institute for Clinical and Experimental Medicine*, Prague, which accord with the *European Convention on Animal Protection and Guidelines on Research Animal Use.* All animals used in the present study were bred at the Center of Experimental Medicine of this Institute, from stock animals supplied by the Max Delbrück Center for Molecular Medicine, Berlin, Germany, which is accredited by the Czech Association for Accreditation of Laboratory Animal Care. Heterozygous TGR were generated by breeding male homozygous TGR with female homozygous HanSD rats and age-matched HanSD rats served as controls. The animals were kept on a 12-hour/12-hour light/dark cycle. Throughout the experiments rats were fed a normal salt, normal protein diet (0.45% NaCl, 19-21% protein) manufactured by SEMED (Prague, Czech Republic) and had free access to tap water.

CHF model.

Male rats at the initial age of 9 weeks were anesthetized (tiletamine + zolazepam, Virbac SA, Carros Cedex, France, 8 mg/kg; and xylasine, Spofa, Czech Republic, 4 mg/kg intramuscularly) and CHF was induced by volume overload induced by creation of ACF using a needle technique as originally described by Garcia and Diebold (1990) and validated by many investigators including our own group (Abasi *et al.* 2011, Benes *et al.* 2011, Brower *et al.* 1996, Červenka *et al*. 2015a, Červenka et al. 2015b, Melenovsky *et al.* 2012). Briefly, after exposure of the abdominal aorta and inferior vena cava between the origin of the renal arteries and iliac bifurcation, the aorta was temporarily occluded for about 40 seconds. An 18-gauge needle (diameter 1.2 mm) was inserted into the aortic lumen and advanced across the wall into the inferior vena cava to create ACF. The needle was withdrawn and the puncture was sealed with cynoacrylate tissue glue. The creation of ACF was confirmed by the pulsatile flow of oxygenated blood into the vena cava from abdominal aorta. Sham-operated rats underwent the identical procedure, but without creating ACF.

Series 1: Evaluation of basal cardiac function variables, blood pressure and organ weights.

In this series animals that underwent either sham-operation or ACF creation as described above were left without treatment for 5 weeks. Previous, including our recent, studies have shown

that 5-10 weeks after ACF induction, cardiac remodeling and renal functional characteristics typical for CHF become apparent (Abasi *et al.* 2011, Benes *et al.* 2011, Brower *et al.* 1996, Červenka *et al*. 2015a, Červenka *et al.* 2015, Melenovsky *et al.* 2012). In the present study, we intentionally shortened the period to 5 weeks, because we had shown that CHF characteristics in TGR are developed by week 5 after ACF induction, at the time when both ACF TGR and ACF HanSD rats exhibit the features of compensated CHF (Červenka *et al.* 2015a, Červenka *et al.* 2015b).

The following experimental groups were investigated:

1. Sham-operated HanSD rats (n = 8)
2. Sham-operated TGR (n = 8)
3. ACF HanSD rats (n = 12)
4. ACF TGR (n = 13)

At the end of experimental protocol (i.e. 5 week after sham-operation or induction of ACF) animals were anesthetized by intraperitoneal (i.p.) administration of ketamine/midazolam combination (50 mg and 5 mg/kg of body weight, respectively) and echocardiography was performed as described in our recent studies (Benes *et al.* 2011, Červenka *et al*. 2015a, Červenka *et al.* 2015b, Neckář *et al.* 2012). Subsequently, the right carotid artery was cannulated and mean arterial pressure was directly assessed for 10 minutes. At the end of experiments, the rats were killed with an excess i.p dose of sodium thiopenthal. The hearts, kidneys, lungs and livers were excised and weighed.

Series 2: In vitro preparation and evaluation of vascular diameter responses of small renal arteries in vitro.

Animals that underwent either sham-operation or ACF creation as described above were left without treatment for 5 weeks. Animals were killed by an overdose of thiopental sodium. The kidney was flushed, removed and placed in ice-cold physiological solution. Subsequently, the vessels were prepared as described in detail previously (Sporková *et al.* 2016). Briefly, the kidney was cut longitudinally into two to three sections from which interlobar arteries were dissected, isolated and cleared of adhering tubules and connective tissue. The outer diameter of the vessels was approximately 300 μm, which is characteristic for renal interlobar arteries (Kriz

and Kaissling 2000). After dissection, the arteries were cannulated with glass micropipettes in a pressure myograph chamber (Danish Myograph Company). The cannulated vessels were perfused with Krebs solution of the following composition (in mM): 117 NaCl, 4.7 KCl, 2.5 $CaCl_2$, 1.2 $MgCl_2$, 1.2 NaH_2PO_4, 25 $NaHCO_3$ and 11 glucose, at 37˚C at a flow rate of about 6 $ml.min^{-1}$, the infusate was continuously oxygenated with a mixture of 95% oxygen and 5% carbon dioxide. Subsequently, the mounted arteries were slowly pressurized to reach the intravascular pressure of 80 mmHg and equilibrated. The output of a black-and-white video camera attached to the microscope was fed to a frame grabber card mounted in a personal computer. Video images were analyzed using MioVIEW data acquisition software that continuously acquires the diameter measurements of the blood vessel. Drugs were added externally via superfusing Krebs solution. The effects of EET-A, acetylcholine and norepinephrine on the vascular diameter were determined after the vessels had been preconstricted by submaximal concentration of phenylephrine (PE) (0.3-1.0 μM). In our previous study and again in the present preliminary experiments we found that the constriction produced by phenylephrine was more stable and reproducible compared to that produced by ANG II (Sporkova *et al.* 2016). Only one well-reacting artery from one animal was used in each experiment. In one vessel only one dose-response curve was performed, which usually took one hour. After performing wash-out procedure of the employed drug, the same vessel was used for a dose-response curve for acetylcholine. This procedure was validated and standardized in our lab as described in our recent study (Sporkova *et al.* 2016). Artery vasodilatory responses are expressed as percent dilation of PE-preconstricted vessels. In the case of norepinephrine the percentage of constriction was calculated from the basal relaxed diameter. Half-maximal effective agonist concentration (EC_{50}) and maximal dilatory or constrictor responses (Emax) were calculated from least squares fit of the individual agonist concentration-response curves using the following logistic function from Origin 8.5:

$$Y = \{[Emin - Emax]/ [1 + (x/EC_{50})_n] + Emax$$

where Emin is the minimum response and was constrained to zero, and n is the slope factor.

The major advantage of the EET-A analog is, compared to native EETs is, that it is resistant to oxidation and degradation by sEH (Falck et al. 2009, Khan *et al.* 2014). EET-A was synthesized by

Professor Falck's group as described previously (Falck et al. 2009, Khan *et al.* 2014). All other chemicals were purchased from Sigma-Aldrich Company.

The following experimental groups were investigated:

1. Sham-operated HanSD rats (n = 8)
2. Sham-operated TGR (n = 7)
3. ACF HanSD rats (n = 9)
4. ACF TGR (n = 9)

Statistical Analysis

All values are expressed as means ± SEM. Graph-Pad Prism software (Graph Pad Software, San Diego, CA, USA) was used for statistical calculations. The differences between groups for E_{max} and EC_{50} were assessed by Student´s two-tailed unpaired *t*-test. Values exceeding the 95% probability limits ($P<0.05$) were considered statistically significant.

Results

Series 1: Evaluation of basal cardiac function variables, blood pressure and organ weights.

As summarized in table 1, sham-operated TGR exhibited significant cardiac hypertrophy [expressed as heart weight (HW) to body weight (BW) ratio] as compared with sham-operated HanSD rats. ACF HanSD rats and ACF TGR showed marked increases in HW/BW as compared with sham-operated rats, but this increase was more pronounced in ACF TGR. ACF HanSD rats as well as ACF TGR exhibited increases in the cardiac output (dependent on the presence of the shunt), significant decreases in left ventricle (LV) fractional shortening (indicative of LV systolic dysfunction) and significant increases in LV and right ventricle (RV) diameters as compared with the sham-operated counterparts, notably, the increases in LV and RV diameters were more pronounced in ACF TGR as compared with ACF HanSD rats. In addition, ACF TGR displayed significantly higher ratio of lung weight to BW as compared with sham-operated TGR (indicating the development of important lung congestion in ACF TGR), but there were not significant differences between experimental groups in kidney and liver weight when normalized to BW. Taken together, these findings indicate that 5 weeks after creation of ACF the untreated ACF HanSD rats as well as ACF TGR are still at the stage of compensated CHF, which is in accordance with our recent findings (Červenka *et al*. 2015a, Červenka *et al.* 2015b), but our present data also suggest that ACF TGR exhibit signs indicating that soon afterwards they will progress toward the decompensated phase of CHF (based on parameters such as LV and RV diameters, cardiac hypertrophy and especially the increased lung weight to BW ratio), similarly as we reported recently (Červenka *et al.* 2015b)

As summarized in table 2, there were no significant differences in the basal outer diameter of isolated interlobar arteries between sham-operated and ACF TGR and HanSD rats. These diameter values refer to the interlobar arteries in rats (Kriz and Kaissling 2000). It is now recognized that these arteries act as resistance vessels playing important role in autoregulation of the renal blood flow and glomerular filtration rate during changes in renal perfusion pressure (Carlstrom *et al.* 2015). As summarized in table 2, application of 1.0 μM phenylephrine (PE) produced stable constriction in all experimental groups.

Figure 1 summarizes the responses of PE-preconstricted renal interlobar arteries to acetylcholine in all experimental groups.

As shown in figures 1A and 1B, arteries from sham-operated TGR and HanSD rats responded to application of acetylcholine with dose-dependent vasodilatation, however, in the HanSD rats the descending slope of the curve was significantly steeper [see also half maximal effective concentration (EC50) in Table 2]. Moreover, the maximal dilatory response (E_{max}) was significantly reduced in the arteries of sham-operated TGR as compared with sham-operated HanSD rats (Table 2).

There was no significant difference in the vasodilatory responses to acetylcholine between the arteries of sham-operated HanSD rats and ACF HanSD rats (Figure 1). Likewise, acetylcholine elicited similar vasodilatory responses in the arteries of sham-operated TGR and ACF TGR (Figure 1B).

On the whole, it is evident from figures 1A and 1B that PE-preconstricted renal interlobar arteries from ACF TGR showed reduced vasodilatory responses to acetylcholine as compared to arteries of ACF HanSD rats, and, again, E_{max} was lower in ACF TGR as compared with ACF HanSD rats (Table 2).

Figure 2 summarizes the response of renal interlobar arteries to norepinephrine in all experimental groups (HanSD sham or with ACF, and TGR sham or with ACF) and shows that norepinephrine induced similar dose-dependent vasoconstriction in each group; nor were there any significant between-group differences in E_{max} (Table 2).

Figure 3 summarizes responses of the PE-preconstricted renal interlobar arteries to administration of EET-A in each of the four experimental groups. The arteries from sham-operated TGR and HanSD rats responded to application of EET-A by similar dose-dependent vasodilatation, however, it is emphasized that vasodilatory responses to EET-A were significantly smaller than those observed in response to acetylcholine (see figure 1 and EC50 and E_{max} values in Table 2).

There were no significant differences in vasodilatory responses to EET-A in the arteries of sham-operated HanSD rats and ACF HanSD rats (Figure 3A). Likewise, EET-A caused similar vasodilatory responses in the arteries of sham-operated TGR and ACF TGR (Figure 3B).

On the whole, it is evident fro the data of Figure 3 that PE-preconstricted renal interlobar arteries from ACF TGR showed reduced vasodilatory responses to EET-A as compared to arteries

of ACF HanSD rats, which was in agreement with lower E_{max} in ACF TGR as compared with ACF HanSD rats (Table 2).

Discussion

The first critically important finding of the present study is that renal interlobar arteries isolated from the kidneys of ACF HanSD rats in the phase when all characteristics of CHF have fully developed (Červenka *et al.* 2015a) exhibit greater vasodilator responses to EET-A compared to arteries from kidneys of ACF TGR.

These findings are in disagreement with our hypothesis suggesting that increased vasodilatory responsiveness of small renal arteries to EETs in ACF TGR could account for the beneficial actions of chronic sEH inhibition on the course CHF in this strain. Moreover, our results show that vasodilatory responses to acetylcholine in ACF HanSD were also greater compared to ACF TGR rats. This suggests that some general dysregulation of the mechanisms contributing to attenuated hyperpolarization of vascular smooth muscle cells might occur in the resistance vessels of ACF TGR, resulting in decreased vasorelaxation in response to various dilatory agents.

Our original hypothesis was also based on findings showing that EETs elicited markedly greater renal vasodilatation in SHR than in WKY, and also vasodilatory actions of EETs analogs in ANG II-infused hypertensive animals were augmented compared to normotensive controls. Therefore, we were at first inclined to share the view that hypertensive animals and human subjects (Ellinsworth et al. 2016, Fan et al. 2015, Khan et al. 2014) and also our ACF TGR should exhibit increased vasodilatory responsiveness to EETs compared to ACF HanSD rats. However, this hypothesis proved incompatible with the data of our previous study which showed that small renal arteries of the nonclipped kidneys of two-kidney, one-clip (2K1C) Goldblatt hypertensive rats exhibit vasodilator responses to EETs that are distinctly reduced compared to those of the arteries from sham-operated normotensive rats (Sporková *et al.* 2016). In addition, our present results show that renal interlobar arteries isolated from the kidneys of sham-operated TGR exhibited vasodilator responses to EET-A similar with those in sham-operated HanSD rats. This finding,, again, puts to doubt the notion about enhanced vasodilatory responsiveness of hypertensive animals, at least of TGR and 2K1C rats i.e. two different models of ANG II-dependent hypertension. Moreover, we found that the renal interlobar arteries from sham-operated TGR and HanSD rats as well as from ACF TGR and HanSD rats showed a similar response pattern to norepinephrine, suggesting that, in general, animals with ACF-induced CHF do not exhibit any alterations in the renal vascular responsiveness to vasoactive agents. These

findings are in agreement with previous in vivo studies showing that TGR do not show any generalized increase in vascular responsiveness to endogenous vasoconstrictors with the exception of an exaggerated renal and peripheral vascular responsiveness to ANG II (Jacinto *et al.* 1999, Kopkan *et al.* 2005).

On the whole, based on the present findings and considering the earlier relevant evidence, we suggest that enhanced vasodilatory responsiveness of small renal arteries to EETs is not responsible for the beneficial actions of chronic sEH inhibition on the development of renal functional impairment and progression of CHF in ACF TGR.

In this context, ***the second critically important finding of the present study*** is that, in general, renal vasodilatory responses to EET-A observed in sham-operated TGR and sham-operated HanSD rats as well as in ACF TGR and ACF HanSD rats were substantially smaller than the responses to acetylcholine (compare the data of figures 1 and 3 and see E_{max} values for EET-A and acetylcholine in Table 2). Our present results are in agreement with our recent findings showing that in the nonclipped kidneys of 2K1C and in sham-operated normotensive rats, vasodilatory responses to EET-A, to a native 14,15-EET and to 11,12-ether-EET-8ZE (an analog of 11,12-EET) were rather modest (Sporková *et al.* 2016). These findings indicate that contribution of renal vasodilatory effects of EETs to the improvement of renal function in ACF-induced CHF is minor if any, strongly suggesting that direct renal tubular effects of EETs on sodium and water reabsorption is likely the main mechanism underlying improvement of renal function in ACF TGR treated with an sEH inhibitor. This interpretation is supported by the evidence that deficiency in natriuretic actions of EETs importantly contributes to the pathophysiology of many forms of experimental hypertension and progression of chronic kidney diseases. Indeed, most of available evidence suggests that EETs´ antihypertensive and organ-protective properties are mainly associated with their action on sodium excretion (Elmarakby 2012, Fan *et al.* 2015, Khan *et al.* 2014, Kopkan *et al.* 2012, Kujal *et al.* 2014, Neckář *et al.* 2012, Sporkova *et al.* 2011).

In conclusion, our present results show that small renal arteries of the kidneys of ACF HanSD rats exhibit greater vasodilator responses to EET-A compared to the arteries of ACF TGR. Therefore, reduced renal vasodilatory actions of EETs cannot be responsible for the lack of beneficial effects of chronic sEH inhibition on the development of renal dysfunction and progression of CHF in ACF HanSD rats.

Conflict of interest

None.

Acknowledgments

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Figure Legends

Figure 1. Vasodilator effects of acetylcholine in phenylephrine-preconstricted renal interlobararteries isolated from kidneys of sham-operated heterozygous Ren-2 renin transgenic rats (TGR), sham operated transgene-negative Hannover Sprague-Dawley (HanSD) rats and in TGR and HanSD rats with aorto-caval fistula (ACF).

Figure 2. Vasoconstrictor effects of norepinephrine in phenylephrine-preconstricted renal interlobar arteries isolated from kidneys of sham-operated heterozygous Ren-2 renin transgenic rats (TGR), sham operated transgene-negative Hannover Sprague-Dawley (HanSD) rats and in TGR and HanSD rats with aorto-caval fistula (ACF).

Figure 3. Vasodilator effects of 14,15-epoxyeicosatrienoic acid analog in phenylephrine-preconstricted renal interlobar arteries isolated from kidneys of sham-operated heterozygous Ren-2 renin transgenic rats (TGR), sham operated transgene-negative Hannover Sprague-Dawley (HanSD) rats and in TGR and HanSD rats with aorto-caval fistula (ACF).

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Table 1. Basal characteristics of cardiac function, organ weights and blood pressure at week 5 after induction of aorto-caval fistula or sham-operation.

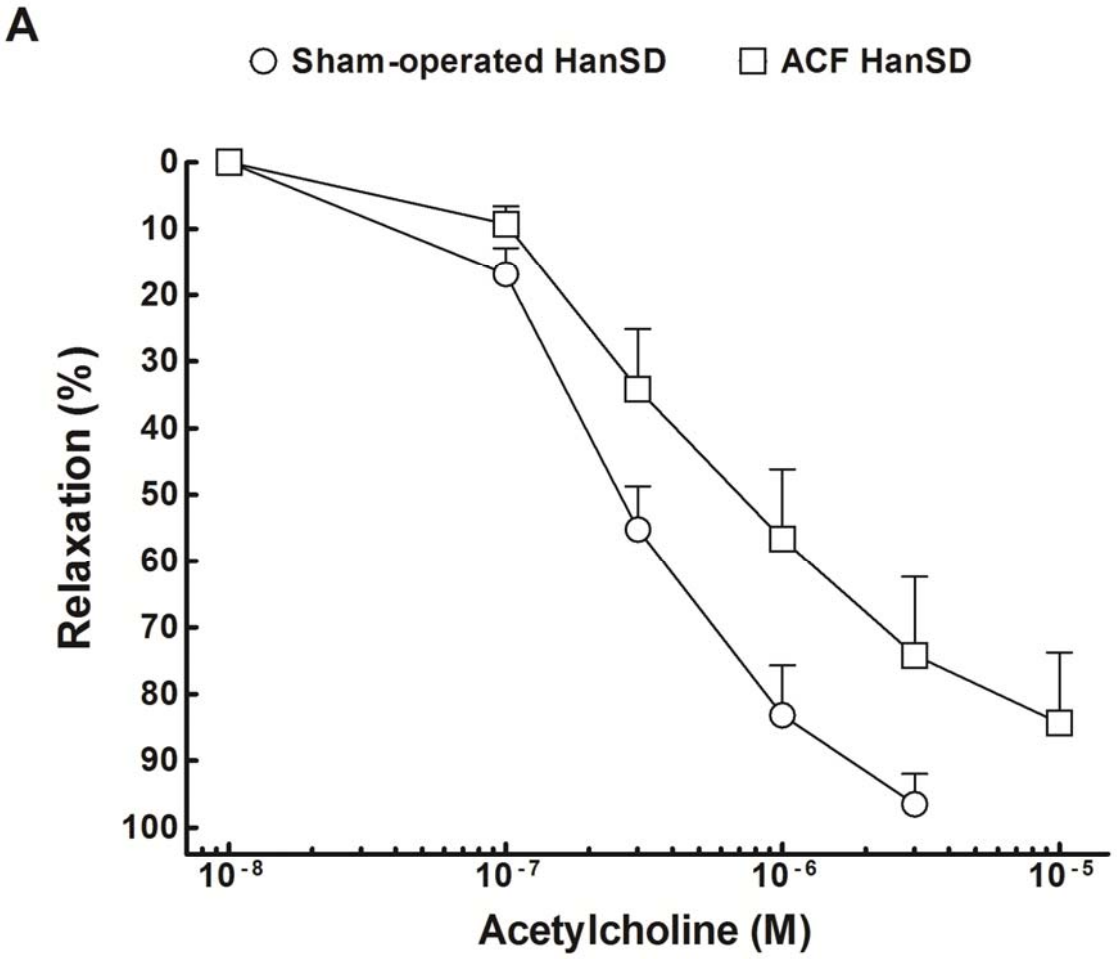
	Group			
Parameter	Sham-operated HanSD	Sham-operated TGR	ACF HanSD	ACF TGR
Heart rate (s^{-1})	384 ± 26	392 ± 18	332 ± 16$^{\#}$	328 ± 22$^{\#}$
LV diastolic diameter (mm)	6.28 ± 0.36	6.36 ± 0.28	8.96 ± 0.54$^{\#}$	10.62 ± 0.36$^{\#@}$
LV systolic diameter (mm)	3.14 ± 0.23	3.27 ± 0.25	6.36 ± 0.18$^{\#}$	7.24 ± 0.22$^{\#@}$
RV diastolic diameter (mm)	3.62 ± 0.21	3.48 ± 0.27	4.57 ± 0.22$^{\#}$	6.68 ± 0.29$^{\#@}$
LV fractional shortening (%)	54 ± 3	52 ± 3	36 ± 3$^{\#}$	35 ± 2$^{\#}$
Cardiac output (ml/min)	106 ± 17	114 ± 19	368 ± 21$^{\#}$	372 ± 25$^{\#}$
Mean arterial pressure (mmHg)	119 ± 6	142 ± 5*	88 ± 4$^{\#}$	105 ± 6$^{\#@}$
Body weight (g)	482 ± 28	496 ± 18	506 ± 24	512 ± 23
Heart weight (mg)/Body weight (g)	3.21 ± 0.14	4.08 ± 0.19*	4.74 ± 0.17$^{\#}$	6.01 ± 0.22$^{\#@}$
Kidney weight (mg)/Body weight (g)	2.59 ± 0.17	2.48 ± 0.19	2.61 ± 0.22	2.63 ± 0.24
Lung weight (mg)/Body weight (g)	3.68 ± 0.31	3.72 ± 0.34	4.29 ± 0.41	4.86 ± 0.29$^{\#}$
Liver weight (mg)/Body weight (g)	29.2 ± 0.88	28.9 ± 0.91	29.6 ± 0.85	30.4 ± 1.22

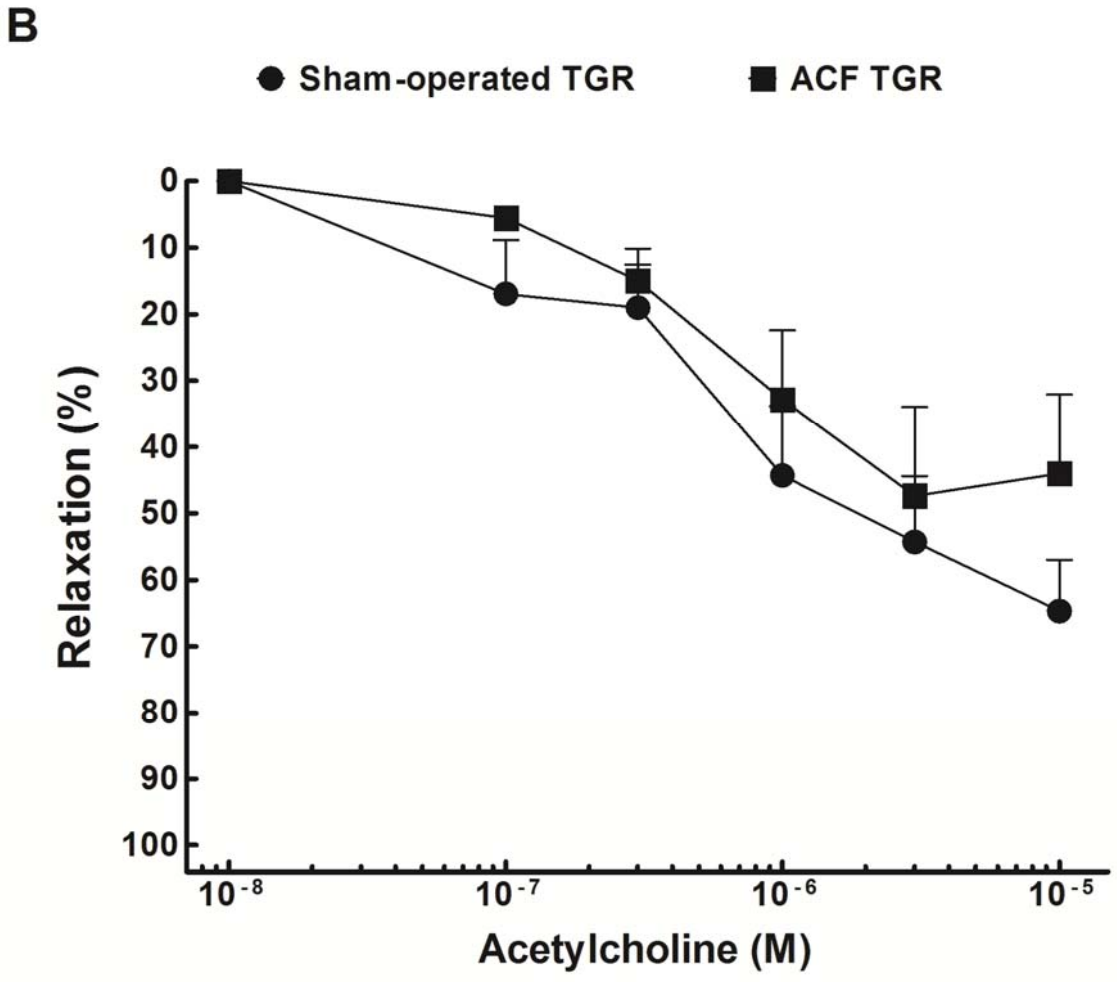
Values are means ± SEM. HanSD, transgene-negative Hannover-Sprague Dawley rats; TGR, Ren-2 renin transgenic rats; ACF, aorto-caval fistula; EET-A, 14,15-EETs agonistic analog; LV, RV, left and right ventricle, respectively. * P<0.05 sham-operated TGR vs. sham-operated HanSD rats; $^{\#}$ P<0.05 ACF rats vs. sham-operated rats (always comparing the same strain). $^{@}$ P<0.05 ACF TGR vs. ACF HanSD rats.

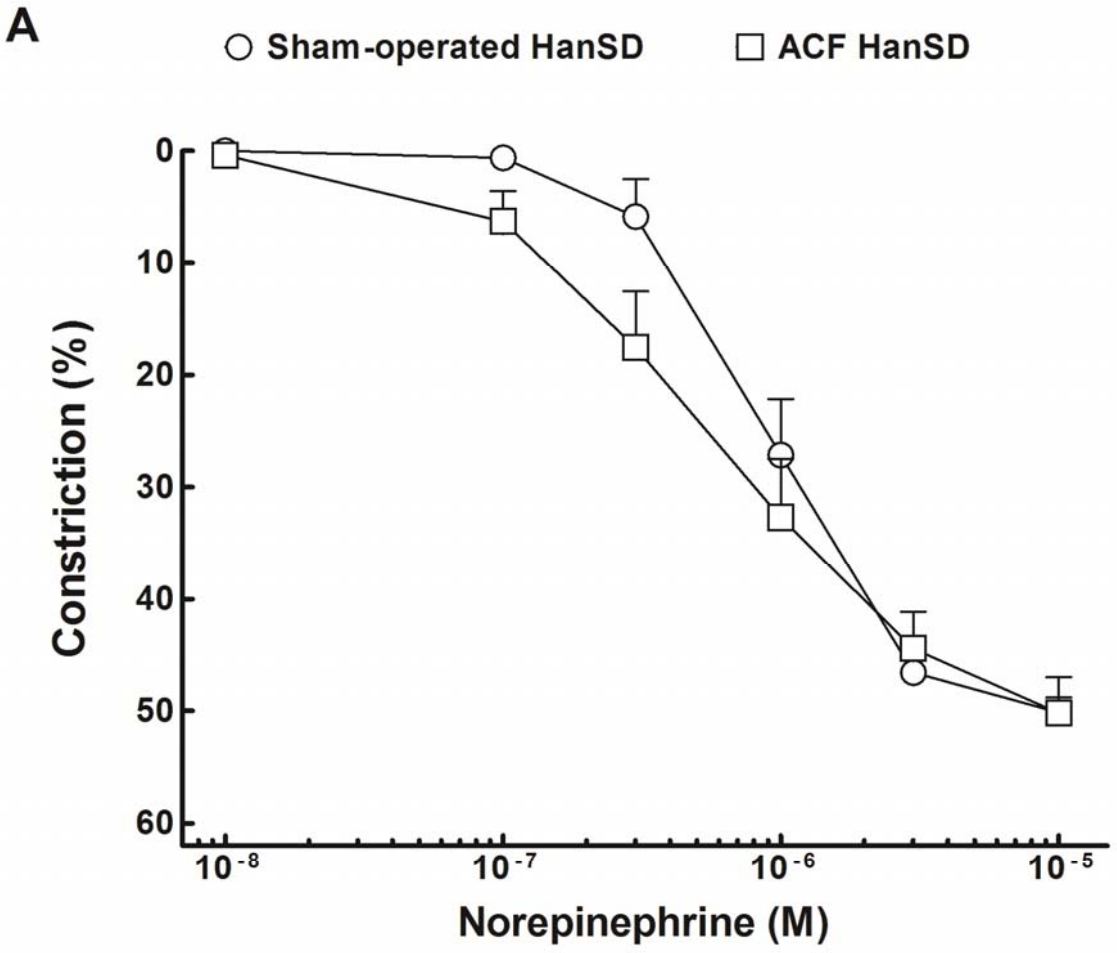
Table 2. Maximal vasodilatory and vasoconstrictor responses (E_{max}) and half maximal effective concentration (EC50) to produce vascular response sof phenylephrine-preconstricted renal interlobar arteries.

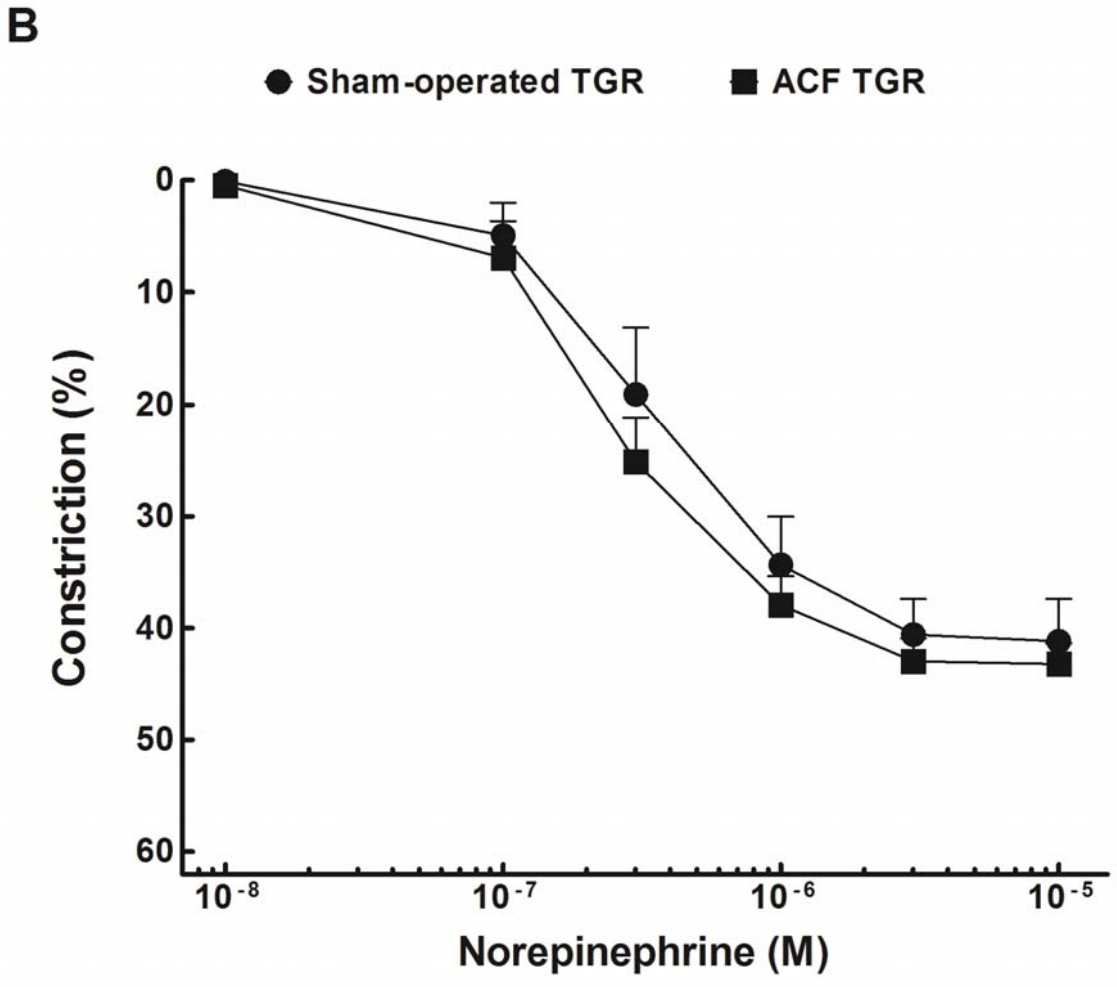
Parameter	Group			
	Sham-operated HanSD (n = 8)	Sham-operated TGR (n = 7)	ACF HanSD (n = 9)	ACF TGR (n = 9)
Basal diameter (µm)	342 ± 13	324 ± 14	327 ± 16	330 ± 17
PE-preconstricted diameter (µm)	269 ± 12	251 ± 11	247 ± 13	260 ± 11
PE-elicited changes in diameter (%)	-21.4 ± 6.1	-22.5 ± 7.1	-24.5 ± 5.9	-21.2 ± 4.4
Acetylcholine				
E_{max} (%)	108 ± 7	64 ± 6*	85 ± 9	61 ± 7$^{\#}$
EC50 (nM)	289 ± 62	549 ± 63*	408 ± 91	863 ± 62$^{\#}$
Norepinehrine				
E_{max} (%)	58 ± 3	46 ± 4	53 ± 3	48 ± 3
EC50 (nM)	998 ± 64	361 ± 49	601 ± 54	280 ± 50
EET-A				
E_{max} (%)	27 ± 4	22 ± 5	35 ± 3	16 ± 3$^{\#}$
EC50 (nM)	124 ± 24	100 ± 18	212 ± 31	98 ± 12$^{\#}$

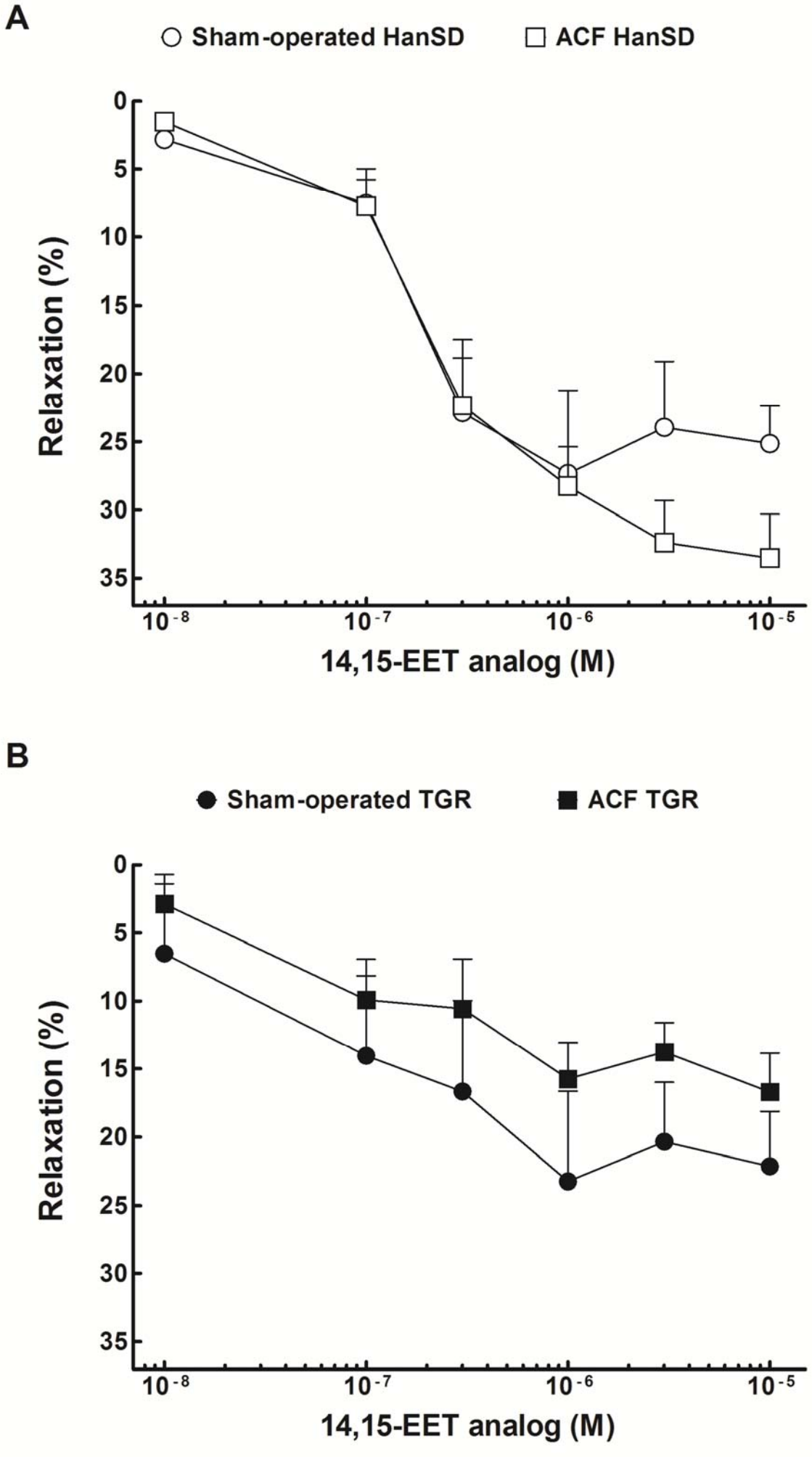
Values are means ± SEM. HanSD, transgene-negative Hannover-Sprague Dawley rats; TGR, Ren-2 renin transgenic rats; ACF, aorto-caval fistula; EET-A, 14,15-EETs agonistic analog; *P<0.05 sham-operated TGR vs. sham-operated HanSD rats; $^{\#}$ P<0.05 ACF TGR vs. ACF HanSD rats.


A
Sham-operated HanSD
ACF HanSD
Relaxation (%)
0
10
20
30
40
50
60
70
80
90
100
10-8
10-7
10-6
10-5
Acetylcholine (M)


B
Sham-operated TGR
ACF TGR
Relaxation (%)
0
10
20
30
40
50
60
70
80
90
100
10-8
10-7
10-6
10-5
Acetylcholine (M)


A
Sham-operated HanSD
ACF HanSD
Constriction (%)
0
10
20
30
40
50
60
10-8
10-7
10-6
10-5
Norepinephrine (M)


B
Sham-operated TGR
ACF TGR
Constriction (%)
0
10
20
30
40
50
60
10-8
10-7
10-6
10-5
Norepinephrine (M)


A
Sham-operated HanSD
ACF HanSD
Relaxation (%)
0
5
10
15
20
25
30
35
10-8
10-7
10-6
10-5
14,15-EET analog (M)
B
Sham-operated TGR
ACF TGR
Relaxation (%)
0
5
10
15
20
25
30
35
10-8
10-7
10-6
10-5
14,15-EET analog (M)