

# Reduction in the Amplitude of Shortening and Ca<sup>2+</sup> Transient by Phlorizin and Quercetin-3-O-Glucoside in Ventricular Myocytes From Streptozotocin-Induced Diabetic Rats

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## Summary

Diabetes mellitus is the leading cause of cardiovascular morbidity and mortality. Phlorizin (PHLOR) and quercetin-3-O-glucoside (QUER-3-G) are two natural compounds reported to have antidiabetic properties by inhibiting sodium/glucose transporters. Their effects on ventricular myocyte shortening and intracellular Ca<sup>2+</sup> in streptozotocin (STZ)-induced diabetic rats were investigated. Video edge detection and fluorescence photometry were used to measure ventricular myocyte shortening and intracellular Ca<sup>2+</sup>, respectively. Blood glucose in STZ rats was 4-fold higher (469.64±22.23 mg/dl, *n*=14) than in Controls (104.06±3.36 mg/dl, *n*=16). The amplitude of shortening was reduced by PHLOR in STZ (84.76±2.91 %, *n*=20) and Control (83.72±2.65 %, *n*=23) myocytes, and by QUER-3-G in STZ (79.12±2.28 %, *n*=20) and Control (76.69±1.92 %, *n*=30) myocytes. The amplitude of intracellular Ca<sup>2+</sup> was also reduced by PHLOR in STZ (82.37±3.16 %, *n*=16) and Control (73.94±5.22 %, *n*=21) myocytes, and by QUER-3-G in STZ (73.62±5.83 %, *n*=18) and Control (78.32±3.54 %, *n*=41) myocytes. Myofilament sensitivity to Ca<sup>2+</sup> was not significantly altered by PHLOR; however, it was reduced by QUER-3-G modestly in STZ myocytes and significantly in Controls. PHLOR and QUER-3-G did not significantly alter sarcoplasmic reticulum Ca<sup>2+</sup> in STZ or Control myocytes. Altered mechanisms of Ca<sup>2+</sup> transport partly underlie PHLOR and QUER-3-G negative inotropic effects in ventricular myocytes from STZ and Control rats.

## Key words

Diabetes mellitus • SGLT inhibitors • Quercetin-3-O-glucoside • Phlorizin • Ventricular myocytes • Streptozotocin-induced diabetic rats

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## Introduction

Diabetes mellitus (DM) is a major global health problem and thirty-five million people with DM live in the Middle East and North Africa. A variety of complications can arise from uncontrolled DM including cardiovascular diseases, neuropathy, nephropathy and retinopathy which makes it the leading cause of cardiovascular morbidity and mortality, blindness, end-stage renal failure and non-traumatic limb amputations (International Diabetes Federation 2013). Control of DM involves different approaches including lifestyle that involves increasing physical activity and weight loss, and therapeutic approaches that involve administration of medications (Ismail-Beigi 2012). The development of new antidiabetic medications without the side effects associated with the use of other available drugs such as weight gain and hypoglycemia as with insulin, sulphonylureas and thiazolidinediones, and diarrhea and nausea as with metformin and incretin mimetics, is a continuous challenge (Chao and Henry 2010). Sodium-glucose co-transporter (SGLT) inhibitors are a new class of antidiabetic drugs that work by a novel insulin-independent mechanism. SGLT inhibitors are subdivided into three subclasses including non-selective or dual SGLT1 and SGLT2 inhibitors such as phlorizin

(PHLOR) (Chao and Henry 2010) and LX4211 (Zambrowicz *et al.* 2012), selective SGLT1 inhibitors such as quercetin-3-O-glucoside (QUER-3-G) (Cermak *et al.* 2004, Gee *et al.* 1998), KGA-2727 (Shibazaki *et al.* 2012) and KGA-3235 (Kissei Pharmaceuticals 2009), and selective SGLT2 inhibitors such as dapagliflozin (Komoroski *et al.* 2009), canagliflozin (Sha *et al.* 2011), seragliflozin (Katsuno *et al.* 2007) and ipragliflozin (Imamura *et al.* 2012). PHLOR is a natural organic phenolic glycoside belonging to the chalcone class (Ehrenkranz *et al.* 2005, Tahrani *et al.* 2013). It was first isolated by French scientists in 1835 from apple tree bark. In 1886, von Mering observed that PHLOR produces glycosuria in doses above 1.0 g (Ehrenkranz *et al.* 2005). PHLOR is the parent compound from which synthesized SGLT inhibitors were derived (Tsujiyama *et al.* 1996). PHLOR was not itself pharmaceutically developed as an SGLT inhibitor because it is poorly absorbed by the intestine. It is hydrolyzed to another compound phloretin which is an inhibitor of facilitative glucose transporter 1 (GLUT1) and thus has low oral bioavailability (Chao and Henry 2010). QUER-3-G is a flavonol glycoside that is found in several plants including apple, tea, onion, crataegus, pistachio nut, saint John's wort in addition to many fruits, vegetables and cereals (Razavi *et al.* 2009, Valentová *et al.* 2014, Wang *et al.* 2013). In addition to inhibiting SGLT1, QUER-3-G has been reported to also inhibit alpha-glucosidase enzyme (Li *et al.* 2009). Therefore, it has dual antidiabetic action which may make it a good parent for the development of antidiabetic drugs. Our previous study showed that the selective SGLT2 inhibitor dapagliflozin significantly reduced the amplitude of shortening and  $Ca^{2+}$  transient in myocytes from STZ rats (Hamouda *et al.* 2014). Therefore, we extended this study to investigate also the effects of other SGLT inhibitors, like PHLOR and QUER-3-G, on shortening and intracellular  $Ca^{2+}$  in ventricular myocytes from STZ-induced diabetic rats.

## Materials and Methods

### Ethical approval

This study was approved by the Animal Ethics Committee, College of Medicine & Health Sciences, United Arab Emirates University.

### Experimental protocol

Experiments were performed in STZ-induced diabetic ( $n=14$ ) and in age-matched Control rats ( $n=16$ ).

Diabetes was induced in 2-month-old rats by injecting STZ (60 mg/kg, i.p.) dissolved in citrate buffer. Control rats received citrate buffer alone. Animals received standard rat chow and water *ad libitum*. Before each experiment, bodyweight, heart weight and non-fasting blood glucose were measured.

### Ventricular myocyte isolation

Ventricular myocytes were isolated according to previously described techniques (Howarth *et al.* 2002). In brief, rats were euthanized by use of a guillotine. Hearts were then quickly removed and mounted on a Langendorff system for retrograde perfusion. Hearts were perfused at a constant flow rate of 8 ml.g heart<sup>-1</sup>.min<sup>-1</sup> and at 35-36 °C with cell isolation solution containing in mM/l: 130.0 NaCl, 5.4 KCl, 1.4 MgCl<sub>2</sub>, 0.75 CaCl<sub>2</sub>, 0.4 NaH<sub>2</sub>PO<sub>4</sub>, 5.0 HEPES, 10.0 glucose, 20.0 taurine and 10.0 creatine (pH 7.3) until heart contraction had stabilized. Perfusion was then switched for 4 min to Ca<sup>2+</sup>-free cell isolation solution containing 0.1mM/l EGTA and then for 6 min to cell isolation solution containing 0.05 mM/l Ca<sup>2+</sup>, 0.60 mg/ml type 1 collagenase (Worthington Biochemical Corp, Lakewood, NJ, USA) and 0.075 mg/ml type XIV protease (Sigma, Taufkirchen, Germany). Ventricle tissue was excised from the heart, minced carefully by the use of scissors and then gently agitated in collagenase-containing isolation solution supplemented with 1 % BSA. Cells were filtered from this solution at 4 min intervals and re-suspended in cell isolation solution containing 0.75 mM/l Ca<sup>2+</sup>.

### Measurement of ventricular myocyte shortening

Myocytes were allowed to settle on the glass bottom of a Perspex chamber mounted on the stage of an inverted microscope (Axiovert 35, Zeiss, Göttingen, Germany). Myocytes were superfused (3-5 ml/min) with normal Tyrode (NT) containing the following in mM/l: 140.0 NaCl, 5.0 KCl, 1.0 MgCl<sub>2</sub>, 10.0 glucose, 5.0 HEPES, 1.8 CaCl<sub>2</sub> (pH 7.4). PHLOR (Sigma-Aldrich, Saint Louis, Missouri, USA) and QUER-3-G (Sigma, Taufkirchen, Germany) were dissolved in dimethylsulphoxide (DMSO) to give a final concentration of 10<sup>-6</sup> M. This concentration was chosen based on a concentration-response experiment done in our previous study on dapagliflozin and to enable comparison with this study (Hamouda *et al.* 2014). The final concentration of DMSO in all experimental test solutions was 0.005 %. It has been reported that 0.01 % DMSO does not significantly affect contractile parameters in rat

ventricular myocytes (Sun *et al.* 2010). Shortening of electrically stimulated (1 Hz) ventricular myocytes was recorded using a video edge detection system (VED-114, Crystal Biotech, Northborough, MA, USA) at 35-36 °C. Resting cell length (RCL), time to peak (TPK) shortening, time to half (THALF) relaxation and amplitude (AMP) of shortening (expressed as a percentage of shortening in Control and STZ myocytes perfused with NT) were measured. Data were acquired and analyzed with Signal Averager software v 6.37 (Cambridge Electronic Design, Cambridge, UK).

#### *Measurement of intracellular Ca<sup>2+</sup> concentration*

Myocytes were loaded with the fluorescent indicator Fura-2 AM (F-1221, Molecular Probes, Eugene, OR, USA) as previously described (Howarth *et al.* 2002). A final Fura-2 concentration of 2.5 µM/l was obtained by adding 6.25 µl of a 1.0 mM/l stock solution of Fura-2 AM (dissolved in DMSO) to 2.5 ml of myocytes suspended in NT solution. Myocytes were loaded with Fura-2 AM by gentle shaking for 10 min at room temperature (24 °C). Myocytes were then centrifuged, washed with NT to remove extracellular Fura-2 and left for 30 min to ensure complete hydrolysis of the intracellular ester. Intracellular Ca<sup>2+</sup> concentration was measured by illuminating myocytes alternately by 340 nm and 380 nm light using a monochromator (Cairn Research, Faversham, UK) which changed the excitation light every 2 ms. The resulting fluorescence emitted at 510 nm was recorded by a photomultiplier tube and the ratio of the emitted fluorescence at the two excitation wavelengths (340/380 ratio) was calculated to provide an index of intracellular Ca<sup>2+</sup> concentration. Resting Fura-2 ratio, TPK Ca<sup>2+</sup> transient, THALF decay of the Ca<sup>2+</sup> transient and the amplitude of the Ca<sup>2+</sup> transient (expressed as a percentage of Ca<sup>2+</sup> transient in Control and STZ myocytes perfused with NT) were measured in electrically stimulated (1 Hz) myocytes maintained at 35-36 °C. Data were acquired and analyzed with Signal Averager software v 6.37 (Cambridge Electronic Design, Cambridge, UK).

#### *Assessment of myofilament sensitivity to Ca<sup>2+</sup>*

Shortening and Fura-2 ratio were recorded simultaneously in some myocytes (Howarth *et al.* 2011). Myofilament sensitivity to Ca<sup>2+</sup> was assessed from phase-plane diagrams of Fura-2 ratio versus cell length by measuring the gradient of the Fura-2-cell length trajectory during late relaxation of the twitch contraction. The

position of the trajectory reflects the relative myofilament response to Ca<sup>2+</sup> and hence, can be used as a measure of myofilament sensitivity to Ca<sup>2+</sup> (Howarth and Qureshi 2008, Spurgeon *et al.* 1992).

#### *Measurement of sarcoplasmic reticulum Ca<sup>2+</sup> release*

Sarcoplasmic reticulum (SR) Ca<sup>2+</sup> release was assessed according to previously described techniques (Bassani *et al.* 1995, Howarth *et al.* 2002, 1999). After establishing steady state Ca<sup>2+</sup> transients in electrically stimulated (1 Hz) myocytes maintained at 35-36 °C and loaded with Fura-2, stimulation was paused for a period of 5 s. Caffeine (20 mM) was then applied rapidly using a solution switching device (Levi *et al.* 1996) for 10 s. Electrical stimulation was then resumed. SR releasable Ca<sup>2+</sup> was assessed by measuring the amplitude of the caffeine-stimulated Ca<sup>2+</sup> transient. Fractional release of SR Ca<sup>2+</sup> was assessed by comparing the amplitude of the electrically-stimulated steady state Ca<sup>2+</sup> transients with that of the caffeine-stimulated Ca<sup>2+</sup> transient. Refilling of SR was assessed by measuring the rate of recovery of electrically-stimulated Ca<sup>2+</sup> transients following application of caffeine.

#### *Statistical analysis*

Results are expressed as the mean ± SEM of 'n' observations. 'n' refers to number of rats or ventricular myocytes. Data were analyzed by either the Independent samples t-test or one-way ANOVA with Bonferroni *post hoc* for multiple comparisons as appropriate using IBM SPSS Statistics for Windows, Version 20.0. (IBM Corp., NY, USA). Statistical significance was set at P<0.05 and was denoted by horizontal lines on all graphs.

## **Results**

#### *General characteristics of streptozotocin-induced diabetic rats*

Experiments began 2 months after STZ treatment. At the time of experiments, non-fasting glucose level was measured in blood taken from the tail vein to confirm diabetes. STZ rats had elevated non-fasting blood glucose level (469.64±22.23 mg/dl, n=14) compared to Controls (104.06±3.36 mg/dl, n=16). STZ rats had significantly (*P*<0.05) lower body weights (267.57±7.45 g, n=14) compared to Controls (352.25±9.09 g, n=16), as well as significantly (*P*<0.05) lower heart weights (1.06±0.02 g, n=14) compared to Controls (1.2±0.03 g, n=16). Heart weight to body weight

ratio of STZ rats was significantly ( $P < 0.05$ ) higher ( $4.00 \pm 0.11$  mg/g,  $n=14$ ) compared to Controls ( $3.42 \pm 0.05$  mg/g,  $n=16$ ).

*Effects of phlorizin and quercetin-3-O-glucoside on ventricular myocyte shortening*

Ventricular myocyte shortening was assessed in electrically stimulated (1 Hz) STZ and Control myocytes maintained at 35–36 °C. Figure 1 shows typical records of shortening in a Control myocyte during superfusion with NT, 5 min NT + PHLOR (Fig. 1A) or NT + QUER-3-G (Fig. 1B) and after 5 min washout with NT. The effects of PHLOR and QUER-3-G on RCL, TPK shortening, THALF relaxation and amplitude of shortening are shown in Figures 1C–J. RCL was not significantly ( $P > 0.05$ ) altered in STZ myocytes compared to Controls or by PHLOR and QUER-3-G (Figs 1C and G). TPK shortening was generally prolonged in STZ myocytes compared to Controls (Figs 1D and H). PHLOR had no significant ( $P > 0.05$ ) effect on TPK shortening (Fig. 1D); however, TPK was significantly ( $P < 0.05$ ) shortened in STZ/QUER-3-G and in Control/QUER-3-G compared to STZ and Control myocytes (Fig. 1H). THALF relaxation of shortening was not altered in STZ compared to Control or by PHLOR and QUER-3-G (Figs 1E and I). Amplitude of shortening was not significantly ( $P > 0.05$ ) altered in STZ myocytes compared to Controls (Figs 1F and J). Amplitude of shortening was significantly ( $P < 0.05$ ) reduced in STZ/PHLOR ( $84.76 \pm 2.91$  %,  $n=20$ ) and Control/PHLOR ( $83.72 \pm 2.65$  %,  $n=23$ ) myocytes compared to STZ and Control myocytes (Fig. 1F). Amplitude of shortening was also significantly ( $P < 0.05$ ) reduced in STZ/QUER-3-G ( $79.12 \pm 2.28$  %,  $n=20$ ) and Control/QUER-3-G ( $76.69 \pm 1.92$  %,  $n=30$ ) myocytes compared to STZ and Control myocytes (Fig. 1J).

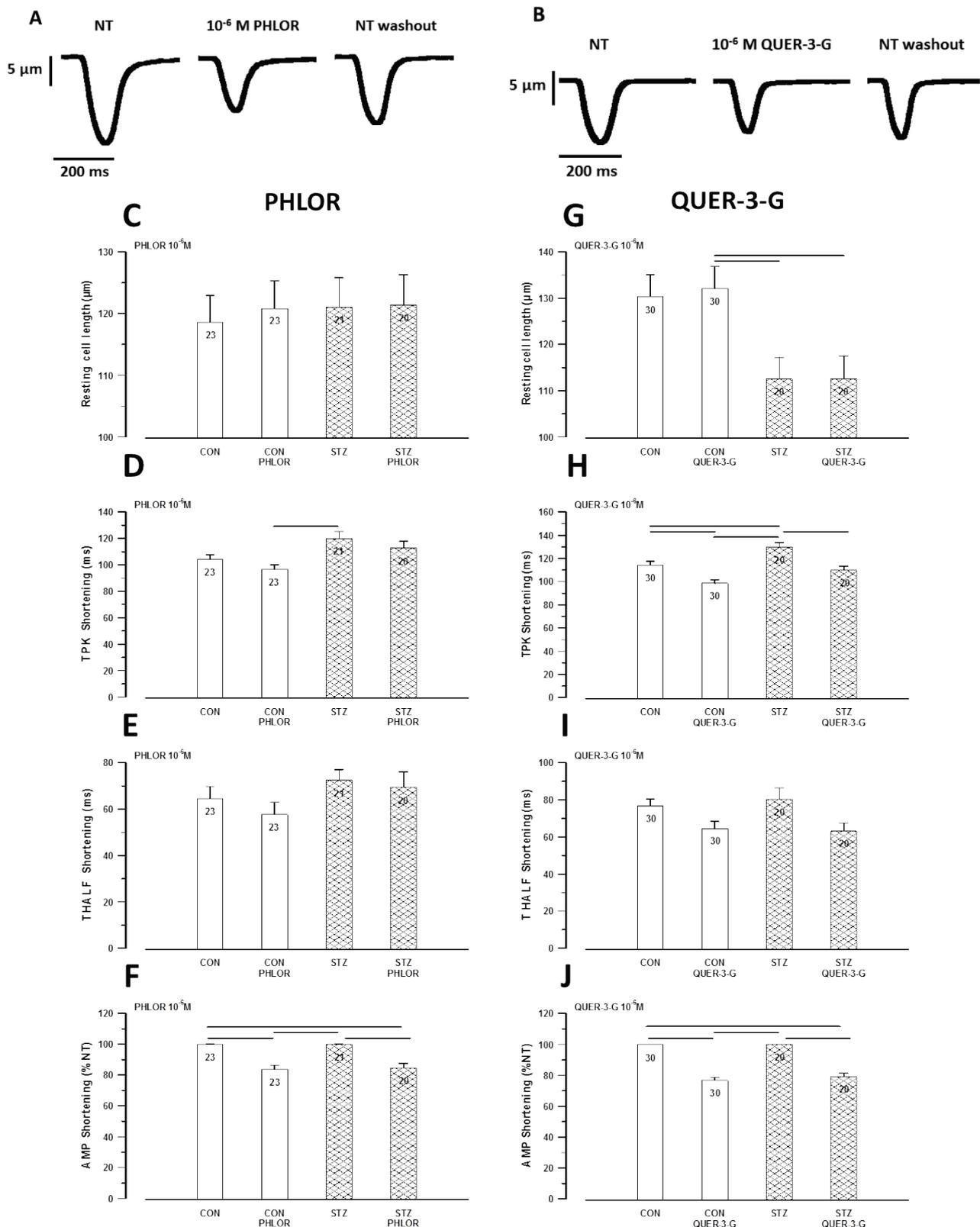
*Effects of phlorizin and quercetin-3-O-glucoside on ventricular myocytes intracellular  $Ca^{2+}$*

Intracellular  $Ca^{2+}$  was measured in Fura-2 loaded, electrically stimulated (1 Hz) myocytes at 35–36 °C. Figure 2 shows typical records of  $Ca^{2+}$  transient in a Control myocyte during superfusion with NT and NT + PHLOR (Fig. 2A) or NT + QUER-3-G (Fig. 2B) for 5 min. The effects of PHLOR and QUER-3-G on resting Fura-2 ratio, TPK  $Ca^{2+}$  transient, THALF decay of the  $Ca^{2+}$  transient and amplitude of the  $Ca^{2+}$  transient are shown in Figures 2C–J. Resting Fura-2 ratio was not significantly ( $P > 0.05$ ) altered in STZ myocytes compared

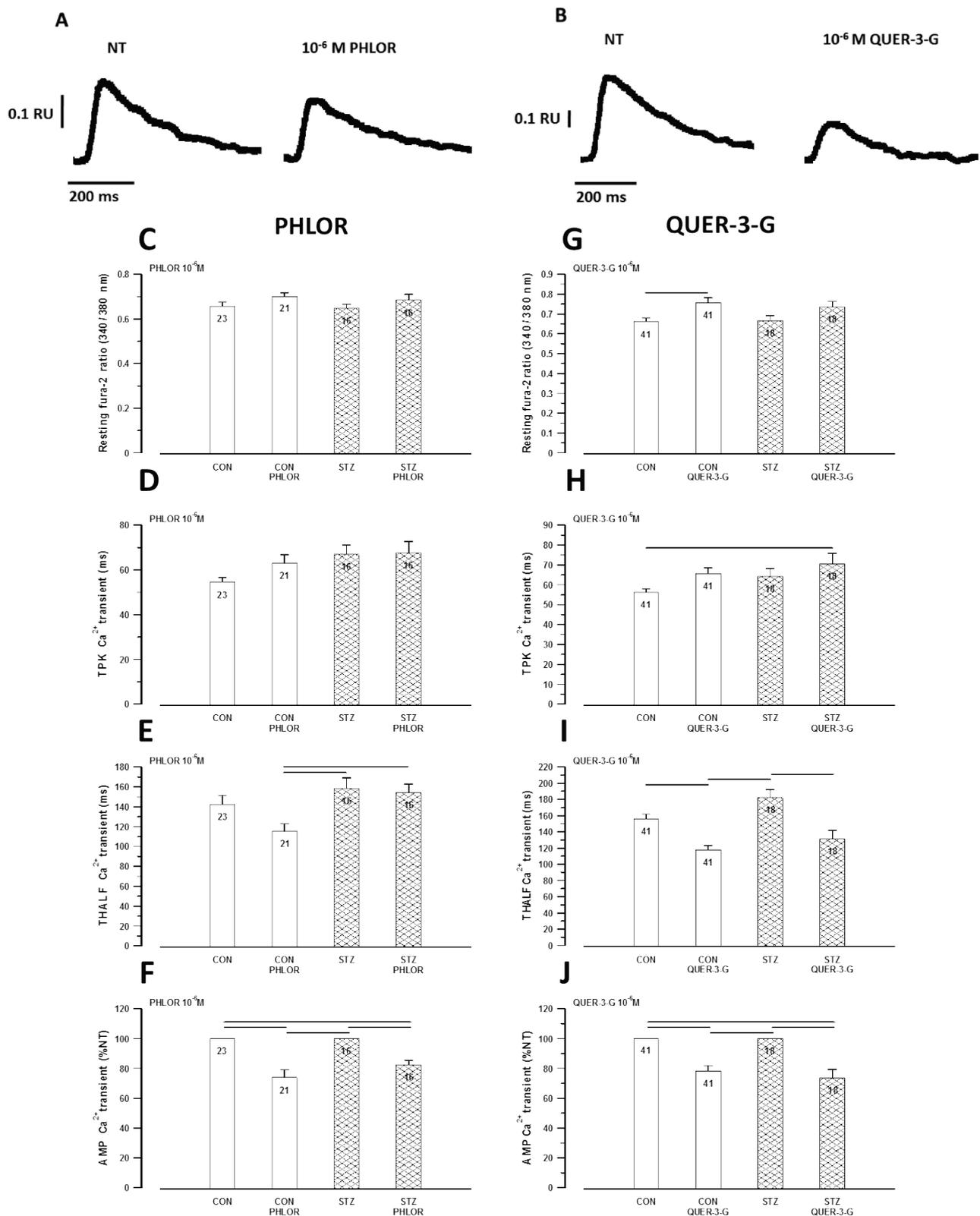
to Controls or by PHLOR (Fig. 1C). QUER-3-G showed a significant ( $P > 0.05$ ) increase in Control/QUER-3-G myocytes ( $0.757 \pm 0.025$ ,  $n=41$ ) compared to Controls ( $0.661 \pm 0.018$ ,  $n=41$ ), but there was no significant ( $P > 0.05$ ) effect in STZ/QUER-3-G compared to STZ myocytes (Fig. 1G). TPK  $Ca^{2+}$  transient was not significantly ( $P > 0.05$ ) altered in STZ myocytes compared to Controls and was not altered by either PHLOR or QUER-3-G (Figs 2D and H). THALF decay of the  $Ca^{2+}$  transient was also not significantly ( $P > 0.05$ ) altered in STZ compared to Control myocytes (Figs 2E and I). THALF decay of the  $Ca^{2+}$  transient was not significantly altered by PHLOR (Fig. 2E); however, it was significantly ( $P < 0.05$ ) shortened by QUER-3-G in STZ/QUER-3-G and Control/QUER-3-G myocytes compared to STZ myocytes and Controls (Fig. 2I). Amplitude of the  $Ca^{2+}$  transient was not significantly ( $P > 0.05$ ) altered in STZ myocytes compared to Controls (Figs 2F and J). However, the amplitude of the  $Ca^{2+}$  transient was significantly ( $P < 0.05$ ) reduced in STZ/PHLOR ( $82.37 \pm 3.16$  %,  $n=16$ ) and Control/PHLOR ( $73.94 \pm 5.22$  %,  $n=21$ ) myocytes compared to STZ and Control myocytes (Fig. 2F). Amplitude of shortening was also significantly ( $P < 0.05$ ) reduced in STZ/QUER-3-G ( $73.62 \pm 5.83$  %,  $n=18$ ) and Control/QUER-3-G ( $78.32 \pm 3.54$  %,  $n=41$ ) myocytes compared to STZ and Control myocytes (Fig. 2J).

*Effects of phlorizin and quercetin-3-O-glucoside on ventricular myocyte myofilament sensitivity to  $Ca^{2+}$*

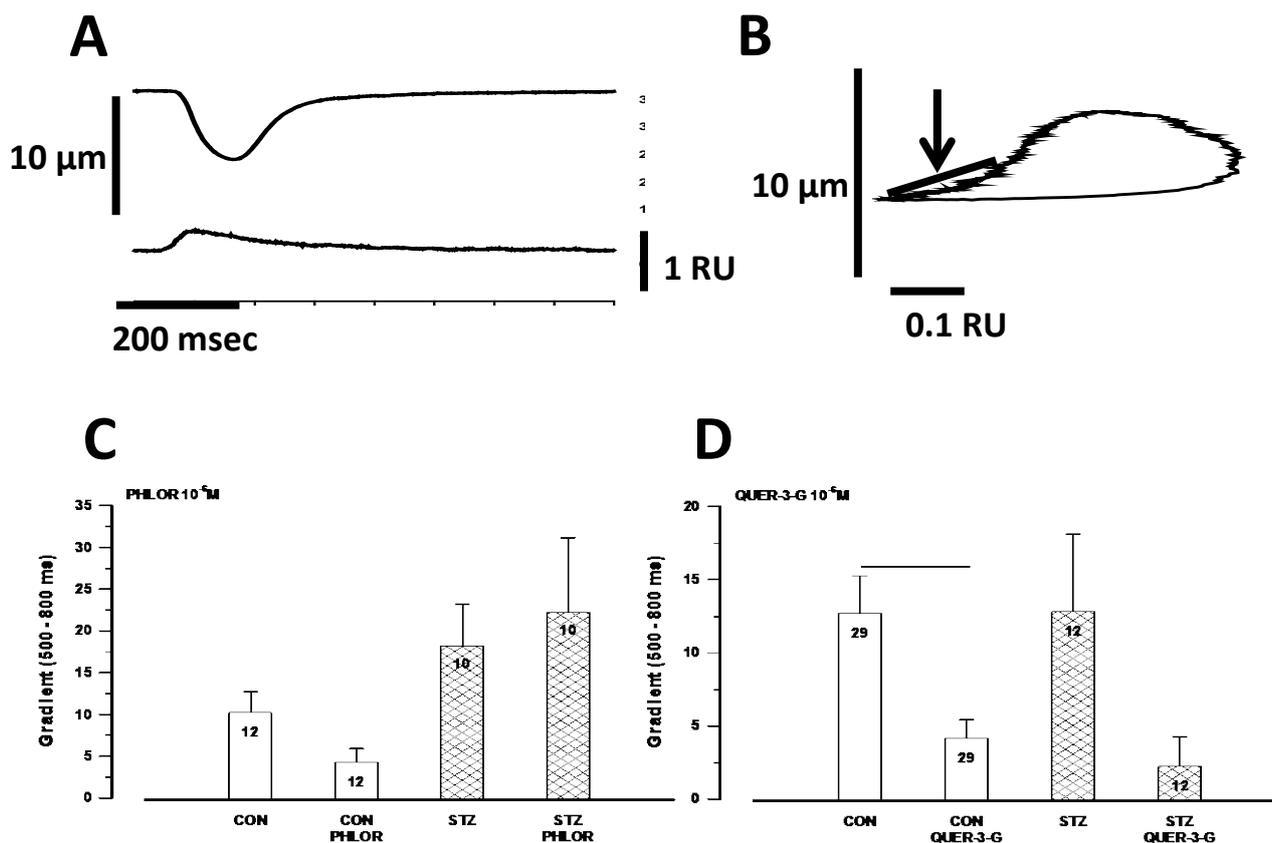
In some myocytes shortening and  $Ca^{2+}$  transient were recorded simultaneously to measure myofilament sensitivity to  $Ca^{2+}$ . A simultaneous recording of shortening and  $Ca^{2+}$  transient in a Control myocyte is shown in Figure 3A and a phase plane diagram showing the relationship between the Fura-2 ratio and shortening is shown in Figure 3B. The gradient of the Fura-2-cell length trajectory was used to assess the relative myofilament response and sensitivity to  $Ca^{2+}$ . There was no significant difference in myofilament sensitivity to  $Ca^{2+}$  in myocytes from STZ compared to Control myocytes (Figs 3C and D) or in STZ/PHLOR and Control/PHLOR compared to STZ and Control myocytes (Fig. 3C). There was a modest reduction in myofilament sensitivity to  $Ca^{2+}$  in STZ/QUER-3-G and a significant ( $P < 0.05$ ) reduction in myofilament sensitivity in Control/QUER-3-G compared to STZ and Control myocytes (Fig. 3D).



**Fig. 1.** Effects of phlorizin and quercetin-3-O-glucoside on shortening in ventricular myocytes from streptozotocin-induced diabetic and Control rats. Typical records of shortening in a Control myocyte superfused with normal Tyrode (NT), NT + 10<sup>-6</sup> M PHLOR and NT during washout (**A**) and in another Control myocyte superfused with NT, NT + 10<sup>-6</sup> M QUER-3-G and NT during washout (**B**). PHLOR panels showing the mean resting cell length (**C**), time to peak (TPK) shortening (**D**), time to half (THALF) relaxation of shortening (**E**) and amplitude (AMP) of shortening (**F**). QUER-3-G panels showing the mean resting cell length (**G**), time to peak (TPK) shortening (**H**), time to half (THALF) relaxation of shortening (**I**) and amplitude (AMP) of shortening (**J**). Data are mean + S.E.M., *n*=20-23 myocytes from 7 rats for PHLOR and *n*=20-30 myocytes from 5-9 rats for QUER-3-G. Horizontal lines above the bars represent significant differences at the level of *P*<0.05.



**Fig. 2.** Effects of phlorizin and quercetin-3-O-glucoside on intracellular  $\text{Ca}^{2+}$  in ventricular myocytes from streptozotocin-induced diabetic rats. Typical records of  $\text{Ca}^{2+}$  transient in a Control myocyte superfused with normal Tyrode (NT) then NT +  $10^{-6}$  M PHLOR (**A**) and in another Control myocyte superfused with NT then NT+  $10^{-6}$  M QUER-3-G (**B**). PHLOR panels showing the mean resting Fura-2 ratio (**C**), time to peak (TPK)  $\text{Ca}^{2+}$  transient (**D**), time to half (THALF) decay of the  $\text{Ca}^{2+}$  transient (**E**) and amplitude (AMP) of the  $\text{Ca}^{2+}$  transient (**F**). QUER-3-G panels showing the mean resting Fura-2 ratio (**G**), time to peak (TPK)  $\text{Ca}^{2+}$  transient (**H**), time to half (THALF) decay of the  $\text{Ca}^{2+}$  transient (**I**) and amplitude (AMP) of the  $\text{Ca}^{2+}$  transient (**J**). Data are mean + S.E.M.,  $n=16-23$  myocytes from 3-4 rats for PHLOR and  $n=18-41$  myocytes from 3-6 rats for QUER-3-G. Horizontal lines above the bars represent significant differences at the level of  $P<0.05$ .



**Fig. 3.** Effects of phlorizin and quercetin-3-O-glucoside on myofilament sensitivity to  $\text{Ca}^{2+}$  in ventricular myocytes from streptozotocin-induced diabetic and Control rats. Typical records of shortening and  $\text{Ca}^{2+}$  transient recorded simultaneously in an electrically stimulated ventricular myocyte from a Control rat (**A**). Typical phase plane diagram of Fura-2 ratio unit (RU) vs. cell length in a myocyte from a Control rat. The arrow indicates the region where the gradient was measured (**B**). Panel showing mean gradient of the Fura-2 cell length trajectory during late relaxation of the twitch contraction during the period 500-800 ms with PHLOR (**C**) and QUER-3-G (**D**). Data are mean + S.E.M.,  $n=10-12$  myocytes from 3-4 rats for PHLOR and  $n=12-29$  myocytes from 3-6 rats for QUER-3-G.

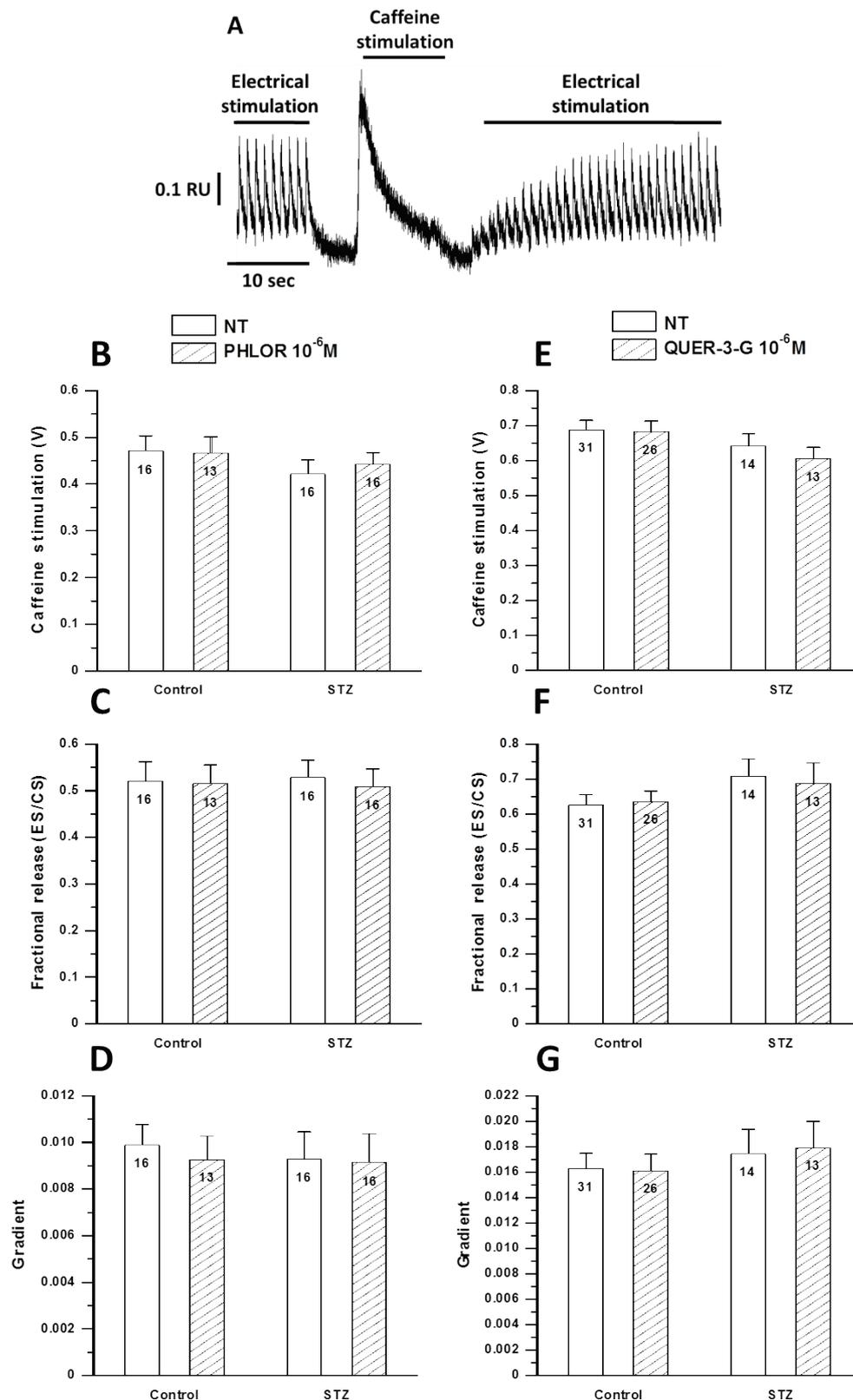
*Effects of phlorizin and quercetin-3-O-glucoside on ventricular myocytes sarcoplasmic reticulum  $\text{Ca}^{2+}$  release*

SR  $\text{Ca}^{2+}$  release was investigated in Fura-2 loaded STZ and Control myocytes maintained at 35-36 °C. Figure 4A shows a typical record of  $\text{Ca}^{2+}$  transients in a Control myocyte. The protocol included a period of electrical stimulation, a brief pause followed by rapid application of caffeine (20 mM) for 10 s and then resumption of electrical stimulation. The protocol was repeated in each myocyte during superfusion with NT and then again following a 5 min superfusion with either NT + PHLOR or QUER-3-G. Amplitudes of the caffeine-evoked  $\text{Ca}^{2+}$  transient (Figs 4B and E), fractional release of  $\text{Ca}^{2+}$  (amplitude of the electrically stimulated  $\text{Ca}^{2+}$  transient / caffeine stimulated  $\text{Ca}^{2+}$  transient) (Figs 4 C and F) and recovery of the  $\text{Ca}^{2+}$  transient after caffeine and after resumption of electrical stimulation (Figs 4D

and G) were not significantly ( $P>0.05$ ) altered in STZ compared to Control or by PHLOR or QUER-3-G.

## Discussion

Similar to findings in previous studies, STZ-induced DM was characterized by a 4-fold increase in blood glucose, lower body and heart weights and higher heart weight to bodyweight ratio compared to Control rats (Bracken *et al.* 2006, Howarth and Qureshi 2001, Howarth *et al.* 2002, 2007). In the heart, the time course of myocyte shortening was prolonged in STZ compared to Control rats (Kotsanas *et al.* 2000, Singh *et al.* 2006). This study investigated the effects of PHLOR and QUER-3-G on contractility and  $\text{Ca}^{2+}$  transport in ventricular myocytes from STZ-induced diabetic rats. The main findings of the study were: (i) PHLOR and QUER-3-G decreased the amplitude of shortening in STZ



**Fig. 4.** Effects of phlorizin and quercetin-3-O-glucoside on sarcoplasmic reticulum  $\text{Ca}^{2+}$  release in ventricular myocytes from streptozotocin-induced diabetic and Control rats. Typical recording showing protocol employed in a Control ventricular myocyte during SR  $\text{Ca}^{2+}$  experiments (A). Initially  $\text{Ca}^{2+}$  transients were recorded during electrical stimulation. Electrical stimulation was then paused for 5 s and 20 mM caffeine was rapidly applied for 10 s. After application of caffeine electrical stimulation was resumed. PHLOR panels showing mean amplitude of caffeine-stimulated  $\text{Ca}^{2+}$  transients (B), fractional release of  $\text{Ca}^{2+}$  (C), and recovery of  $\text{Ca}^{2+}$  transients following rapid application of caffeine (D). QUER-3-G panels showing mean amplitude of caffeine-stimulated  $\text{Ca}^{2+}$  transients (E), fractional release of  $\text{Ca}^{2+}$  (F), and recovery of  $\text{Ca}^{2+}$  transients following rapid application of caffeine (G). Data are mean + S.E.M.,  $n=13-16$  myocytes from 3-4 rats for PHLOR and  $n=13-31$  myocytes from 3-6 rats for QUER-3-G.

and Control myocytes, (ii) PHLOR and QUER-3-G decreased the amplitude of the  $\text{Ca}^{2+}$  transient in STZ and Control myocytes, (iii) PHLOR did not alter myofilament sensitivity to  $\text{Ca}^{2+}$  in STZ and Control myocytes; however, QUER-3-G decreased myofilament sensitivity to  $\text{Ca}^{2+}$  significantly in Control myocytes and modestly in STZ myocytes, (iv) PHLOR and QUER-3-G did not significantly alter fractional release of SR  $\text{Ca}^{2+}$  in STZ or Control myocytes.

PHLOR has been shown to have several beneficial cardioprotective effects. *In vivo* treatment of PHLOR prevented diabetic cardiomyopathy in *db/db* mice by changing the expression of some cardiac damaging proteins, and adjusting cardiac energy metabolism and lipids (Cai *et al.* 2013). PHLOR has also been shown to exert partial cardioprotection against isoproterenol-induced myocardial necrosis (Gupta *et al.* 2013) and to prevent electrically-induced ventricular tachyarrhythmia in guinea pig hearts during ischemia (Hirose *et al.* 2014). Previous studies have reported the effects of PHLOR on healthy ventricular myocyte shortening and intracellular  $\text{Ca}^{2+}$  (Olson *et al.* 2007); however, the effects of PHLOR on myocytes from diabetic heart remain to be clarified. QUER-3-G has been shown to have anticancer (Sudan and Rupasinghe 2014), antidiabetic, antioxidant (Panda and Kar 2007) and anti-allergic (Makino *et al.* 2013) effects; however, its effects on the heart also remain to be clarified. PHLOR and QUER-3-G decreased the amplitude of shortening to similar extents in ventricular myocytes in STZ and Control rats. Since cardiac contraction is regulated by intracellular  $\text{Ca}^{2+}$  levels the reductions in amplitude of shortening might be partly attributed to the action of PHLOR and QUER-3-G on intracellular  $\text{Ca}^{2+}$ . PHLOR and QUER-3-G decreased the amplitude of the  $\text{Ca}^{2+}$  transient to similar extents in myocytes from STZ and Control rats suggesting that alterations in  $\text{Ca}^{2+}$  transport might partly underlie the reductions in myocyte shortening.

STZ-induced diabetic rats develop cardiovascular complications in a short period of time starting with reduced heart rate 5-7 days after injection, reduced mean arterial pressure 14 days after injection, and decreased heart rate and mean arterial pressure variability 30-45 days after injection (Schaan *et al.* 2004). Although, experiments were carried out after 2 months of STZ injection allowing all the mentioned complications to develop, the extent of the observed effects of PHLOR and QUER-3-G on myocyte shortening and intracellular  $\text{Ca}^{2+}$  were similar

suggesting that PHLOR and QUER-3-G affect healthy and diabetic cells in the same manner.

Further experiments were performed to investigate whether the change in the amplitude of shortening caused by PHLOR and QUER-3-G could be partly attributed to altered myofilament sensitivity to  $\text{Ca}^{2+}$ . Myofilament sensitivity to  $\text{Ca}^{2+}$  was not significantly altered by PHLOR in STZ and Control myocytes. However, QUER-3-G decreased myofilament sensitivity to  $\text{Ca}^{2+}$  in ventricular myocytes from Control rats and to a smaller extent in myocytes from STZ rats. This suggests that the effects of QUER-3-G might be partly attributed to changed myofilament sensitivity to  $\text{Ca}^{2+}$ .

PHLOR and QUER-3-G had no effects on SR  $\text{Ca}^{2+}$ , fractional release of  $\text{Ca}^{2+}$  or recovery of the  $\text{Ca}^{2+}$  transient after application of caffeine in either STZ or Control myocytes suggesting that the effects of PHLOR and QUER-3-G on myocyte shortening are unlikely to be related to an effect of these compounds on SR  $\text{Ca}^{2+}$  transport. In a previous study, Olson and colleagues demonstrated that PHLOR modestly decreased the amplitude and area of the  $\text{Ca}^{2+}$  transients. They also found that PHLOR did not significantly change SR  $\text{Ca}^{2+}$  load after caffeine application which is consistent with the current study (Olson *et al.* 2007).

Recent studies have shown that the selective SGLT2 inhibitor dapagliflozin, an analogue of PHLOR (Meng *et al.* 2008), reduced the amplitude of shortening in a dose dependent manner, reduced the amplitude of the  $\text{Ca}^{2+}$  transient and reduced the amplitude of L-type  $\text{Ca}^{2+}$  current over a range of test potentials in rat STZ and Control myocytes (Hamouda *et al.* 2015). Further experiments would be required to establish whether alterations in L-type  $\text{Ca}^{2+}$  current are also involved in the negative inotropic effects of PHLOR and QUER-3-G.

Overall, PHLOR and QUER-3-G both reduced the amplitude of shortening to similar extents in STZ and Control myocytes. Owing to their negative inotropic effects, it is suggested that PHLOR and QUER-3-G might have a wide range of clinical applications in cardiovascular diseases such as angina, arrhythmias and hypertension. Considering their antidiabetic effects, they would be of a great benefit to diabetic patients who are prone to develop angina, myocardial infarction and congestive heart failure (International Diabetes Federation 2013).

### Conflict of Interest

There is no conflict of interest.

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